WHITEFLY CONTROL ON GUERNSEY TOMATOES BY *ENCARSIA FORMOSA*

by

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ABSTRACT

Biological control of the glasshouse whitefly, Trialeurodes vaporariorum Westwood, by the chalcid parasite Encarsia formosa Gahan, has been practised in Guernsey since the mid-1970s. The technique has not proved so effective as in the UK or the Netherlands; this study investigates the reasons for, and solutions to, the problems encountered in the island.

The development of biological and integrated glasshouse pest control is reviewed, as is the history of its use in Guernsey. After an initial period spent monitoring whitefly and Encarsia in commercial tomato crops in Guernsey and a detailed survey of 50 growers using biological control, the factors considered to be important were examined individually.

Physical factors include the presence of a whitefly population breeding throughout the year due to mild weather in winter and carry-over of adults between the close-packed glasshouses in summer. The effect of adverse weather on Encarsia performance during the winter months is also considered. Several cultural factors affect biological control in Guernsey; the growing system, deleafing practices, the trend towards earlier growing and lower temperatures. The effects of tomato variety were also investigated.

The use of soil-applied γ-HCH to control tomato leafminer was shown to be harmful to the parasite and effects of the systemic insecticide, oxamyl (Vydate), were studied. Unusual results of spot-treatment with pyrethrum/resmethrin (Pynosect) were also considered.

Finally, several experimental methods of parasite introduction were tested in commercial trials. Banker plants looked promising, but a variant, 'mini-bankers' (a modified pest-in-first system), was not successful. The whole story of biological control in Guernsey is discussed and prospects for its future success examined.

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PREFACE

Throughout this thesis, three abbreviations are used:

HAS = States of Guernsey Horticultural Advisory Service;

GCRI = Glasshouse Crops Research Institute;

ADAS = Ministry of Agriculture, Fisheries and Food, Agricultural Development and Advisory Service.

The names, whitefly and *Encarsia*, refer specifically to the glasshouse whitefly, *Trialeurodes vaporariorum*, and *Encarsia formosa*, unless stated otherwise.

INTRODUCTION

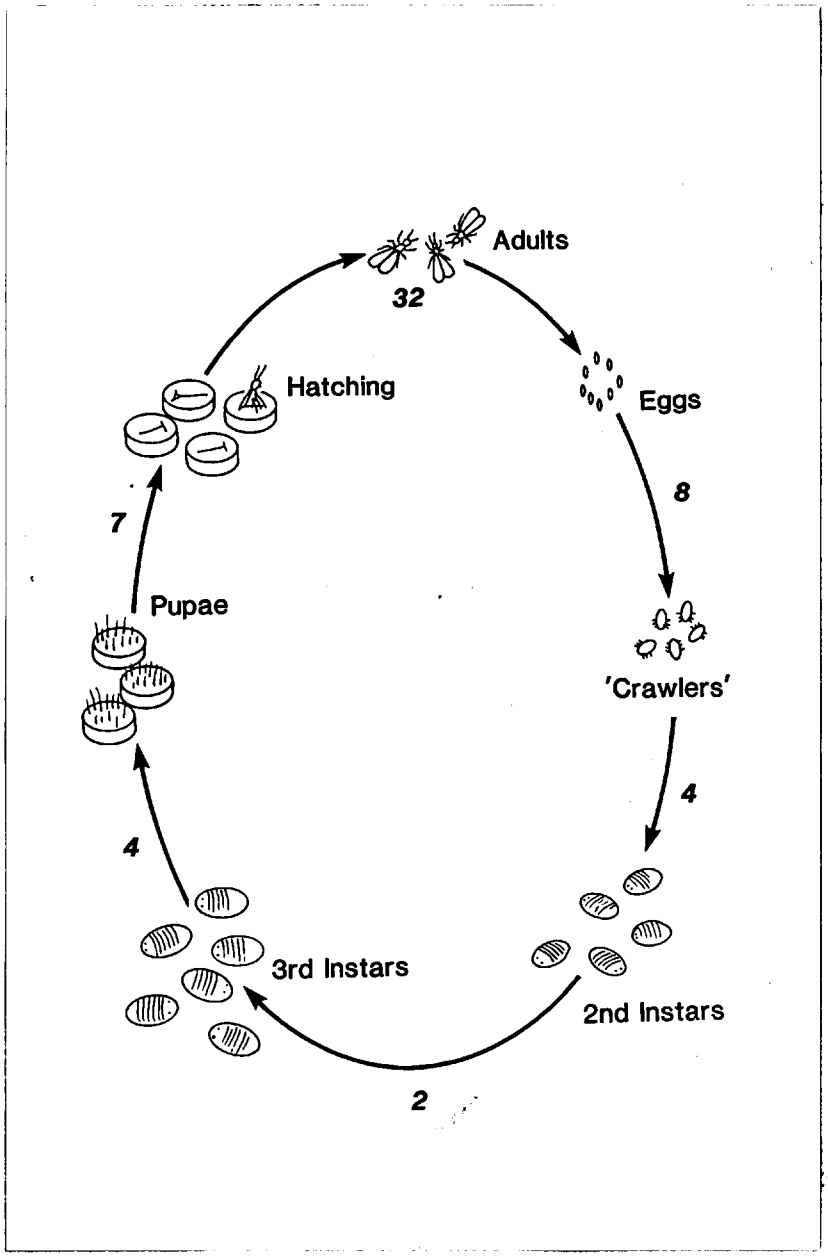
1.1 PEST STATUS OF THE GLASSHOUSE WHITEFLY

The glasshouse whitefly, Trialeurodes vaporariorum Westwood (Hemiptera; Homoptera; Aleyrodidae), was first discovered in Britain in 1856 at Kew, where it was thought to have been imported on plant material from Mexico (Westwood, 1856). The new pest was studied in later years and detailed descriptions of its biology were published by Hargreaves (1915) and Lloyd (1922) among others. The life cycle of the glasshouse whitefly is summarized in Figure 1. Leaflets are available which explain the life history and suggest control methods (Anon, 1978; Scopes & Ledieu, 1979).

The very wide range of host plants of T. vaporariorum (Russell, 1963, 1977; Mound & Halsey, 1978) makes its spread easy and rapid. This was exemplified recently by colonization in Japan. Before the early 1970s, when it was accidentally imported, T. vaporariorum was unknown in Japan. It first came to prominence in 1974 and within a few years had spread throughout the country to become a major pest of glasshouse crops (Nakazawa, Hayashi, Hosoda & Naba, 1976; Koshihara, Tanaka & Yamada, 1978; Okada & Santa, 1978; Yamada, Koshihara & Tanaka, 1979).

T. vaporariorum became a glasshouse pest in England around 1912 and was most serious on tomatoes (Lloyd, 1921 a; Speyer 1929 b). Schrader (1926) considered that its early increase may have been due to the spread into Britain of the American race (where mating is normal and fertilized eggs produce males). This race may have reproduced faster than the native British parthenogenetic race (where males are rare), or have been more resistant to adverse conditions.

Figure 1. Diagram of the life-cycle of the glasshouse whitefly.



Numbers indicate the approximate duration (days) of each stage at 21°C

Alternatively, the races may have interbred to produce a more vigorous strain. Nowadays there is usually a 1:1 sex ratio in whitefly populations and mating is normal (GCRI observations).

It has been estimated that, at 21°C, a single mated female could theoretically give rise to one million adults in three months (Anon, 1974 a). Detailed studies of the fecundity and development of whitefly at different temperatures have been made by Burnett (1949), Hussey & Gurney (1958), Stenseth (1971), Ibrahim (1975) and Madueke (1979).

The principal damage caused by whitefly is the dirtying of fruit by honeydew, which, at high humidity, is colonized by sooty mould, Cladosporium sphaerospermum Penz. The fruit must be wiped before marketing, which is time-consuming and increases the producers' costs. In Guernsey, sticky fruit must be wiped (Hussey & Bravenboer, 1971) whether or not sooty mould is present. Strict controls are kept on the standards of fruit cleanliness by the Guernsey Tomato Marketing Board (GTMB) (GTMB, pers. comm.). However, if left unchecked, a whitefly population can destroy a tomato crop within a few months by direct depletion of plant nutrients (Lloyd, 1921 a). Hussey, Parr & Gurney (1959) concluded that although 10 scales per ¾" leaf disc produced sufficient honeydew to support sooty mould, there was no yield loss until the density of whitefly scales reached 70 per ¾" leaf disc. Sakai (1979) investigated the possibility of using fungicides to control the sooty mould, but decided that it was easier to limit the amount of honeydew by using insecticides against the whiteflies.

In Guernsey, the HAS produces weekly Advisory Notes for growers which are published in the local newspaper, the Guernsey

Evening Press. In Advisory Notes in the early 1970s whitefly were mentioned only under routine pest control programmes. However, with the increasing difficulty of control in Guernsey, whitefly now feature more frequently in these Notes. In a comparison of the situation in Holland and Guernsey, it was stated that the whitefly problem had built up more slowly in Guernsey than in Holland, but that it had increased in significance in recent years (HAS, 1978 e). Whitefly have long been a problem on Dutch tomato crops (Woets, 1974) and it was estimated that before the development of effective fumigation techniques for whitefly control in the early 1920s (see Section 1.2), one third of the UK Lea Valley tomato crop was lost, costing £30,000 annually in yield losses and fruit cleaning expenses (Speyer, 1929 b). Tomato trials in the USA achieved a gross income increase of $8,000 per acre where whitefly were controlled by endosulfan (Lindquist, Bauerle & Spadafora, 1972).

Unlike tropical whitefly species such as Bemisia tabaci Genn., T. vaporariorum is not noted as a disease vector. In the past it has been shown to be capable of transmitting Xanthomonas pelargonii Starr & Burk, a bacterial disease of Pelargonium hortorum Bailey, under laboratory conditions (Bugbee, 1962), and in California, glasshouse whitefly transmitted beet pseudo-yellows virus to several plant species (Duffes, 1965), However, the discovery of beet pseudo-yellow virus in glasshouse lettuce and endive crops in the Netherlands in 1978 was the first record of whitefly transmission of viruses in Europe and it has now spread to cucumber crops (Bos, 1980; Bos, van Dorst & Huijberts, 1980; van Dorst, Huijberts & Bos, 1980). This new phenomenon may well threaten biological control since the virus is spread in a persistent manner, whereby a few

whitefly vectors can be very damaging. This eliminates the acceptability of a low level whitefly population in the crop, which is a pre-requisite of a biological control interaction. Currently, the disease is confined to the Netherlands where chemical whitefly control is practised in cucumber crops (see Section 1.8), but, were beet pseudo-yellow virus to occur in UK glasshouses, biological control in cucumbers may be jeopardised.

1.2 EARLY CHEMICAL WHITEFLY CONTROL

The first reference to glasshouse whitefly in Britain includes a comment that fumigation killed the adults but did not reduce the population, as more hatched afterwards from surviving scales and eggs (Westwood, 1856). It was Lloyd, at Cheshunt, who developed cyanide fumigation as the standard control measure used for many years (Lloyd, 1921 a, 1922). Great care had to be taken, for, not only is cyanide lethal to man, but tomato plants that were too turgid or were fumigated in sunny conditions became severely scorched. Speyer (1929 b) considered that there was considerable crop loss through bad fumigation. A modification of Lloyd's system by Speyer & Owen (1926) made cyanide fumigation both more efficient and safer.

Tetrachloroethane fumigation gave as good control as cyanide and was much safer to plants and operators. However, at ten times the price, its cost was prohibitive for commercial use, although it was useful for conservatories and small glasshouses (Lloyd, 1921 a, 1922; Fox-Wilson, 1926). Nicotine and naphthalene fumigations were ineffective. Paraffin emulsion sprays were sometimes used (Speyer, 1929 a).

1.3 DISCOVERY OF ENCARSIA & EARLY BIOLOGICAL CONTROL

In 1914 and 1915, parasitized whitefly had been found at Wisley and had been distributed to growers in September, which proved to be too late in the year for establishment. Efforts to breed this parasite, which was identified as Encarsia partenopea Masi, were disrupted by the First World War (Speyer, 1927 b; Fox-Wilson, 1931).

Black parasitized whitefly scales were discovered by a Hertfordshire grower in 1926. He sent them to the "Gardeners' Chronicle" (Anon, 1926) from where they were forwarded to Cheshunt. The parasites were identified as Encarsia formosa Gahan (Hymenoptera; Aphelinidae), described as a new species in the USA two years previously (Gahan, 1924; Speyer 1927 a,b). Detailed descriptions of the parasite and its life history were given by Speyer who considered that Encarsia's parthenogenetic reproduction would be advantageous for mass rearing. E. formosa was considered to be better than E. partenopea for whitefly suppression, for although less hardy, it established quicker. However, it is surprising that E. partenopea is not included in modern investigations of alternative species and strains of parasites more suited to cooler conditions (See Section 3.4).

After its discovery, E. formosa was successfully reared in heated glasshouses at Cheshunt. It multiplied sufficiently from the three surviving individuals of the eight scales received from Hertfordshire for 10,000 parasites to be distributed to 12 nurseries in the following year (Speyer, 1928, 1929 1). The parasite gave good whitefly control on cucumbers and, for the first time for many years, there was no need to fumigate them on tomato crops. By the end of that season there was evidence of natural spread of Encarsia for 1 - 3 miles (Fox-Wilson, 1931).

Cheshunt received a grant from the Empire Marketing Board to construct a glasshouse for rearing Encarsia (Speyer, 1930 b). The parasite was reared on tomato, while clean whitefly cultures were maintained on tobacco, which was reported to repel Encarsia. (Nowadays Encarsia is successfully reared on tobacco (Anon, 1975 a)).

In 1928 Encarsia was sent to growers and research stations in England, Canada and the Channel Islands. About half the recipients reported successful whitefly control, there were very few failures, and the rest were partially successful. Increasing numbers of parasites were more widely distributed in subsequent years as the technique became more popular. The first shipments to Australia and New Zealand perished, but later consignments became established in New Zealand and from there parasites were successfully sent to Australia (Tonnair, 1937). At first, parasites were distributed free in Britain, but after a postal charge was imposed in May 1930 there was a reduction in demand (Speyer, 1929 a, 1930 b).

In Canada, McLeod (1938) stated that the usual rate of Encarsia usage was 1 - 2,000 parasites per 1,000 sq.ft. of glasshouse area. But, in Britain, all pre-war biological control was on an empirical basis. Applicants were asked how many glasshouses they had to treat and they were sent an unspecified number of black scales on tomato leaves. The instruction leaflet told growers to hang the bunches of leaves from the wires for three weeks and at 70°F (21°C), establishment could be expected two to three weeks later if whitefly were breeding in the glasshouse. Black scales could then be distributed elsewhere in the nursery. It was recognized that early introduction of parasites was necessary, April to June introductions

gave best control on tomatoes (Speyer, 1929 a,b, 1930 a).

Excessive whitefly populations could be fumigated with cyanide or tetrachloroethane without harming the parasites. Paraffin emulsion sprays killed Encarsia, but where they were necessary for red spider mite control, whitefly were also killed and it was considered that sufficient parasites could re-invade the glasshouse from outside for this to be unimportant (Speyer, 1929 a,b, 1930 a).

Biological control became the standard pre-war practice and whitefly populations were significantly decreased.

1.4 POST-WAR & MODERN CHEMICAL CONTROL

Organochlorine (OC) and organophosphorous (OP) pesticides developed during the Second World War were fairly effective at controlling whitefly but were lethal to the parasite (Speyer & Parr, 1947 a,b). The use of improved broad spectrum chemicals led to a decline in demand for Encarsia, and mass rearing ceased in 1954 when Cheshunt closed and GCRI was founded (Parr, 1968). A similar decline in parasite usage occurred overseas, for example the Dominion Parasite laboratory in Ontario, Canada, stopped rearing Encarsia in 1951 (McClanahan, 1972 a). However, the need for further studies on Encarsia was recognised, in case biological control should be needed in the future (Anon, 1957).

Among chemicals recommended by the Agricultural Chemicals Approval Scheme (ACAS) for whitefly control on tomatoes, BHC, DDT, malathion and parathion were used for many years (ACAS 1956). A shorter persistence OP, dichlorvos, was introduced in 1966 (ACAS, 1966). In their comprehensive manual of glasshouse pests, Hussey, Read & Hesling (1969) suggest that malathion and DDT were

the most suitable for whitefly control, although DDT/BHC or parathion were also effective, and in certain cases petroleum emulsion sprays, dichlorvos and naled might be appropriate. However, Adamson, Tonks & Maas (1972) found that naled vapour reduced fruit set in tomatoes.

The first carbamate insecticide to appear in the ACAS list was propoxur (ACAS, 1972) at about the time of the first reports of the whitefly resistance to some older materials (see Section 1.5). The systemic carbamate, oxamyl (Vydate) was approved for use on glasshouse tomatoes in 1977 (ACAS 1977) and is now widely used in Guernsey (see Section 4.2).

Novel methods of insecticide application were developed and pirimiphos-methyl was approved for fogging in glasshouses in 1975 (ACAS 1975). This broad spectrum OP has lower mammalian toxicity than the older organic insecticides (Worthing, 1979). BHC and parathion were dropped from the ACAS list for use on tomatoes in 1976 and 1977 respectively.

Synthetic pyrethroids heralded a new era in glasshouse pest control. They arrived when resistance was making the situation difficult and effective short-persistence materials were required for integration with natural enemies (see Section 1.5 & 1.6). Resmethrin has the shortest persistence and is widely used in conjunction with Encarsia to reduce excessive populations of adult whitefly. Bioresmethrin can be used with parasites, but the increasingly persistent permethrin, cypermethrin and deltamethrin, which provide good whitefly control in their own right, are incompatible with biological control. It is an added advantage that most synthetic pyrethroids can be applied as both fogs and wet sprays. The efficiency

of permethrin for whitefly and leafminer control has apparently halted the pattern of increasing Encarsia usage (Gould, pers.comm. 1979 (Bristol ADAS); Wardlow, pers.comm. 1979 (Wye ADAS)). Growers now have a much wider choice of both materials and methods for pest control than was available a decade ago. The latest pest control manual lists 26 chemicals as effective against whitefly larvae and/or adults on tomatoes (resistant strains excepted) (Morgan & Ledieu, 1979).

1.5 PESTICIDE RESISTANCE

A recent article by Dunne (1981) gives an account of the causes of pesticide resistance in insect populations and methods of delaying its occurrence by more judicious use of chemicals and adoption of an integrated pest management approach.

It was the development of pesticide resistance in the red spider mite, Tetranychus urticae, Koch, and aphids on chrysanthemums which led to renewed interest in biological control of glasshouse pests (Hussey, 1965, 1966). Phytoseiulus persimilis A-H was accidentally introduced from Chile and a programme was successfully devised to use it for control of red spider mite on cucumbers (Hussey, 1967). The predator was very susceptible to the broad spectrum pesticides currently in use, so alternative methods were necessary for control of other pests such as whitefly, aphids and thrips. GCRI published a "Growers' Bulletin" outlining a complete integrated programme for control of cucumber pests and diseases in 1972 (Anon, 1972).

Insecticide resistance in glasshouse whitefly first appeared in 1971 in south-east England, the Netherlands and the

USA (Sleesman & Lindquist, 1971; Wardlow, Ludlam & French, 1972). Tests and surveys revealed resistance to a range of OP and OC materials which varied from slight to 100-fold resistance in different populations of whitefly on tomatoes (Wardlow, Ludlam & Hammon, 1975; Wardlow, Ludlam & Bradley, 1976).

In Japan, where the recent occurrance of the whitefly has already been mentioned (see Section 1.1), it was the failure of control by malathion that first drew attention to the presence of whitefly in that country (Hosoda, Naba, Nakazawa & Hayashi, 1976). Tests to find more chemicals to register for whitefly control revealed cross-resistance in the Japanese populations (Nakazawa, Hayashi, Hosoda & Naba, 1978). Sharaf (1978) tested OPs against whiteflies in Germany and also found evidence of cross-resistance.

Biological control of whitefly using Encarsia would have been redeveloped in any case, because the use of Phytoseiulus against red spider mite prevented the use of OP and OC insecticides for whitefly control. However, the appearance of resistant strains of whitefly gave impetus to the research. In 1976 GCRI published a "Growers' Bulletin" on the biological control of tomato pests, principally red spider mite and whitefly (Anon, 1976).

In Guernsey, Advisory Notes warned of the danger of chemical resistance in red spider mite and recommended the alternation of acaricides in the spray programme to avoid it (HAS, 1971, 1972 b). In particular the likelihood of whitefly developing resistance to malathion, the principal insecticide used against it, was noted (HAS, 1974 a). Growers were also told of the development of biological control using Encarsia formosa as a solution to the increasing difficulty and expense of whitefly control by chemicals (HAS, 1973 a).

As mentioned in Section 1.4, the development of the synthetic pyrethroids provided a welcome respite from the problems posed by OP and OC resistance. Morgan & Ledieu (1979) noted that there may be resistance to 11 of the 26 materials available for whitefly control. To date, there are no positive records of resistance to synthetic pyrethroids, although it was suspected in Guernsey (HAS, 1981 e), but not confirmed (Wardlow, pers. comm.). It will doubtless develop, and progress must continue in biological control, both as a preferable alternative and as a replacement for chemicals when they fail.

1.6 WHITEFLY - ENCARSIA RESEARCH

The present programmes for biological control of whitefly are derived from much fundamental research on insect interactions. For example, in Canada, Burnett spent about twenty years studying T. vaporariorium and E. formosa. Initially he used these species simply as a model interaction, but with the need to explain some failures in Canadian biological control of whitefly, his interest became more specific (Burnett, 1960 a, 1967).

1.6.1 Fecundity and Development Rates

Burnett's (1949) studies on fecundity and development rates at different temperatures produced the oft-quoted results that:

a) At 18°C the host population increases because the whitefly lays three times as many eggs as Encarsia but developmental rates are equal;

b) At 24°C the populations remain in balance as their rates of increase are equal;

c) At 27°C the parasite population increases because

fecundities are equal but Encarsia develops twice as fast as the whitefly.

Other studies on the effect of temperature on Encarsia fecundity and development rate have been made by Ibrahim (1975), Stenseth (1975, 1976 a), Madueke (1979) and Arakawa(in litt.).

In a recent review of biological control the accuracy of Burnett's data was disputed by Vet, van Lenteren & Woets (1980). who suggested that his claim of Encarsia having constant fecundity between 18 - 27°C may have been inaccurate, as he offered the parasites too few host scales, and Encarsia resorbs follicles in the absence of suitable hosts, thus not fulfilling its egg-laying capacity. Nevertheless, it is recognised that higher temperatures favour the success of biological control, a fact supported by the recent demonstration that E.formosa has a flight threshold of 21°C below which dispersal in the glasshouse does not occur (Madueke, 1979; Ledieu, 1981 b).

1.6.2 Population Fluctuations

Burnett (1960 b) concluded that the pest and parasite populations fluctuate with an increasing amplitude that is dependent on the infestation period and the initial host and parasite densities. With equal periods of infestation, the higher the initial host and parasite densities, the greater the population fluctuations. With equal initial host and parasite densities, long infestation periods result in small fluctuations, and short infestation periods produce large population fluctuations. If the host infestation period is long, the peaks of parasite numbers are as high as, or higher than, the corresponding peaks of host numbers; the parasite population peaks are lower if the host infestation period is short.

1.6.3 Host Mortality by Encarsia

Encarsia kills whitefly scales in three ways; parasitism, direct killing by stabbing (especially smaller scales) and host-feeding. Burnett (1962, 1964) studied the importance of direct killing and parasitism as larval mortality factors and concluded that they were related to the host-parasite density ratio and host size. Increasing numbers of whitefly larvae are killed with increasing parasite density per scale and decreasing host size; increasing numbers of larvae are parasitized with decreasing parasite density per scale and increasing host size. The phenomenon of host-feeding by E. formosa was not recorded until 1966, although it was known in other species (Gerling, 1966). Previously the parasite was thought to feed only on honeydew. Host-feeding occurred on all whitefly stages, but it was more frequently on second instars and pupae; hosts used for feeding were never parasitized, and Encarsia was not seen feeding on parasitized scales (van Alphen, Nell & Sevenster-van der Lelie, 1976; Nell, Sevenster-van der Lelie, Woets & van Lenteren, 1976).

1.6.4 Encarsia Dispersal and Host Finding

Much work has been done on Encarsia dispersal and host finding. Speyer's early work (1927 b) showed that Encarsia was capable of moving a long way (up to 70 ft) to find hosts and he described how the parasite hovered near infested foliage before landing on the leaf and feeling the whitefly scales with its antennae prior to oviposition.

Experiments at GCRI demonstrated that Encarsia was capable of moving long distances (up to 16m) within a few minutes of release and could detect infested plants among clean ones. The parasite was

attracted to both aphid and whitefly honeydew but did not remain long on the former. It was suggested that the attraction was due to a volatile substance , perhaps a kairamone, in the honeydew. The size of the target area did not affect searching ability, but once it was located, the parasite did not readily move away (Hussey, Parr & Stacey, 1976; Parr, Ledieu & Stacey, 1976 a; Ledieu, 1976, 1977 a).

Madueke (1979) also studied Encarsia dispersal, especially in relation to a uniform, rather than focal, whitefly infestation, and found that dispersal was slow. She concluded that there were two stages in the process; firstly an indiscriminate long range response to host food plants, and secondly a short range response to plants infested with whitefly scales. This theory substantiates the findings of Savage (1976) who detected a positive response by Encarsia to light in the yellow wavelength range, 500 - 600 nm. She considered that the colour of the host leaves was the overriding attractive factor for the parasite, rather than the presence of host scales. However, in a glasshouse monocrop situation parasites will display the attraction for infested plants found by Ledieu, as there will be no discriminatory difference among the host plants' leaf colour.

Detailed studies on the searching behaviour of Encarsia on the leaf surface confirmed the good long-distance ability of the parasite to find hosts at low densities (Eggenkamp-Rotteveel Mansveld, Ellenbrook & van Lenteren, 1980). Once on the leaf surface, Encarsia's searching behaviour is entirely at random and is not influenced by olfactory or visual responses to nearby scales. The numbers of hosts parasitized is determined by the walking speed of the parasite (which is influenced by leaf surface morphology and the amount of honeydew present) and the density and distribution of host scales.

A clustered scale distribution increases parasitism efficiency because of a shorter walking distance between hosts (Burnett, 1958 a,b; van Lenteren, Nell, Sevenster-van der Lelie & Woets, 1976 a).

1.6.5 Encarsia Oviposition and Superparasitism

Encarsia will oviposit in all scale stages although fewer aggs are laid in pupae. The development of the parasite first instar larva is delayed until the host scale has matured to the fourth instar, when there is sufficient food to sustain complete parasite development. Hence the period from oviposition to melanization decreases with increasing age of the whitefly scale at the time of oviposition, but the period from blackening to parasite emergence is constant, regardless of the size of scale attacked (Nechols & Tauber, 1977; Madueke, 1979).

Hussey, Parr & Gurney (1959) observed that Encarsia cannot distinguish between parasitized and unparasitized hosts by external stimuli and that they probed scales with the ovipositor regardless of previous probes by themselves or other individuals. Later experiments showed that Encarsia can make the distinction after antennal and ovipositor tests, so parasitized hosts are usually rejected for oviposition (van Lenteren, Nell, Sevenster-van der Lelie & Woets, 1976 b). Madueke (1979) found that supernumary Encarsia were suppressed in the egg and first larval instar stages, once the first parasite to hatch commenced feeding. Presumably its feeding changes the host environment such that it becomes unfavourable for the development of other parasites within the same host.

1.6.6 Host Plant Quality

Whitefly are initially attracted to a host plant by its

colour. They have a yellow tropism which attracts them to the younger, lighter green leaves at the growing point of tomatoes and other plants (Lloyd, 1921 b; Macdowall, 1972; Vaishampayan, Kogan, Waldbauer & Woolley, 1975). Olfaction plays little part in the selection process (Vaishampayan, Waldbauer & Kogan, 1975). Once they have landed, whiteflies probe the leaf surface with their stylets; if it is a favourable host they stay, if not, they frequently fly off and probe again when they land on the same, or another, leaf. Whiteflies seemingly choose their host plant during their pre-oviposition period and, if undisturbed, will remain on that plant until they die (Verschoor-van der Poel & van Lenteren, 1978).

Dabrowski (1972) suggested that resistance of Pelargonium species to whiteflies may be due to different mechanisms ; non-preference in P. peltatum Bailey, where the tough leaf tissue was a mechanical obstacle to feeding, and antibiosis in P. hortorum, where some chemical in the leaves exerts both an antifeedant and a direct toxic effect.

Ibrahim (1975) found that whitefly fecundity on cucumber was almost three times that on tomato, although longevity was similar on both hosts. Tanaka (1978) looked at the host plant quality of ten crops in relation to whitefly fecundity and longevity and the survival of eggs and larvae as an explanation of the differences in susceptibility to whitefly infestations. His results may be summarized as follows:

Crop	Fecundity & Longevity	Egg & larval Survival	Infestation Level
Cucumber	H	H	H
Pumpkin	H	H	H
Eggplant	H	H	H
Tomato	I	H	H
Kidney bean	I	H	H
Melon	L	I	L
Watermelon	L	I	L
Pepper	L	L	L
Strawberry	L	L	L
Lettuce	H	L	L

H = high I = intermediate L = low

Van Boxtel, Woets & van Lenteren (1978), van de Merendonk & van Lenteren (1978) and Verschoor-van der Poel & van Lenteren (1978) showed decreasing host plant quality from eggplant, to cucumber, to tomato and pepper, as measured by whitefly flight, fecundity, development rate and larval survival. However, in further studies which included melon, gherkin and gerbera, the pattern was not consistent for all criteria (van Sas, Woets & van Lenteren, 1978; van Lenteren, Ramakers & Woets, 1980). For example, although gerbera gave high adult longevity and fecundity, larval survival and development rate were low. Host plant studies by O'Reilly (1974) had given similar discrepancies. For example, nettle and sowthistle, which are important overwintering hosts, were not as attractive to adult whitefly as cucumber, tomato and tobacco, but they were good for larval development. Tanaka (1978) found lettuce to give high adult longevity and fecundity but few larvae survived, confirming O'Reilly's result for that species.

In examining host plant quality for Encarsia, Gerling (1966) found decreasing efficiency of parasitism on hairy leaf

surfaces and a similar correlation between the nature of the leaf surface and parasitic efficiency was found by Ibrahim (1975). Hulspaas-Jordan & van Lenteren (1978) demonstrated that although Encarsia showed no host plant preference, except between infested and uninfested plants, its walking speed was inversely proportional to leaf hairiness.

Leaf stickiness, either from natural leaf exudates or whitefly honeydew, also decreases Encarsia efficiency as more time is spent preening (Gerling, 1966 ; Woets & van Lenteren, 1976; van Lenteren & Woets, 1977). Lloyd (1922) considered that the spray of honeydew bursting from the ani of a group of whitefly scales acts as a defence mechanism against parasites.

It is the interaction of host plant quality for T.vaporariorum and for E. formosa which determines the success of biological control on different crops. This is best illustrated by the results of Woets & van Lenteren (1976), van Lenteren & Woets (1977) and van Lenteren, Ramakers & Woets (1980) as follows:

Crop	Whitefly development rate	Encarsia parasitism efficiency	Biological control success
Eggplant	++	+	+-
Cucumber	+	-	-
Tomato	+-	+	+
Pepper	-	+	not necessary

Biological control is best on tomato where the pest does not develop too rapidly and parasites operate efficiently. On eggplant Encarsia is efficient, but whitefly develops too rapidly for the parasite to maintain good control. On cucumber, the leaf hairiness retards the

parasite and although whitefly development is not as fast as on eggplant, it is still too rapid for control by Encarsia. This is true in the glasshouse as well as the laboratory despite the higher growing temperatures for cucumber which should favour the parasite. There is no need for biological control on pepper since whitefly does not thrive on it. Biological control should be easy on gerbera since it is a poor whitefly host and has smooth leaves. The hairiness of gherkin and melon leaves hinders Encarsia, but they are poorer whitefly hosts than eggplant, so biological control should be reasonably good (van Sas, Woets & van Lenteren, 1978).

1.6.7 Plant Breeding for Resistance to Whitefly

Much screening of plants for whitefly resistance has been done with a view to breeding resistant varieties. Curry & Pimental (1971 a,b) and Harborough & Mattson (1976), suspected varietal differences in tomatoes from field observations, however, screening produced no substantial differences. Other programmes have included other species of Lycopersicon and also Solanum pennelli Correll. Of these, accessions of L. hirsutum Humb. & Bonpl., L.hirsutum glabratum C.H. Mull and S. pennelli have shown resistance through leaf hairs and sticky exudates which trap whitefly adults. These characters are transferable to L. esculentum L. but they would also be unfavourable to Encarsia. To date, no whitefly-resistant tomato varieties have been commercially released (Gentile, Webb & Stoner, 1968; Claybery & Kring, 1974; de Ponti, Pet & Hogenboom, 1975; de Ponti & Hogenboom, 1980).

Results have been more encouraging with cucumber breeding. Although hairy Cucumis species were shown to be resistant to whitefly (Kowalewski & Robinson, 1977), de Ponti found no varietal differences

in C. sativus L. A successful Dutch breeding programme was set up to try and enhance biological control by reducing leaf hairiness in order to improve Encarsia performance rather than by trying to reduce the suitability of cucumbers for whitefly. New glabrous varieties are now being developed (de Ponti, 1980). On the other hand, cucumber varieties have been selected for resistance to red spider mite, and having overcome initial problems of linkage of the resistance factors with a gene for bitterness, a breeding programme is now in progress to develop commercial varieties which are less susceptible to red spider mite damage. A reduction in the need for acaricides will enhance integrated pest control overall (de Ponti & van Lenteren, 1981).

1.7 INTEGRATED CONTROL PROGRAMME

Much has been written on the concepts and development of modern biological and integral control programmes and their application worldwide. Stern, Smith, van der Bosch & Hagen (1959) gave an early review of the integrated control concept. Parr (1972 a) defined biological control as "the limiting of pest populations by the use and manipulation of predators, parasites and other pathogens so as to prevent economic damage to the plants". He recognised that the controlled environment of the glasshouse was an ideal situation in which to "establish a prolonged interaction between the pest and its natural enemy which will maintain the pest at a low level during the greater part of the life of the crop".

For whitefly control, the advantages of biological over chemical methods may be summarized as follows:

a) Safety - non-toxic to plants, operators and consumers;

b) Selectivity - only T. vaporariorum is parasitized;

c) Self-perpetuation;

d) Potential efficiency - parasites seek out scales for oviposition;

e) Economy of materials and labour - a few introductions should give control throughout the season instead of a weekly spray programme.

(Parr, 1969 ; Hussey & Bravenboer, 1971; Parr & Scopes, 1971 a).

In England, integrated control programmes for pests and diseases of glasshouse crops were developed principally at GCRI. They are the result of work started in the mid-sixties (Hussey, 1965) to study all aspects of the interactions involved. Wyatt (1972) stated that "it is only by a full understanding of all the interactions between the plant, its pests and diseases, chemicals and natural enemies that a reliable programme for integrated control can be devised". Such programmes have now been devised and tested in GCRI and ADAS trials. They are currently available for cucumbers (Parr & Scopes, 1971 b; Anon, 1972), chrysanthemums (Wardlow, 1980, 1981) and tomatoes (Scopes & Ledieu, 1979; Hussey, 1979).

1.7.1 Parasite Introduction Methods

For whitefly control on tomatoes there are three methods of Encarsia introduction: classical 'pest-in-first', dribble introductions and banker plants (Scopes & Ledieu, 1979).

1) Pest in first

In March, the crop is infested with a known whitefly population (10 whitefly per 100 plants) introduced as pupae and distributed evenly throughout the glasshouse. Three parasite introductions are then made three, five and nine weeks later (at tomato programme temperatures - see Appendix 1 - at rates of 150,150 and 75 black scales per 100 plants (i.e. $\pm$50,000, 50,000 and 25,000/ha). If whitefly are present

in the propagating house, an introduction of 40 Encarsia per 100 plants (± 12,000/ha) should be made.

Satisfactory control should be achieved within three months provided the parasites establish properly.

2) Dribble introductions

Parasites are introduced into the crop every fortnight at a rate of one per plant (±30,000/ha) from mid-February until two weeks after black scales are established on the crop. Introductions should commence about three weeks after seedling germination rather than waiting until the first whitefly are seen, because of the danger of missing a pocket of infestation which will become difficult to control.

3) Banker Plants

In this system a few tomato plants are raised, separately from the crop, upon which a dense whitefly-Encarsia interaction is set up. Each seedling is infested with 100 whitefly followed by 200 parasites per plant two weeks later (at 18°C). When the first generation of Encarsia has completed its development (about one month later) and starts to emerge, the banker plants are introduced into the crop at a rate of 50/ha, after first removing excess adult whitefly with a Pynosect spray to the heads of the plants. The interaction should produce about 8-10,000 parasites, emerging into the crop over an 8 - 10 week period.

Studies by Parr (1968) demonstrated that an even whitefly infestation was more easily controlled by Encarsia than a more natural, patchy distribution. The pest-in-first method sets up such an infestation and provides more predictable and reliable whitefly control than dribble introductions of parasites. This was demonstrated

in commercial cucumber trials (Parr, 1970, 1971, 1972 b; Parr & Scopes, 1971 b), however, it was not liked by growers who resisted the suggestion of artificially infesting their crop with the pest. Consequently, most commercial usage of Encarsia is by the dribble method of multiple parasite introductions, despite the less reliable results achieved (Parr & Scopes, 1971 a; Gould, Parr, Woodville & Simmonds, 1975).

The method of parasite introduction developed in the Netherlands is a dribble system. The idea of artificial infestation of the crop was not favoured, and the predictability of an interaction established by the GCRI method was doubted. The Dutch method, which has been used successfully for six years (van Lenteren, Ramakers & Woets, 1980), involves the introduction of one parasite per plant per fortnight, starting 1-3 weeks after planting. Trials have shown that four introductions spread over two whitefly generations can achieve successful biological control on tomatoes (Woets, 1973, 1974). The rationale behind this system is that most growers' seedlings are supplied from a few specialised nurseries and are likely to be infested with whitefly of a similar age. The first two parasite releases kill first generation scales by direct killing or parasitism (depending on their age). The final two introductions cover the second whitefly generation which develops at an unpredictable rate in the poor weather conditions of January and February (Woets, 1978 a).

The banker plant concept was first applied to red spider mite control by Phytoseiulus on cucumbers (Hussey, 1967) and tomatoes (Parr, 1973 a). Later the idea was developed for whitefly control by Encarsia . It worked well in commercial trials and has been used

successfully at GCRI for several years (Parr, Stacey & Hart, pers. comm. 1976 (GCRI); Stacey, 1977 a, 1978: Parr & Stacey, 1977). However, it is not used commercially, presumably because of the ready availability of Encarsia and the effort required in producing banker plants. Freuler & Paccaud (1980) reported successful use of bankers in Swiss trials with more lasting control than that achieved by multiple introductions. A major benefit of bankers is that the parasite population is sustained by honeydew and host scales on the banker plant, although whitefly may be scarce in the crop, whereas parasites introduced in the usual way would perish (Parr, pers. comm. 1975 (GCRI); Parr, Stacey & Hart, pers, comm. 1970 (GCRI); Stacey, 1977 a).

ADAS and GRCI trials were done to see whether lower rates of Encarsia could be used for dribble introductions and whether the density of release points altered the establishment of biological control. Parasites used at one per plant were generally better than two per plant (Williams, pers. comm. 1975 (Wolverhampton ADAS); Lane, Ludlam & Wardlow, pers. comm. 1975 (Wye ADAS)). But even lower rates (one per four plants) could achieve successful biological control, provided there were very few whitefly at the start (Parr & Stacey, pers. comm. 1975 (GCRI); Simmonds, pers. comm. 1976 (Starcross ADAS); Lane, pers. comm. 1976 (Wye ADAS)). Trials using twice as many parasite release points (at one per 50 plants compared to one per 100 plants) gave only slightly better results (Lane, Ludlam & Wardlow, pers. comm 1975 (Wye ADAS)). In 1976 'contract' biological control had been operated in the Netherlands, and with its likely spread to the UK in 1977 and the probability that 'contractors' would tend to use more, rather than fewer parasites, research emphasis was switched to the effect of whitefly density on biological control as it was

probably a more significant factor than parasite density (French, pers. comm. 1976 (Newcastle ADAS); Foster & Kelly, pers. comm. 1976 (W. Scot.Agric. Coll.)).

1.7.2 Effect of Whitefly Density

The importance for biological control of whitefly density at the time of the first parasite introduction was first recognised after ADAS/GCRI trials in 1969 (Parr, 1970). Since then, much research has been done to determine the maximum initial whitefly population density which can be controlled by Encarsia. Results vary somewhat but numbers were always low (see Table 1).

Table 1. Threshold adult whitefly density for first Encarsia introductions on tomatoes

Density	Reference
$10/100m^2$	Ekbom, 1977
0.1/upper leaf = 0.5/plant	Foster & Kelly, 1978
0.1/upper leaf	Foster, 1980 a
0.1/plant	Dunne, 1977
0.1-0.5/plant	Kowalska & Pruszynski, 1979
0.1/plant	Woets, 1978 a
0.54/upper leaf	Gould, pers.comm. 1978 (Bristol ADAS)

Growers were urged to start parasite introductions as soon as the first whitefly was seen on their crop; once sprays are considered necessary it is too late for biological control (Anon, 1974 a). Dunne & Donovan (1977) considered that starting when there were too many whitefly in the crop was the most important cause of failures of biological control in Ireland, as did Foster (1980) in Scotland. This also accounted for poor biological control in some ADAS trials (Williams, pers. comm. 1975 (Wolverhampton ADAS); Simmonds, pers. comm. 1975 (Starcross ADAS)).

On the other hand, the use of too many parasites early in the season can create a problem. If all their hosts are obliterated the parasites cannot survive in the crop which is then susceptible to later reinfestation. This difficulty was pointed out by Lindquist & Spadfora (1971 a), Gould (pers.comm. 1975 & 1976 (Bristol ADAS)) and Freuler & Paccaud (1980).

Gould recognised the need for a method of estimating whitefly populations to avoid overkill of low density infestations. Experiments with yellow sticky traps to detect whitefly were unsuccessful and it was considered that it was easier to search the crop (Gould, pers. comm. 1976 (Bristol ADAS)). The difficulty of estimating whitefly populations from random sampling was clearly demonstrated by Eggenkamp-Rotteveel Mansveld, Ellenbroek, van Lenteren & Woets, (1978) and Eggenkamp-Rotteveel Mansveld, Ellenbroek & van Lenteren (1980) in the Netherlands. Ekbom (1980), in Sweden, confirmed this difficulty and the need for traps to monitor populations. Light traps are too expensive and so yellow sticky traps were once again considered.

Growers tend to be aware of patches of whitefly around doorways and hot-spots, but pest monitoring is a minor part of their job. Hence, the Dutch routine introduction system was designed to overcome the problem of locating early whitefly (Woets, 1978 a). The GCRI recommendation is for growers to walk through the crop tapping the heads of the plants to make adult whitefly fly up (Scopes, pers. comm.). It was proposed that 10% of the plants should be inspected in areas up to ½ acre and 5% in larger areas (Lane, pers.comm 1977 (Wye ADAS)). Distribution of black scales throughout the crop is important, but establishment can be assisted by concentrating the

parasites near whitefly patches (Ekbom, 1977; Lane, pers. comm. 1977 (Wye ADAS)).

In Poland, (Kowalska, 1969; Kowalska & Pruszynski, 1976), successful parasite establishment was considered to depend on:

1) Initial whitefly density - early introduction into a low host population;
2) Introduction of sufficient parasites, especially at first;
3) Timing and length of introduction period - to ensure that second and third instar scales are available for parasitism;
4) High temperatures - to favour Encarsia establishment.

1.7.3 Integration with Chemicals

If too many whitefly are initially present in the crop, the population can be reduced by an insecticide treatment which synchronizes the whitefly population with future parasite introductions. A low dose of pirimiphos-methyl (Actellifog) kills all whitefly stages except eggs, which develop to third instars suitable for parasitism 2 - 3 weeks later. Pyrethrum/resmethrin (Pynosect) can be used to kill adults, eggs and young larvae, leaving surviving pupae from which adults emerge to lay eggs that produce larvae ready for parasitism about four weeks after application (Scopes & Ledieu, 1979). In ADAS trials pirimiphos-methyl gave better results than Pynosect (Woodville, pers.comm 1975 (Cambridge ADAS)) but if used on too low an initial whitefly population it can hinder Encarsia establishment by leaving too few eggs for subsequent development and parasitism (Ludlam & Hammon, pers. comm. 1975 (Wye ADAS)). Alternatively, short persistence insecticides such as Pynosect, resmethrin and bioresmethrin can be used (often at a low dose rate) simply to reduce the adult whitefly population prior to parasite introductions. These

insecticides can also help restore the balance of the pest-parasite interaction by means of a spray through the tops of the plants to kill adult whitefly without harming the parasites beneath (Dunne & Donovan, 1977; Ekbom, 1977; Stacey, 1977 b; Parr & Stacey, pers. comm. 1977 (GCRI)). Spot-treatment of localised whitefly patches may also be beneficial (Lane, pers. comm. 1977(Wye ADAS)), although not all the materials mentioned by Gould (1977) would now be considered suitable; resmethrin and dichlorvos are useful, but dimethoate and malathion are unnecessarily persistent. Once parasites are established, fogs are more damaging to them than localized sprays (Williams, pers. comm. 1980 (Wolverhampton ADAS)) but may be more practicable if a Guernsey arch training system is employed (see Section 3.1).

The judicious use of suitable chemicals with natural enemies is the basis of all integrated control programmes. At GCRI Ledieu (1977 b, 1979) has screened many pesticides against Encarsia and Phytoseuilus to determine their direct and residual effects. From this work simple tables have been produced showing the effects of pesticides on natural enemies. These can be used by growers to select the materials for control of other pests and diseases that are least damaging to biological control (Morgan & Ledieu, 1979; Scopes & Ledieu, 1979).

Pesticides may also have sub-lethal effects on behaviour or fecundity of natural enemies. This was demonstrated by Irving & Wyatt (1973) who differentially treated scales and substrates and concluded that parasite efficienty may be seriously impaired by sub-lethal pesticide residues. Perera (1977) found that reduction in parasitism by Encarsia due to sub-lethal doses of Pynosect was

greater when the insecticide deposit was uniform than when the droplets were aggregated on the leaf surface.

1.7.4 Parasite Supplies and Costs

Coincident with early research on methods of Encarsia usage, techniques were developed for the mass rearing and cool storage of the parasites (Scopes, 1968, 1969 a,b, 1971; Scopes & Biggerstaff, 1971, 1977; Scopes, Biggerstaff & Goodall, 1973). Until commercial rearing units were set up, it was the supply of natural enemies which limited their employment by growers (Parr & Scopes, 1971 b). A bulletin was produced by GCRI describing methods of rearing natural enemies for growers (Anon, 1975 a). However, except for large companies and cooperatives, this has not been done in practice and the majority of growers buy parasites and predators from commercial rearing companies.

Successful biological control is much cheaper than using pesticides. The major British producer first sold Encarsia for £1.30/1000 and Phytosieulus for £10.00/1000 in 1973. Parr (1973 a) estimated that biological control of whitefly and red spider mite would cost £130/acre on cucumbers (slightly more on tomatoes) compared to a probable chemical cost of £250/acre. Additionally a 20% increase in yields could be expected from not using routine sprays.

The price of Encarsia has increased from £2.50/1000 in 1976 to £4.20/1000 (+VAT) in 1981. On the other hand Phytoseiulus cost £15.00/1000 in 1976 and reached a maximum price of £18.00/1000 in 1979. Since then, increased usage of the predator on a wider range of crops has led to a dramatic fall in its price to £7.00/1000 in 1981. (Gould, 1976; Worrall, pers. comm.).

In the Netherlands, Phytoseiulus was first used in 1967 and Koppert BV started mass rearing of the predator in 1970.

Following a bad outbreak of whitefly in 1971, Encarsia was imported and commercial parasite distribution started in 1972. In that year 30 million predators and 15 million parasites were sold (Woets, 1973; Koppert, 1978). Since then, the business has expanded to meet demand from all over Europe and now produces two million Encarsia a day in the spring. Dutch material was first sold under contract in Britain in 1977. Encarsia have increased by about 10% to £3.75-4.75/1000 (depending on quantity) in 1980. Again, the maximum price for Phytoseiulus, £15.00/1000, was reached in 1979, dropping to £5.80-7.20/1000 the following year. The strong pound and favourable exchange rate has helped maintain the Dutch natural enemies at a competitive price with British ones in the UK (Applied Horticulture, pers.comm.).

1.8 EXTENT OF ENCARSIA USAGE

Greathead (1976) reviewed the early biological control situation in European countries. A more recent survey was compiled by van Lenteren & Woets (1980). Its greatest development and usage has always been in the Netherlands and the UK, although other countries such as Sweden, Finland, Norway and Poland have done research and trials with natural enemies. Encarsia has been used in Canada since the first exports in the 1930s (see Section1.3) although an apparent recent decline in demand since a peak in the early 1970s has been attributed to the naturalization of the parasite (McClanahan, 1980 b). However, in the USA, development of biological control was minimal. According to Lindquist (1976) this was due to the small, scattered nature of the US glasshouse industry, the larger number of pest species to contend with, insecticides were effective until

recently and the registration of new pesticides for glasshouse crops is difficult, making the newer selective materials unavailable. Even in 1979 there was no dependable source of natural enemies and chemicals suitable for integration remained unregistered in the USA (Anon, 1979; Gould, pers. comm. 1979 (Bristol ADAS)). Parasites are now available (Scopes, pers. comm.) but the emphasis there has always tended to be on short term ornamentals such as poinsettias, rather than on tomatoes and cucumbers as in Europe.

Encarsia was used in Guernsey after its initial discovery in 1927 (see Section 1.3). The first mention in the HAS Advisory Notes of Encarsia as a solution to the increasing difficulty and expense of chemical whitefly control was in 1973. Further information was given in 1974 and 1975 and growers were advised to consider the use of Encarsia the following season and to arrange for supplies of the parasite (HAS, 1973 a, 1974 b, 1975 b,d).

A few Guernsey growers tried biological control in 1975 and 1976 but it was not adopted on a large scale until 1977. By 1978 Encarsia had been introduced into about 150 acres (60ha) of tomato crops (HAS, 1978 e). Three island companies acted as suppliers for the UK and Dutch producers. One operated on a fixed-price contract basis for complete pest and disease control, the others supplied the parasites with an after-sales monitoring service (HAS, 1977 b). However, after the unreliable results achieved using Encarsia in the 1978 season (see Section 1.9), all companies adopted a supply-only policy in the following years.

The extent of biological control usage has regularly been surveyed in England and Wales and in the Netherlands for the past few years. No such assessments had been made in Guernsey, consequently the three natural enemy suppliers in the island were asked for data

on the numbers of growers supplied and the areas treated for the past few years. The results of the surveys are given in Tables 2 & 3 and the information from Guernsey is summarized in Table 4.

Table 2. ADAS biological control survey for England and Wales (heated crops only).

Year	No. Growers	Area (ha)	Phytoseiulus (ha) cuc. (%)	tom. (%)	Encarsia (ha) cuc (%)	tom. (%)	% satisfactory Phyto.	Enc.
1975	117	57.0	15.4	11.3	19.7	22.2	87	72
1976	209	179.8	89.2 (45)	42.1 (8)	53.8 (27)	85.6 (16)	72	86
1977	236	248.6	94.1 (47)	78.8 (15)	86.6 (43)	145.5 (27)	80	86
1978	550	336.6	163.9 (72)	107.7 (20)	80.6 (36)	168.2 (31)	95	88
1979	471	374.2	145.0 (63)	143.8 (26)	91.0 (40)	223.1 (40)	94	94
1980	451	394.0	169.5 (74)	72.5 (11)	98.7 (46)	216.2 (39)	95	92

(Gould, pers.comm., 1980 (Harpenden))

Table 3. Statistics for succesful biological control on principal glasshouse crops in the Netherlands.

Year	Tomatoes Total Area(ha)	Area + Phyto.	% using Phyto.	Cucumbers Total Area(ha)	Area + Enc.	% using Enc.	Peppers Total Area(ha)	Area + Phyto.	%using Phyto
1969	2200	-	-	860	25	2	-	-	-
1970	2380	-	-	870	200	25	-	-	-
1971	2430	4	-	750	75	10	70	-	-
1972	2290	20	1	840	100	12	75	-	-
1973	2040	120	5	790	150	20	150	10	7
1974	2090	400	20	785	150	20	160	12	10
1975	2060	500	25	780	200	25	160	15	10
1976	2040	600	30	720	300	40	160	20	12
1977	2090	550	25	770	350	45	175	30	15
1978	2000	530	25	750	400	50	180	40	20
1979	2050	560	25	720	400	55	180	40	20

(Woets, Ramakers & van Lenteren, 1980)

Table 4. Encarsia usage in Guernsey.

Year		Parasite Supplier R.L.Le Huray	Fruit Export	Stan Brouard	Total	Total tomato area (ha)	% using Encarsia
1975	growers	12	*	*	12		
	ha	2.0	*	*	2.0	*	
1976	growers	21	*	*	21		
	ha	5.6	*	*	5.6	*	
1977	growers	36	51	*	87		
	ha	10.0	15.0	*	25.0	228	11%
1978	growers	83	69	23	175		
	ha	24.4	30.4	5.1	59.9	227	23%
1979	growers	26	122	+30	+178		
	ha	10.8	53.0	8.0	71.8	219	33%
1980	growers	42	75	11	128		
	ha	15.3	50.2	3.2	68.7	182	38%
1981	growers	23	41	5	69		
	ha	6.5	10.0	0.8	17.3	*	

* Data unavailable + Estimated figure

(Data from: R.J.le Huray Ltd., Fruit Export Ltd., Stan Brouard Ltd., Mr I. Worrall and HAS)

It must be remembered that ADAS and other government authorities do not deal with all growers, therefore the data are probably an underestimate of the true picture. Also, the classification of success or failure of biological control is merely the subjective opinion of the grower or advisory officer for whom different standards may apply. Nevertheless, the surveys reflect the general trends of usage and success rates.

Data from Guernsey had not been well documented, hence some figures are missing and others have been estimated (Table 4). The total area of tomatoes includes both heated and unheated crops,

therefore, the actual percentage of heated crops using Encarsia is rather higher than shown. There was no accurate record of the degree of success achieved, but it is known to be considerably lower than in the UK (Table 2). Encarsia usage in Guernsey reached a peak in 1979 and there was a sharp drop in 1981, following continuing difficulties with the technique. Very little Phytoseiulus has been used and no data were available.

Several points are apparent from the Tables. Firstly, there are differences in the Netherlands and UK integrated control programmes. Whereas in Britain both parasites and predators are used on tomatoes and cucumbers, in the Netherlands Encarsia is used on tomatoes,with acaricides for red spider mite control, and Phytoseiulus is used on cucumbers (and gherkins and peppers) with cyanide fumigation for whitefly control. (Woets & van Lenteren, 1979). Secondly, the pattern of rapidly increasing natural enemy usage can be seen, followed by a levelling off for a few years, and lately, a decline. This is due to problems with control of secondary pests. In the Netherlands, tomato leafminer (Liriomyza bryoniae Kalt.) has become troublesome, and as the chemicals necessary to control it are incompatible with biological control of whiteflies, Encarsia usage has declined (Woets & van Lenteren, 1979; van Lenteren, Ramakers & Woets, 1980). Leafminer control is considered to be a major factor limiting biological control in Dutch tomatoes (Woets, 1974, 1976: Zucchi & van Lenteren, 1978). In Britain, thrips (Thrips tabaci Lind.) on cucumbers has become a threat to biological control of other pests (Gould, pers. comm. 1979, 1980 (Bristol ADAS & Harpenden)). A method of thrips control employing a strip of sticky polythene impregnated with insecticide (Thripstick) laid beneath the crop, is being

developed as a control method which is compatible with natural enemies (Atkinson, pers. comm. 1980 (Leeds ADAS)).

1.9 FAILURE OF ENCARSIA IN GUERNSEY

The results of biological control in Guernsey have been very variable. While in the Netherlands growers achieved over 80% success using Encarsia from January onwards and no longer considered whitefly to be a problem (HAS, 1978 d), the degree of success in Guernsey was limited and in many cases parasites either failed to establish or did not maintain control (HAS, 1978 e). It was this situation which led to close collaboration with GCRI and support from the HAS, to try and determine the causes of biological control failures in Guernsey (HAS, 1978 c,e, 1979 l,m, 1980 d). Meetings and Open Days were arranged to enable growers to learn techniques of biological control from GCRI and parasite rearing companies (HAS, 1979 d, 1980 i). Nursery staff also needed to be trained to note and report areas of pest build-up in the crop and how to manage biological control (HAS, 1980 l).

As mentioned in Section 1.8, Guernsey entered the biological control scene rather late and Encarsia was first used widely in the island during 1977 and 1978. Adopting the methods used in the UK and the Netherlands, the HAS Advisory Notes at first told growers that two or three parasite introductions would be necessary (HAS, 1973 a, 1976 c). Later, at least four fortnightly introductions were recommended, continuing until black scales were found on the crop (HAS, 1977 a,b). The numbers of parasites used and the introduction programmes varied from one supply company to another and advice varied between them and the HAS, so growers were then advised

to adhere to one source of advice through the season to avoid confusion and contradiction (HAS, 1980 d).

It was perhaps unfortunate that many Guernsey growers' first experience of biological control was through the contract services offered in the island, which were not very successful there or in the UK. Contract control was first used in the Netherlands in 1976 and then in the UK in 1977, at £300/acre for whitefly control and £500/acre for whitefly and red spider mite control (French, pers. comm. 1976 (Newcastle ADAS)). The complete operation of biological control and crop monitoring by professional contractors was intended to overcome delayed parasite introduction, bad management and use of incompatible chemicals when growers did their own biological control (Gould, 1977; Koppert, 1978). However, in Guernsey, in many instances the contractors had to resort to chemicals when Encarsia failed to control the whitefly. Contract services were discontinued in Guernsey after the 1978 season. In the UK, the success of biological control did not improve in 1977, despite the contract services and the educational efforts of ADAS and the Agricultural Training Board, but since then results have improved (Gould, pers. comm. 1977, 1980 (Bristol ADAS & Harpenden)).

The correlation between a grower's interest, enthusiasm and experience, and his success with biological control has long been recognized in Guernsey (HAS, 1979 h, 1980 d,e,m). In early Advisory Notes the life cycle of whitefly was explained (HAS, 1974 c, 1976 b). Later, growers were encouraged to buy the GCRI "Growers' Bulletin" on integrated control and to take a greater interest in managing the system correctly (HAS, 1979 m, 1980 g).

With increasing efforts to get satisfactory biological

control it became a more frequent topic for comment in the Advisory Notes. From 1979 there was a regular feature detailing the progress of a correct pest-parasite interaction through the season and points for growers to watch out for. As problems with Encarsia continued, many growers became disillusioned with the system and the HAS had to help them decide what method of whitefly control to use. The current advice is that only growers who have used Encarsia succesfully in the past should continue to do so; inexperienced growers, those who have had difficulty with Encarsia, have too many early whitefly or leafminer present in the crop should use chemicals until the problems with biological control in the island have been sorted out (HAS, 1980 m, 1981 a).

1.10 BIOLOGICAL CONTROL SURVEY IN GUERNSEY

1.10.1 Introduction

In 1978 the HAS carried out a survey of growers in an attempt to determine whether there were any common factors influencing the success of biological control in the island. The following year I did another survey, based on the one done by the HAS, to examine some factors in more detail, especially physical factors which had been suggested as being likely to influence the performance of Encarsia in the glasshouses, such as the source (and hence salinity) of water used for damping down and the use and positioning of CO_2 appliances. It was also hoped to see whether the situation early in the season could be used to predict the ultimate outcome of biological control. Consequently growers were questioned in April and July.

1.10.2 HAS Survey 1978 (HAS, 1978 f,g; Smith, in litt. 1978)

In the HAS survey 41 randomly selected growers were asked about biological control in 50 glasshouse units during July, 1978. The success achieved in each glasshouse was categorized as follows:

A: Black scales established throughout the crop and whitefly under control (no dirty fruit) at the time of the survey. Small patches of whitefly, easily spot treated, were acceptable.

B: Black scales established throughout the crop but whitefly not sufficiently controlled.

C: Some black scales found away from introduction points but no whitefly control.

D: No appreciable establishment of black scales.

Nearly three quarters of the units had parasite establishment throughout the crop (A & B) and 42% had satisfactory control (A). Many of the factors examined were apparently unrelated to the success of the biological control; these are given in Appendix 2. Factors which had a significant effect on biological control, according to the survey, were:

Time of introduction in relation to crop age. 20/50 crops had the first parasite introduction when the plants were at or over the wires (usually early to mid- March). Of these 11 were unsatisfactory (C & D). Only 3 units in categories C & D had introduced Encarsia earlier.

Whitefly levels. 9/11 crops with no whiteflies seen before the first parasite introductions were successful (A). Conversely 6/9 crops with more than just "a few adults" at the time of the first introduction were unsuccessful (C & D).

Movement of scales. 11/13 growers who redistributed black scales to areas of poorer establishment were in categories A and B.

Temperatures. Generally biological control was successful in warmer crops or those where temperatures could be kept up in cold weather. 6/10 growers who kept up to full programme temperatures were in category A, while only 1/19 who kept below programme temperatures was successful.

Trimming (sideshooting). 20/33 growers who trimmed every week were successful (A), but only 1/17 who trimmed less frequently was in this category.

Deleafing. Crops which were deleafed to leave 5 - 6 feet of foliage tended to fall into category A (14/26), while those who left only 4 - 5 feet of foliage were generally less successful (7/24 in A).

Carbon dioxide. All 13/50 glasshouses where there was no CO_2 enrichment were in categories A and B, but so too were two with combustion problems in paraffin burners.

Excluding CO_2 enrichment, the remaining six significant factors could be regarded as 'guidelines' for successful biological control:

1) Early parasite introduction;
2) Initially few adult whitefly;
3) Redistribution of black scales to aid establishment;
4) Temperatures at or near programme;
5) Regular, frequent (weekly) trimmingearly in the season;
6) Conservative deleafing with a minimum of 5-6 feet of foliage left on the plants.

If these 'guidelines' are scored with a point for each one

applied, a clear trend emerges between the growers' adherence to them and the success of biological control, as shown in Table 5.

Table 5. Correlation between adherence to the 'guidelines' of biological control and success with the system, as shown by the HAS survey.

No. Units	Score	Biological control categories A (good)	B	C (bad)	D	% successful A & B
6	6	4	2	0	0	100
12	5	9	2	1	0	92
6	4	4	1	1	0	83
6	3	3	2	1	0	83
16	2	1	8	4	3	44
4	1	0	0	3	1	0

From the survey results it became apparent that, although in some cases there was no obvious reason for the failure of biological control, on the whole it could be attributed to the failure of the grower to take note of the 'guidelines' and provide optimum conditions for the establishment of Encarsia on the crop.

1.10.3 1979 Survey

For this survey a sample of 47 growers were questioned on 52 glasshouse units. The questions fell into four sections covering:

I: Structure of the glasshouse;

II: Culture of the crop;

III: Encarsia usage;

IV: Chemical usage.

Most of the information was collected during April, but

growers were visited again in July to assess how the situation had changed during the season and to find out whether they were coping adequately with biological control. Owing to outbreaks of bacterial canker in the island and the strict hygiene precautions required, a less detailed assessment was made of parasite establishment than in the previous year. Growers were asked their own opinion about the success of Encarsia in their crop but this is, of course, purely subjective, depending on their personal standards of pest control. Where growers agreed, the surveyor made her own assessment of ten plants and recorded the general pattern as follows:

Number of adult whitefly at the top of the plants (1,10, 50, 100)

% parasitism on lower leaves (10, 50, 75, 100%)

Number of black scales on lower leaves (0, 10, 50, 100)

From the grower's opinion and the surveyor's assessment the biological control situation was classed as good, moderate or bad in April, and again in July.

The survey questions and replies are summarized in Appendix 3.

In order to determine whether there were correlations between various factors and the success of biological control, the questions and answers were classified and analyzed. 116 contingency tables were drawn up and were tested for significance by a χ^2 test. Owing to the number of zeros in some of the tables, the data were not strictly applicable to a χ^2 test; however, it provided a simple means for analysing the survey, and the results obtained seem to tally with those from the previous HAS survey (see Section 1.10.1). Examples of a significant and a non-significant contingency table

are given below.

E.g.1 Contingency table for the length of time leaves were kept in the glasshouse after deleafing and the early (April) success of biological control.

April biological control assessment :		good	moderate	bad	too soon	% good
Leaves kept for:	4 days	14	5	0	0	73.7
	2-3 days	10	5	3	1	52.6
	0-1 day	6	3	0	5	31.6
Total:		30	13	3	6	

χ^2 = 17.318 on 6 degress of freedom

Significant at $P < 0.01$, i.e. there is a clear correlation between successful biological control and the preservation of leaves in the glasshouse for several days after deleafing early in the season.

E.g.2 Contingency table for the parasite supply used (i.e. cards or tobacco leaves) and the ultimate (July) success of biological control.

July biological control assessment:		good	moderate	bad	% good
Parasite supply:	cards	6	4	12	27.3
	tobacco	13	3	13	44.8
Total:		19	7	25	37.3

1 missing value

χ^2 = 1.860 on 2 degrees of freedom

Not significant at $P < 0.05$, i.e. although it would perhaps appear that parasites on cards performed worse than those on tobacco, there is no significant correlation between the parasite supply and the success of biological control.

From analysis of the contingency tables by χ^2 tests, the following factors were found to be significantly correlated:

I Structure of the glasshouse.

Consistency of the glasshouse temperatures was significantly correlated with the tighter glazing in the modern metal glashouses ($P < 0.001$) and the degree of shelter of the glasshouse site ($P < 0.01$). Similarly, newer hot air or 2" pipe heating systems were associated with the modern glasshouses ($P < 0.01$). However, there was no correlatin between the degree of success of biological control and the type of glasshouse structure or the consistency of the temperatures and the temperature programme employed ($P > 0.05$).

The type of CO_2 appliance, or absence of CO_2 enrichment was not correlated with biological control results ($P > 0.05$).

II Culture of the crop.

Although the insides of the glasshouses tended to be freer of weeds than the surrounding site, weedy glasshouses were correlated with weedy nurseries ($P < 0.001$), but there was no correlation between weediness and the degree of success of biological control ($P > 0.05$).

Regular trimming out of sideshoots (every 7 days) was correlated with more successful biological control than 10- or 14-day sideshooting ($P < 0.025$). Although there was no correlation between the frequency of deleafing or the amount of foliage left on the plants and the success of biological control ($P > 0.05$), preservation of deleafed foliage in the glasshouse for at least four days was significantly correlated with success ($P < 0.01$).

The frequent use of overhead spraylines early in the season was correlated with poorer biological control results at the July

assessment ($P < 0.025$), but there was no correlation between the results and the frequency and vigour of hand syringing or the source of the water used ($P > 0.05$).

There was a correlation between poor biological control and the tomato varieties Eurocross BB and Sonatine ($P > 0.05$), although half the Grenadier crops (the commonest variety) had bad results by July.

III Encarsia usage.

There was a significant correlation between the parasite supplier and the degree of distribution of Encarsia through the glasshouse ($P < 0.001$). Stan Brouard's and Fruit Export's customers spread the parasites throughout the crop, while growers supplied by R.J.Le Huray tended to put them at only a few sites in each glasshouse. There was no correlation between the parasite supplier or degree of distribution and the success of biological control ($P > 0.05$), although there was a strong trend (not quite significant at the 5% level) for better results where parasites were placed on the plants rather than in trays hanging in the crop or placed on the pipes.

The number of growers who started introductions earlier than in previous seasons was correlated with the number who had started introductions before late January ($P < 0.025$). There was a trend for better results where introductions started after late January, despite prolonged periods of dull weather during the first three weeks of February 1979 (not quite significant at the 5% level). There was a correlation between the number of parasite introductions made and the degree of success ($P < 0.025$), which was worse in crops which had eight or more introductions. Most growers made six regular

fortnightly introductions.

There was a correlation between the number of years' experience growers had of biological control and the degree of interest taken in it ($P < 0.05$). More experienced growers took moderate interest in the system by observing the situation while doing other jobs in the crop, and tended to have better results than the newer users, who were divided between those who took little interest in the parasites and those who were very keen.

There was a correlation between the degree of success at the April assessment and the continuation of biological control later in the season ($P < 0.05$). The worse the situation in April, the sooner the grower tended to abandon biological control.

IV Chemical usage.

Crops where Vydate was not used were correlated with early commencement of parasite introductions ($P < 0.025$), although several treated crops had apparently had Encarsia introduced before the Vydate was applied. But, Vydate usage was not correlated with the success of biological control ($P > 0.05$).

The need to use chemicals against whitefly after Encarsia introductions had been made was correlated with plants that had been bought in from plant raisers ($P < 0.05$). A similar number of growers using no insecticides against whitefly, or only a preliminary treatment had raised their own seedlings as had bought them in. There was a strong trend (not quite significant in a χ^2 test at the 5% level) that early biological control was worse where there were whitefly on the seedlings.

There was a correlation between the need for insecticides

against pests other than whitefly and the use of Phytoseiulus ($P < 0.025$). Only half the predator users were successful with it. But, neither the use of these insecticides nor of fungicides was correlated with biological control success ($P > 0.05$). The survey revealed no correlation between the use of γ-HCH and the effectiveness of Encarsia ($P > 0.05$)

1.10.4 Discussion

Several of the correlations in the 1979 syrvey are obvious, such as the better temperature control in more modern glasshouses. Some of the factors found to have no effect are somewhat surprising, for example, there being no correlation between the use of γ-HCH and the success of biological control, despite evidence to the contrary in subsequent experiments (see Section 5.2). Similarly weeds, temperature and Vydate have also been cited as important factors although this was not shown by the survey. This may be due to problems with phrasing of the questions, conducting the survey and analysis of the results. The ideas that physical factors such as water salinity and the use of CO_2 burners affect biological control were not substantiated, but it was clear that if biological control is not good early in the season it is unlikely to improve.

Owing to the subjective nature of the assessment of biological control and the difficulty of obtaining accurate information from growers in a standardised form, the surveys can only act as a guide to some of the points worthy of further investigation; these include weeds as a source of infestation (Section 2.13), low winter light and sunshine levels early in the season (2.2.2), deleafing (3.2), infestations on seedlings (3.3.4), glasshouse temperatures (3.4),

tomato variety (3.5), use of Vydate (4.2) and γ-HCH (4.3).

Although different factors were shown to be influencing biological control in the 1978 and 1979 surveys, the overall theme was that the "Guernsey factor" causing biological control to be so unreliable is not so much the physical aspects of the glasshouse, as the failure of growers to manage the system correctly. There were some discrepancies in the results of the two surveys, mainly factors which were found to be important in 1978, but not in 1979. These included temperature programme, CO_2 and deleafing practices. However, combining both surveys the following points may be regarded as being important:

a) Experience in managing biological control;

b) Time of first parasite introduction. February would appear to be best;

c) Few whitefly initially and adequate inspection of seedlings for scales;

d) Redistribution of black scales to aid establishment;

e) Temperatures at or near programme;

f) Regular weekly trimming early in the season;

g) Conservative deleafing with a minimum of 5 - 6 feet of foliage on the plants;

h) Preservation of deleafed foliage in the glasshouse for a few days;

i) Tomato variety. Biological control may have to be modified to allow for 'unfavourable' varieties;

j) Overhead spraylines should not be used too frequently early in the season.

2 PHYSICAL FACTORS CONTRIBUTING TO THE GUERNSEY PROBLEM

2.1 YEAR-ROUND WHITEFLY POPULATION

2.1.1 Introduction

In Guernsey, whitefly can be found throughout the year, both inside and outside glasshouses. Hence, there is no clear period when plants are free from the risk of infestation. It cannot be assumed that seedlings are free of whitefly at the start of each season and few crops escape further infestation throughout the year. Several factors were thought to contribute to this situation and were examined in this Section:

1. The glasshouse density in Guernsey is such that carry-over of pests and diseases from one glasshouse to another and to neighbouring nurseries is easier than elsewhere;
2. Many glasshouses are surrounded by weeds, or are adjacent to gardens, and the horticultural recession has resulted in abandoned, derelict nurseries where pests and diseases can multiply;
3. The mild winter weather in Guernsey and relative lack of frosts allows whitefly to survive outdoors and migrate into glasshouses in spring.

2.1.2 Glasshouse Density

Glasshouses are an integral part of the Guernsey landscape, but their density is most apparent from the air, as in Figures 2 & 3. Although declining nowadays, the tradition of part-time growing means that many small nurseries are in close juxtaposition, so that whitefly transfer between them is easy. With different standards of pest hygiene and control methods on each property, few growers' pest

Aerial photographs showing the high density of glasshouses in Guernsey.

Figure 2.



Figure 3.



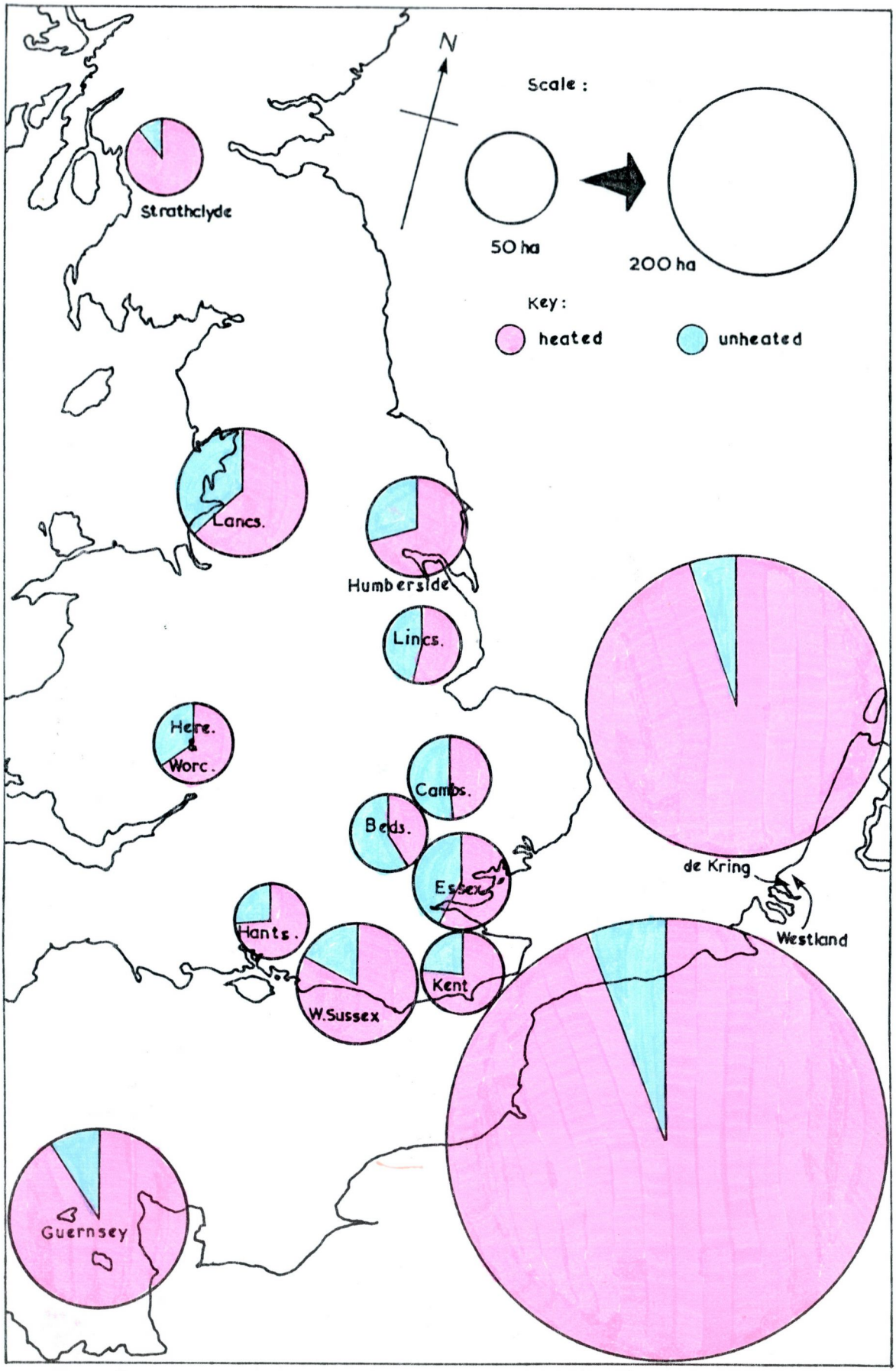
problems are isolated from their neighbours'. Although there are now some very large companies in the island, most Guernsey nurseries are still small, 53% of the tomato area being made up of nurseries under 0.5ha (Dempster, 1980).

Dempster (1980) recently made a comparative review of the tomato industry in Guernsey, the UK and the Netherlands. He illustrates the similarity in the density of glasshouses in Guernsey, where they cover approximately 7% of the land area, and South Holland, where the figure is 2%. In contrast, the UK glasshouse industry is more dispersed, and even in the major areas, the density is much lower than in Guernsey. Hence, pest populations tend to be much more isolated and natural carry-over from one nursery to another is less probable.

Figure 4 illustrates the areas of glasshouse tomatoes in Guernsey and the major areas (counties) of England, Scotland and the Netherlands. The total acreage of tomatoes in Guernsey, 182 ha, is concentrated in approximately 25 square miles and is larger than the acreage in any of the major English counties, e.g. 98ha in Lancashire, 86ha in West Sussex and 59ha in Humberside (HAS, 1980 a; MAFF 1980). Although the Dutch tomato acreage (1140ha in Westland and 528ha in De Kring) is much greater than in Guernsey, so too is the land area.

Berendt (1980) considered that in Sweden, the forest location of many nurseries isolated them from infestation, and hence many remained free of whitefly all season. Foster (1981) surveyed the incidence of pests in tomato crops in the Clyde Valley region of Scotland. He found a decline in whitefly occurrance from about 50% of the crops in 1974 to only 20% in 1980 (Foster, pers.comm.1981 (W.Scot. Agric.Coll.)), whereas it is assumed that most crops are

Figure 4. Diagram to show the main areas of glasshouse tomatoes in the UK (1980), Guernsey (1980) and the Netherlands (1979).



(Data from HAS, 1980a; Mackay, pers.comm. (DAFS); MAFF, 1980; van der Linden, pers.comm. (Naaldwijk))

infested in England and Guernsey. The lower incidence of whitefly may be attributed both to colder winters which eliminate outdoor populations (see Section 2.1.4) and less carry-over between more scattered glasshouses.

2.1.3 Weeds and Dereliction

The role of weeds as a source of whitefly infestation has been recognized since the earliest papers on whitefly control. Lloyd (1921 a) noted the importance of weeds and ornamentals in glasshouses in winter as a reservoir for invasion the following season. Weeds have been cited as overwintering hosts and sources of infestation by authors in many countries (Lipa, 1972; McClanahan, 1972 b; Smith, 1972; Tauber & Helgesen, 1974; Smith & Webb, 1977; Okada & Santa, 1978; Hosoda & Naba, 1979).

Guernsey glasshouses are frequently surrounded by weeds and nettles, rather than by mown grass, which provide breeding sites and a constant source of reinfestation. Dorey (1960) considered that the effect of insecticides may be nullified by weeds supporting outdoor populations of whitefly. The need for weed control in and around glasshouses has regularly been emphasised in the HAS Advisory Notes (HAS, 1973 b, 1974 a, 1975 c, 1977 c, 1978 h, 1979 j,k, 1980 e,g,m, n,o). It was highlighted by Dr Nigel Scopes in a talk to growers, who said that he was "appalled" by the number of weedy nurseries he had seen in the island (Guernsey Evening Press, Nov. 16th, 1978). A marked increase in herbicide sales was noted by agrochemical salesmen following Dr Scopes' talk! Nevertheless, the problem persists. Growers are recommended to treat weeds and old crops prior to emptying houses, to kill adults and prevent them flying on to other plants when their hosts are disturbed and destroyed (HAS, 1979 j,k, 1980 m,o).

The weed problem is nowadays being exarcerbated by the abandonment of small, old, uneconomic glasshouses and their subsequent dereliction. In 1978 there was a 9% decline in the number of the smallest nurseries in Guernsey (under 0.1ha) after a similar reduction the previous year (HAS, 1979 a). Many growers are tenants and there is no incentive for them to clear out the old crop or peat modules when giving up their lease. Consequently, whitefly and other pests continue to breed on weeds which colonize the abandoned glasshouses. Old property is difficult to let and much of it is falling into disrepair, while owners wait for permission to redevelop the site, frequently for housing rather than horticulture. Meanwhile, whitefly invade tomato crops on neighbouring nurseries. This problem is illustrated in Figures 5 & 6.

Even without the weeds, Guernsey would most likely have a regular source of whitefly infestation from gardens adjoining the nurseries. It would perhaps be feasible to enforce statutory weed control, but the elimination of host plants from gardens is impossible. There is also a tendency for growers to plant a few cucumbers among the tomatoes for home consumption; or to raise garden plants in the corner of the glasshouse. In 1922, Lloyd considered that much of the whitefly problem in Guernsey stemmed from the propagation of tomato seedlings in glasshouses containing infested beans and potatoes as well as the presence of ornamentals in the cropping houses. In some instances the situation has not improved since then.

Biological control of whitefly is always more difficult in mixed crops. This has been demonstrated in ADAS trials where the presence of ferns and ornamentals in tomato houses have increased whitefly populations and necessitated the use of chemicals or extra Encarsia for control compared to crops of tomatoes alone (Simmonds,

Figure 5. Photograph showing a derelict glasshouse, now a common sight in Guernsey.



Figure 6. Photograph showing the proximity of an old derelict glasshouse to a modern cropping house.



pers. comm. 1978 (Starcross ADAS)). Nevertheless, a few growers in Guernsey use the cucumbers as 'banker' plants. Whitefly multiply more rapidly on these and, by concentrating parasite introductions on the cucumbers, a supply of Encarsia is built up for distribution through the tomatoes as required. This practice was suggested by McClanahan (1972 b) as a means of preserving a parasite reservoir to compensate for the loss of Encarsia when tomatoes are deleafed.

2.1.4 Mild Winters

Guernsey lies further south than any of the UK or Netherlands glasshouse areas. This southerly position, together with the influence of the Gulf Stream, results in milder weather and fewer frosts than elsewhere in tomato growing regions. Meteorological data were acquired from Guernsey Airport, GCRI, Stockbridge House EHS at Cawood in Humberside and the Glasshouse Crops Research Station at Naaldwijk in the Netherlands, in order to compare the incidence of frosts during the winter months (November to April) since 1975, when biological control of whitefly began to be widely adopted. The data are summarized in Table 6 a. Analysis of variance (Table 6 b) showed that Guernsey has significantly fewer days with frost (both air and grass frost) than all the other sites. There are significant differences in grass frost between all the sites at the 5% level, with Naaldwijk having less air frost than GCRI.

Lloyd (1922) partly attributed the worse whitefly situation in the Channel Islands to milder winters. Although Speyer (1929 b) thought that, as the glasshouse whitefly was of tropical origin, it would be unlikely to survive outdoors in winter, the eggs, pupae and adults are quite cold tolerant. However, adults require

Table 6 a. Mean number of days with air and grass frost during the months November to April, 1975 to 1981 at the four meteorological sites studied.

		Guernsey	GCRI	Humberside (Cawood)	Naaldwijk
Air frost	Nov	0	5.0	5.8	2.7
	Dec	0.8	8.8	9.5	8.3
	Jan	2.7	15.7	13.8	8.3
	Feb	2.2	9.7	10.8	10.3
	Mar	0.3	5.0	5.5	3.2
	Apr	0.2*	3.3	3.5	1.0
Grass Frost	Nov	3.8	13.2	14.2	6.2
	Dec	4.5+	15.2	19.7	12.8
	Jan	9.2	20.7	23.3	18.0
	Feb	6.7	15.7	18.3	15.2
	Mar	5.7	12.8	14.2	7.5
	Apr	5.8	13.5	12.0	6.3

* 1 day air frost April 1978 = new record

\+ 10 days grass frost December 1976 = new record

(Lillington, pers.comm. (Gu.Met.Office))

Table 6 b. Overall means and least significant differences from analysis of variance of the frost data from each site.

	Cawood	GCRI	Naaldwijk	Guernsey	5% L.S.D.	1% L.S.D.
Air frost	0.271	0.261	0.186	0.034	0.065	0.086
Grass frost	0.568	0.502	0.365	0.197	0.069	0.091

fresh foliage, and consequently, it is the eggs and pupae which usually overwinter (Lloyd, 1921 a, 1922; O'Reilly, 1974). Japanese studies showed that cold and leaf-withering were major winter mortality factors (Okada & Santa, 1978; Hosoda & Naba, 1979; Kajita, 1979). Eggs laid in autumn survived and developed slowly, all stages being found on weeds, despite the cold winters. (At Hiroshima Prefectural Agricultural Experimental Station there were frosts on an average of 21, 26 and 20 days in December, January and February in the last five years (Hosoda, pers. comm.)).

In more extreme climates such as Canada and the USA, whitefly cannot survive outdoors in winter (Sleesman & Lindquist, 1971; McClanahan, 1972 b) but they do survive mild winters in the UK (Anon, 1974 a). Foster & Kelly (1978) noted an increased problem with whitefly in Scotland in 1976 following a mild winter when they survived outdoors, and reduced incidence the next year, partly due to a more severe early winter. The habitually mild winters therefore contribute to the problems of year-round infestations in Guernsey.

2.2 POOR ENCARSIA PERFORMANCE

2.2.1 Introduction

When biological control first started to produce diverse and often disappointing results in Guernsey, many suggestions were made about the presence of some unique "Guernsey factor". These included the salinity of water used for damping down, high ethylene levels and combustion products from the paraffin burners used for CO_2 enrichment (but not in the UK or the Netherlands (Dempster, 1980)). Exploratory experiments produced no positive results, so

attention was turned to natural physical factors which affect Encarsia behaviour, principally temperature and light.

Parr, Scopes, Biggerstaff, Ledieu & Stacey (1975) observed that Encarsia performance was poor in the UK before March and that establishment seemed to depend on sunshine during the life of the introduced parasites. The maximum pipe heat at programme tomato growing temperatures (see Appendix 1) is only 18-20°C which is below Madueke's (1979) flight threshold for Encarsia of 21-22°C. In sunny conditions the glasshouse temperature is raised by radiant heat, allowing parasites to disperse.

This Section considers the effect of winter sunshine and light intensity on Encarsia. The dispersal of the parasite was monitored in Guernsey glasshouses during one winter, and the possibility of its enhancement by boosting temperatures above the 22°C flight threshold for short periods is also examined.

2.2.2 Winter Light and Sunshine Levels

Low light and the absence of sunshine have long been considered to have an adverse effect on Encarsia. In 1931, Fox-Wilson noted that the parasite's life cycle was retarded in winter despite high glasshouse temperatures. He maintained that this was characteristic of tropical species introduced into temperate climates. Milliron (1940) considered that light and humidity affected Encarsia performance, although temperature was the most important factor. McDevitt (1973) showed that photoperiod affected the oviposition of Encarsia. In laboratory experiments, at optimal light intensity (7200 lux) there was no oviposition with 8 hours lighting, increasing to maximum oviposition under a 16-hour photoperiod. Hence, the short winter days in Britain will reduce

oviposition even in sunny weather.

Experiments to quantify the effect of light intensity have produced rather discrepant results. Biggerstaff (1977) apparently found little difference in Encarsia fecundity over a range of light intensities (500 - 8500 lux). However, Ibrahim (1975) had concluded that parasite efficiency is optimal under medium light intensities around 3340 lux, while McDevitt (1973) reported no oviposition at 3150 lux and most at 7300 lux (Scopes, 1973). Nevertheless, it is generally accepted that low light inhibits the parasite and consequently, in the northern latitudes of America and Finland no attempt is made to use Encarsia until February when daylength and light conditions improve (Lindquist, Frost & Wolgamott, 1980; Raiskinmäki, 1980).

Parr, Ledieu & Stacey (1976) suggested that Encarsia movement may be stimulated by bright sunlight. In experiments at GCRI in shaded and unshaded glasshouses, twice as many parasites were found on the plants in the shaded houses, concentrated near their emergence point, suggesting that they had not dispersed in the absence of sunshine (Hussey, Parr & Stacey, 1976).

Since Guernsey tends to experience prolonged periods of dull weather and fog in winter and early spring, it was decided to compare meteorological data for the daily solar radiation levels and sunshine hours from Guernsey, GCRI, Cawood (Humberside) and Naaldwijk to determine whether there were significant differences that could explain the erratic performance of biological control in Guernsey compared to that in the UK and the Netherlands.

The meteorological observer at each site kindly supplied monthly solar radiation totals and daily sunshine records for the winter period (November to April) for the past six years, 1976 to

1981. These have been summarized in Table 7 a.

Table 7 a. Summary of mean daily solar radiation and sunshine hours during the months November to April, 1975 to 1981 at the four meteorological sites studied.

		Guernsey	GCRI	Humberside (Cawood)	Naaldwijk
Solar radiation ($gm.Cal.cm^{-2}$)	Nov	82.4	95.6	73.1*	69.6
	Dec	55.2	58.5	38.7*	44.1
	Jan	73.7	76.1	49.4	57.5
	Feb	111.5	111.4	86.7	107.5
	Mar	199.3	216.8	162.9	188.0
	Apr	340.4	338.5	332.6	332.6
Sunshine hours	Nov	2.5	2.6	2.3	1.9
	Dec	1.5	1.7	1.5	1.5
	Jan	2.1	2.1	1.6	1.6
	Feb	2.3	2.0	1.8	2.2
	Mar	3.5	3.2	2.8	3.3
	Apr	5.9	5.2	4.2	5.6

* No data for 1980

Table 7 b. Overall means and least significant difference from analysis of variance of the solar radiation and daily sunshine hours data from each site.

	Guernsey	GCRI	Naaldwijk	Cawood	5% L.S.D.
Solar radiation	4.770	4.958	4.424	3.748	0.331
Sunshine hours	2.955	2.805	2.683	2.388	0.321

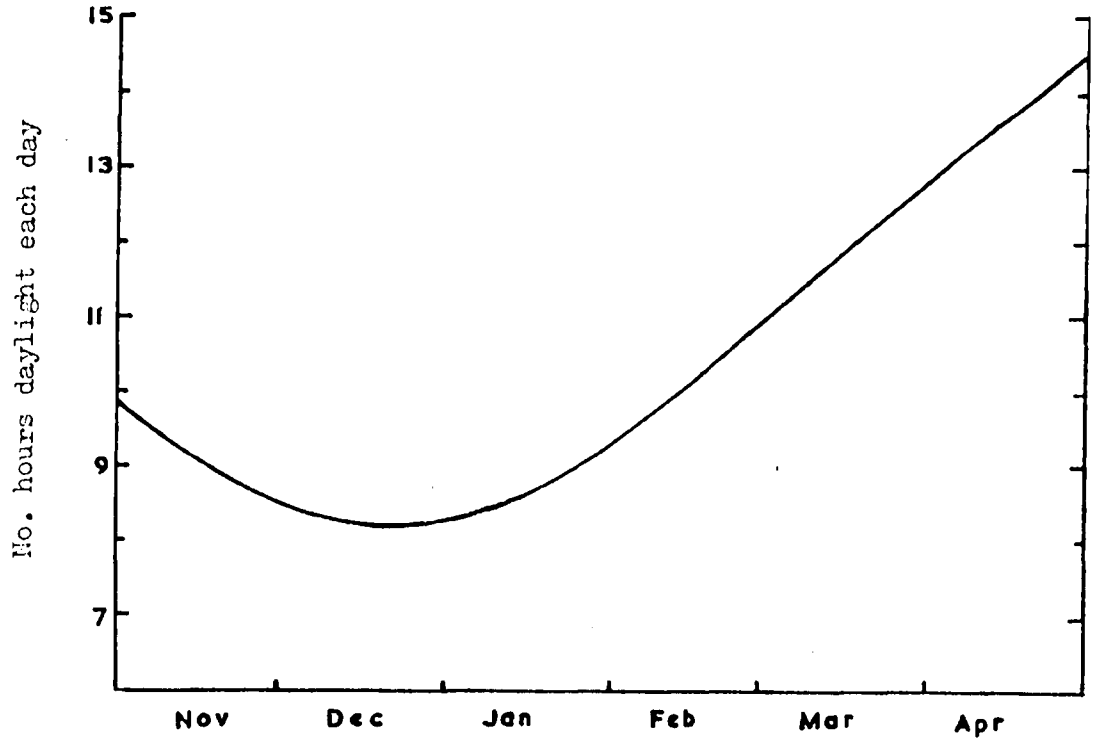
Analysis of variance (Table 7 b) revealed that Cawood has significantly less solar radiation than the other sites, as would be expected because of its northerly location. There are no significant differences ($P > 0.05$) in the sunshine hours experienced at Guernsey, GCRI or Naaldwijk, although the latter site has less solar radiation. Further analysis of the data compared the number of days each month with no sunshine, with less than half an hour or one hour of sunshine. This found no difference between Guernsey, GCRI and Naaldwijk, although Cawood had significantly more days without sun than Guernsey and GCRI. Similarly, although Guernsey experiences long periods with little or no sunshine (up to one week is not unusual) no differences between the sites were revealed when the pattern of sunshine periods was analysed.

It is therefore apparent that there is no intrinsic difference in the amount of sunshine or solar radiation that could account for the problems in Guernsey. If anything, parasites should perform better as daylengths tend to be longer by virtue of Guernsey's southerly latitude (Guernsey, 49°15'N; Sussex, 50°50'N; South Holland, 52°N).

Although there are no differences in the overall pattern of sunshine and solar radiation in Guernsey, the poor performance of Encarsia there may still be affected by them. The early and ubiquitous occurrence of whitefly in Guernsey was explained in Section 2.1. For this reason, control measures need to be initiated earlier there than in the UK. Where growers use biological control from standing-out the crop in December the light and sunshine conditions are much more unfavourable for Encarsia than in March, for example, when English growers may start introductions. Figure 7

illustrates the changes in daylength in Guernsey through the winter months. Clearly, according to McDevitt's (1973) evidence (mentioned earlier), the period until about February is unfavourable for Encarsia oviposition, even when there are sunny intervals which enhance parasite dispersal

Figure 7. Graph showing daylength (sunrise to sunset) in Guernsey during the winter months.



(Data from Guernsey Met. Office)

Early on in the development of biological control, Scopes & Biggerstaff (1973) suggested that the techniques should be modified as daylength and light intensity change. This is a comment that should have been heeded earlier. The idea of an artificial temperature boost to help parasite dispersal early in the season is discussed in Section 2.4, while the role of chemicals for early-season whitefly control prior to using Encarsia should also be reviewed.

2.3 GLASSHOUSE MONITORING PROJECT

2.3.1 Introduction

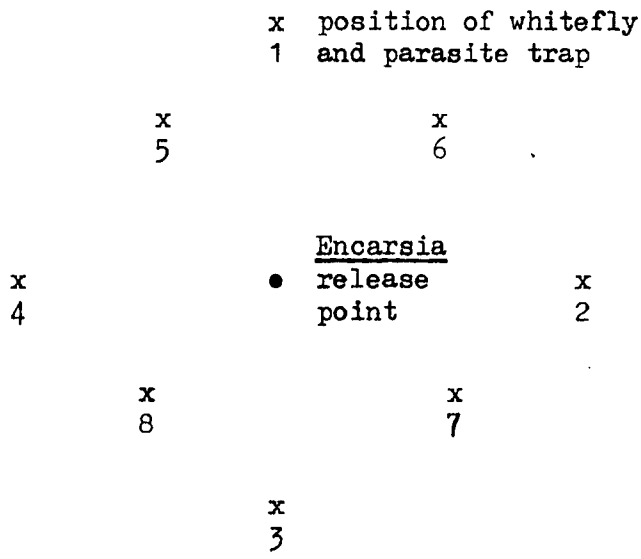
To observe and record whitefly and *Encarsia* movements in tomato crops under natural conditions, a monitoring project was undertaken from January to March, 1979, in commercial glasshouses in Guernsey. Seven sites in five glasshouses on three nurseries were visited at two- or three- day intervals to record catches of whitefly in yellow water traps and the presence of parasites on whitefly-infested trap plants. Additionally, at approximately monthly intervals, detailed records were made of whitefly and parasite development on all plants surrounding the parasite introduction sites, from which sequential maps of the pest-parasite interaction could be made. The sites were chosen to represent different types of glasshouse, whitefly density, source of parasites and Vydate usage as follows:

Glasshouse type:	old single span wooden houses	A & B
	old wooden multi-span house	F & G
	modern metal twin-span house	C,D & E
Whitefly density:	dense whitefly population	B
	few whitefly initially	A,C,D,E,F & G
Parasite source:	tobacco leaves	A & B
	cards	D,E,F & G
	banker plant	C
Vydate usage:	no Vydate	A & B
	one Vydate application	C,D & E
	two Vydate applications	F & G

2.3.2 Materials and Methods

At each site, four or eight whitefly and parasite traps were set out in a diamond-shaped pattern (see Figure 8) centred on a point at which Encarsia were released during normal dribble introductions, or from a banker plant at site C. The traps were 1.25 - 4.75m away from the release point and 2.0 - 3.75m diagonally apart from each other.

Figure 8. Layout of traps around an Encarsia release point.



Whitefly traps. The yellow tropism of T.vaporariorum (Appelby, in litt.; Lloyd, 1921 b; Macdowall, 1972; Vaishampayan, Kogan, Waldbauer & Woolley, 1975) has freqently been exploited for trapping the insect (Anon, 1975 b; Berlinger, 1980; de Ponti & Hogenboom, 1980; Webb, in litt.; Webb & Smith, 1980; Lindquist, Frost & Wolgamott, 1981). These traps usually involve yellow sticky cards, however, I used yellow water traps, based on Taplin's method (pers.comm. 1978 (Plymouth Polytech)), for ease of counting

and removal of whitefly from the water with a teat pipette. The whitefly trap is shown in Figure 9. The underside of the petri dish was sprayed with "Ford Signal Yellow" paint. The dish was supported on the inverted lid and partly filled with water, plus detergent as a wetting agent to prevent the insects escaping. The traps were hung amongst the tops of the plants where whitefly adults congregate.

Encarsia traps. Although Savage (1976) detected a colour response in E. formosa and maintained that it was more influential than the presence of host scales, Appelby (in litt.) found no significant response to different colours. Taplin (pers.comm. 1978 (Plymouth Polytech.)) considered that yellow water traps were suitable for trapping both whitefly and Encarsia and Ledieu (1981 b) also used yellow sticky traps for Encarsia. However, in preliminary experiments comparing methods of trapping parasites, I recorded many more Encarsia on whitefly-infested French bean plants than on yellow sticky or water traps. The advantage of coloured traps is that they provide a permanent record of parasite presence . But trap plants, if kept until scales have matured, provide a record of activity in terms of the number of hosts which have been parasitized. Since adequate parasitism is the objective of biological control, whether one Encarsia lays many eggs, or several parasites lay a few eggs each, is less important. Consequently, it was decided to use trap plants for recording parasite distribution.

Infested primary-leaf French beans (Phaseolus vulgaris L.) were used (see Figure 10) suspended below the whitefly traps (see Figure 11). The seeds were germinated in potting compost, but when large enough to handle, they were lifted and transferred to beakers of nutrient solution. When the primary leaves were partially expanded,

Figure 9. Yellow water trap for whitefly.

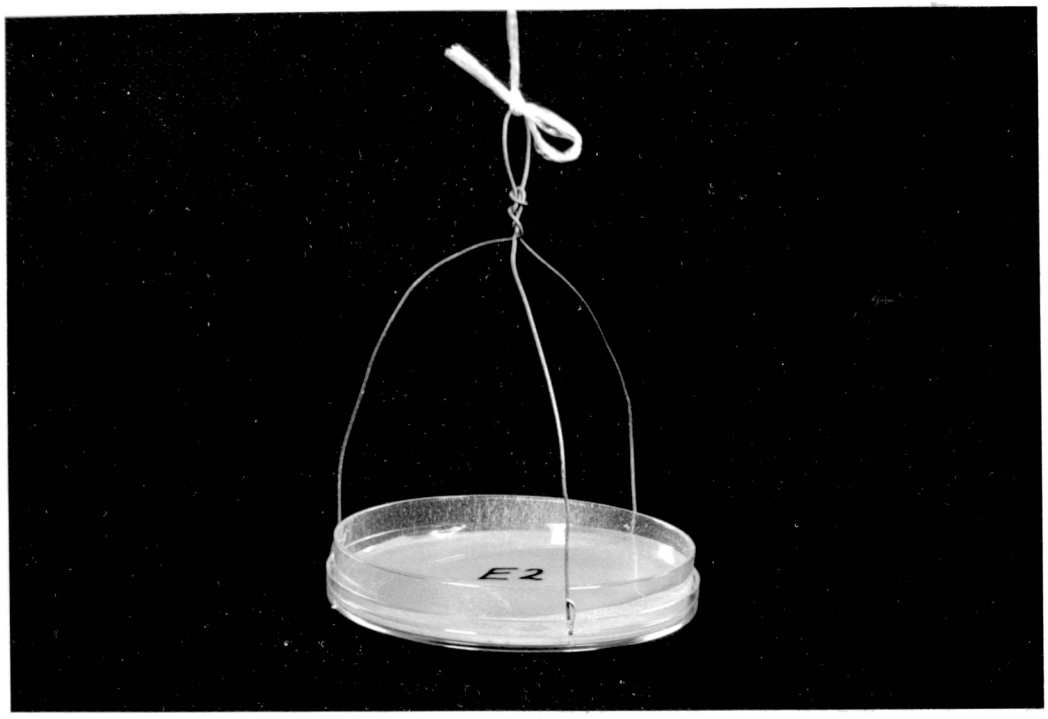


Figure 10. Infested French bean Encarsia trap plant.

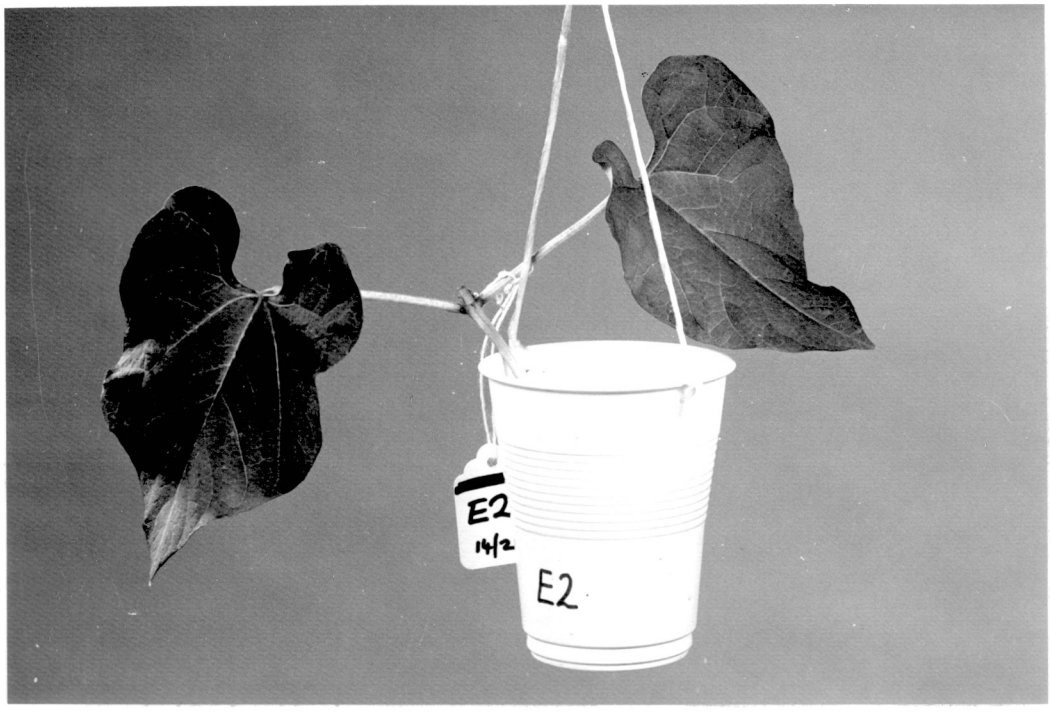


Figure 11. Positioning of whitefly and Encarsia traps in the tomato crop.



the beans were infested for 24 hours by a whitefly culture in a separate small glasshouse. After infestation, most of the adults were blown off and the rest removed by dipping the seedlings in soapy, and then clear, water. The beans were returned to the clean glasshouse to await development of third instar scales. The beakers were kept topped up with nutrient solution which was periodically changed, and the young shoots pinched out as they developed. When ready, the trap plants were placed in beakers of water and suspended at the monitoring sites. They were changed every two or three days to avoid any emerging whitefly infesting the crop.

Recording. The traps were visited daily, except at week-ends. The numbers of whitefly (and occasionally Encarsia) in the water traps were counted and the insects removed. As the crop plants grew the traps were raised to keep them level with the area of adult whitefly activity. Parasites were recorded by very carefully removing the bean plants from the beakers and counting the number of adults present. After being recorded they were blown off. Every Monday, Wednesday and Friday, the trap plants were changed and the old ones retained to record black scale development.

Mapping. In addition to the daily trap counts, a thorough survey of all the plants in each trapping area was made at approximately three to four week intervals. Thus each site was mapped three or four times during the monitoring project. The leaf petioles were marked with coloured tape to indicate the presence of white scales, black scales and emerged black scales. Mapping the colour-coded plants gave a purely qualitative picture of pest and parasite distribution. When coupled with the quantitative trap catches, a more detailed comparison of the situation at each site was achieved.

2.3.3 Results and Discussion

From the trapping records, figures were calculated for the mean daily numbers per trap per site during January, February and March. Mean adult Encarsia catches were added to the mean number of black scales per trap plant per day for February and March. These figures give a quantitative comparison of pest and parasite numbers or activity at each site.

From the distribution maps (an example is shown in Figure 12) the percentage of plants at each site infested with white and black scales was calculated. These statistics give an indication of the spread of pest and parasite.

The results were classified from A to D or E for increasing numbers of whitefly and Encarsia and for increasing percentage infestation and parasitism. The classified results are shown in Table 8 with a summary of the situation at each site in Table 9.

Figure 13 reveals the changing pattern of pest and parasite levels in relation to Vydate usage. Where no Vydate was used (sites A & B) both the spread of whitefly and percentage parasitism increased steadily. It is interesting to note that there was higher parasitism and better biological control following a lower initial whitefly population at site A than in the higher whitefly population at site B, confirming the findings of other researchers discussed in Section 1.7.2. One Vydate dosage (sites C, D and E) stopped the increase in parasitism, but did not reduce the spread of whitefly. At sites F and G Vydate was applied twice to a crop with well established parasitism. This then declined sharply, with an equivalent decline in the numbers of hatched black scales. The increasing spread of whitefly slowed down slightly but did not stop.

It was not possible to make any meaningful correlation

Figure 12. Example of the whitefly and parasite mapping for one site (C) during the Guernsey monitoring project.

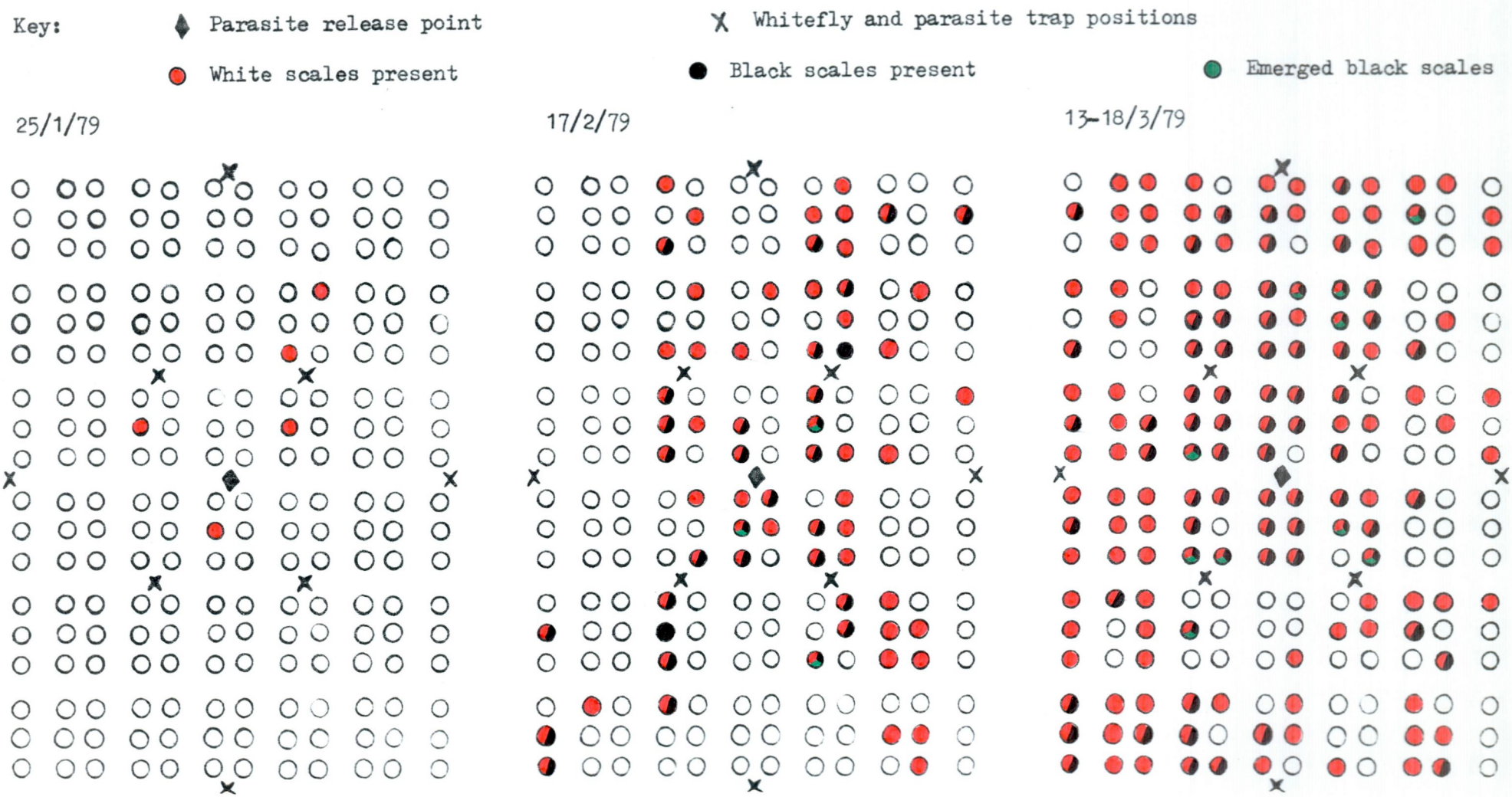


Table 8. Classified results of the Guernsey monitoring project, 1979.

Site	Date of first *Encarsia* introd	January		February				March			
		White-fly nos.	% wh.fly infest.	White-fly nos.	% wh.fly infest.	*Enc* nos.	% para.[m]	White-fly nos	% wh-fly infest.	*Enc* nos.	% para.[m]
A	5/1*	A	A	B	B	C	B	B	E	D	D
B	17/1*	D	C	A	C	A	A	A	E	B	B
C	11/1	A	A	A	C	B	C	C	D	B	C
D	11/1	A	B	A	C	C	C	C	D	D	C
E	11/1	A	A	A	B	D	D	C	D	D	C
F	5/12	A	B	A	D+	A	C+	D	E	A	A
G	5/12	B	A	A	C+	B	D+	D	D	C	B

* Some black scales carried over from old crop into seedling house A

\+ Average of two mappings made during February

Classification Key

From trapping:

Mean daily whitefly numbers per trap	A ≤ 0.5	B ≤ 1.0	C ≤ 1.5	D ≤ 1.5+	
Mean daily parasite and black scale numbers per trap	A ≤ 0.1	B ≤ 1.0	C ≤ 1.5	D ≤ 1.5+	

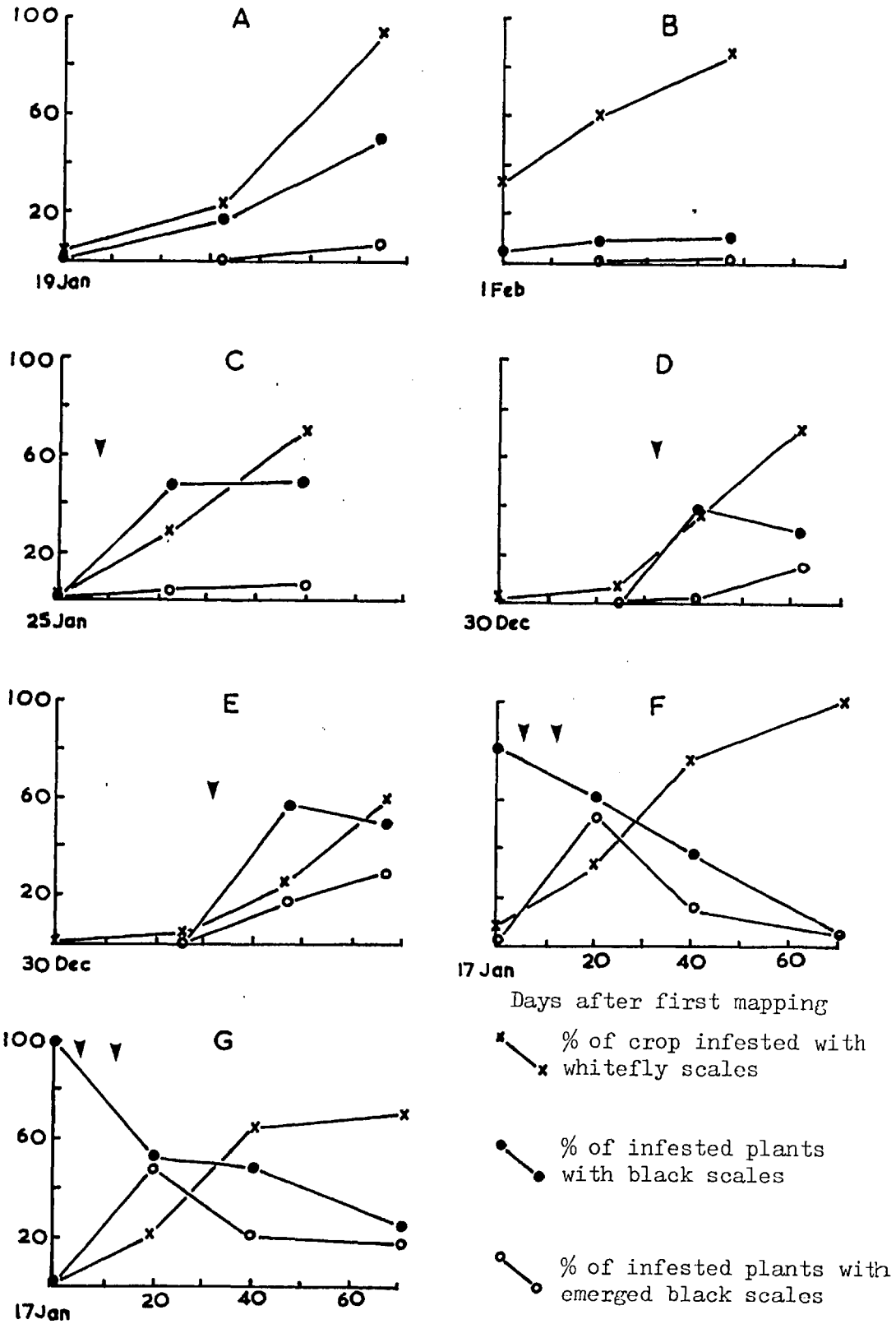
From mapping:

% of crop infested with whitefly scales each month	A < 5%	B ≤ 25%	C ≤ 50%	D ≤ 75%	E 75%+
% of infested plants with black scales	A ≤ 10%	B ≤ 25%	C ≤ 50%	D ≤ 75%	

Table 9. Summary of results from each monitoring site.

Site	Initial criteria	Whitefly development	Parasite development
A	Old wooden house. Few whitefly. *Encarsia* on tobacco. No Vydate.	Sparse whitefly population gradually spread through the house but remained at a low level.	Quite good early parasitism increased gradually with fairly high numbers of *Encarsia*.
B	Old wooden house. High whitefly numbers. *Encarsia* on tobacco. No Vydate.	High density whitefly population spread rapidly through the crop, although Plictran (for red spider mite) reduced adult numbers.	Low parasitism with little increase and no real spread through the crop. No whitefly control by *Encarsia*.
C	Metal twin-span house. Few whitefly. *Encarsia* on bankers. One Vydate dose.	Sparse low-level whitefly population gradually increased in numbers and distribution.	Low parasite numbers but moderate parasitism with a slight decline after Vydate.
D & E	Metal twin-span house. Few whitefly. *Encarsia* on cards. One Vydate dose.	Low-level whitefly population gradually increased in numbers and distribution.	Fairly high early parasite numbers and parasitism declined slightly after Vydate.
F	Old wooden multi-span. Low whitefly population. *Encarsia* on cards. Two Vydate doses.	Low whitefly numbers on a few plants gradually spread throughout the crop.	Low parasite population with good percentage parasitism declined noticeably after Vydate.
G	Old wooden multi-span. Moderate whitefly pop. *Encarsia* on cards. Two Vydate doses.	Moderate whitefly population gradually increased to a high percentage infestation.	Moderate parasite numbers increased but high percentage parasitism declined after Vydate.

Figure 13. Graphs to show patterns of whitefly and parasite population development at each monitoring site.



between Encarsia trap catches and daily sunshine levels, owing to the non-permanency of the trapping method. Had some sort of permanent sticky trap been used, a more accurate record of parasite activity would have been available. However, since Encarsia were free to fly off the trap plants, the likelihood of counting them on a sunny day was, if anything, less than on a dull day since the insects would be more likely to fly when the trap plant was disturbed.

2.3.4 Conclusion

Although it was not possible to correlate Encarsia activity with daily sunshine by the monitoring methods employed, the project gave some useful information about the development of pest and parasite populations in commercial situations. There was a good spread of parasites where the whitefly population developed from a low initial population. However, there was little spread at site B which had a high initial whitefly population and by late March only about 15% of the infested crop plants had black scales and there was no biological control of whitefly. This result suggests that the parasites were well supplied with host scales in the vicinity of their emergence (either from introduced material or from scales on the crop) and so there was no incentive to disperse through the crop. This effect could be counteracted to some extent by more thorough distribution of black scales when introducing them into a crop which has a higher initial whitefly population, remembering that less than one adult per ten plants is usually regarded as the maximum population than can be controlled by Encarsia without use of an insecticide before introductions commence.

The harmful effect of Vydate on an established pest-parasite system was clearly shown by the graphs in Figure 13. As expected,

two applications were more damaging than one. The effects of Vydate and the debate about when to use the material in relation to Encarsia introductions are examined fully in Section 4.2.

2.2.4 Temperature Boost

As described in Section 1.6.4, Encarsia apparently has a long-distance response to kairamones from whitefly honeydew.

However, in sunless winter conditions, the maximum glasshouse pipe heat of 18°C is below the flight threshold of 21-22°C determined by Madueke (1979) and confirmed by Ledieu (1981 b). Hence, Encarsia fails to disperse from the introduction point where the adults emerge. My own observations confirmed that, in dull weather, parasites could be found walking over the plant on which they were introduced, but none was seen elsewhere.

In an attempt to stimulate parasite dispersal it was suggested that if there was no sunshine the glasshouse temperature should be boosted to at least 22°C for a couple of hours on each of three consecutive days after parasites started hatching (HAS, 1979 h,1). However, with increasing fuel costs, growers tend to be reluctant to implement this suggestion.

Further attempts to prove the value of such a temperature boost in experiments at the HAS Experimental Station were not successful, owing to the problems of monitoring the degree of parasite dispersal and also the frequent occurrence of sunny intervals during the three-day temperature boost period. In experiments at GCRI, Ledieu (1981 b) progressively raised the temperature in an empty glasshouse in dull weather and found that most Encarsia flight started around 22°C, confirming the value of such a temperature boost. However, a few parasites flew even at 18°C, and this

proportion increased if they were starved prior to release, suggesting that dispersal should occur even at programme temperatures if Encarsia starved waiting for suitable flight conditions. On the other hand, the availability of honeydew on the tobacco leaves or the 'nutrient strip' now provided on card material may negate this effect.

For practical use by growers this technique requires more monitoring than normal dribble introductions. To gain the full benefit of the temperature boost, it should be applied whilst parasites are emerging; if too soon, no adults would be present, if too late, the period of maximum parasite oviposition, three days after emergence (Madueke, 1979), would have passed before they were able to disperse and find host scales. Hence, the grower should check the condition of the black scales at two or three introduction sites in the glasshouse each day after placing them out, in order to judge the optimum period for boosting the temperature if there has been no sunshine during that time.

Accepting that temperature boosting would enhance parasite dispersal, growers should be encouraged to implement the method to ensure that Encarsia reach their target and are not wasted through inactivity during prolonged dull weather. This is especially so early in the season before they have established on the crop, at a time when an unrestricted whitefly population becomes much more difficult to control later on.

It has been estimated (Cokeley, pers. comm. (HAS)) that a temperature boost to 22°C for two hours for 3-day periods twice per month would increase fuel consumption by about 0.6% (December consumption rates), costing approximately £25 per acre per month (at Guernsey fuel prices in December, 1980). Stage III temperatures

are raised to 20°C in the tomato growing programme, so reducing the cost of temperature boosting during January for a November-sown crop. This is, however, a small price to pay compared to losing the benefit of even a single Encarsia introduction costing £45-58 per acre, let alone compared to the price of chemical whitefly control if parasites fail to establish in unfavourable conditions.

3 CULTURAL FACTORS CONTRIBUTING TO THE GUERNSEY PROBLEM

3.1 GROWING SYSTEM

The differences in tomato growing in Guernsey, the UK and the Netherlands were described by Dempster (1980). The principal cultural system in Guernsey involves the use of peat modules (89% of the area (HAS, 1980 a)) with plants trained in a modified Guernsey arch pattern, as shown in Figure 14. In the UK, 80-85% of the crop is still grown in border soil (Bedding, pers.comm. (GCRI ADAS)) with an increasing number of growers changing directly to the nutrient film technique (NFT) rather than peat culture; layering is the commonest training method. Most crops in the Netherlands are soil-grown, owing to problems with water pollution which limit the use of NFT and peat; they are trained in the Dutch hedge pattern. High wire layering is a new development which is used on a small, but increasing, scale. The different training patterns are illustrated in Figure 15.

The effects of tomato training systems on biological control were recognised by Samways (1978), although in Sweden, Ekbom (1977) detected no difference in parasite performance due to tomato training. As mentioned in Section 1.7.3, an imbalance in the pest-parasite interaction can often be rectified by an insecticide spray directed to the tops of the plants so as to reduce the number of adult whitefly. In a layered crop this zone is always accessible, but with a Guernsey arch, once the tops of the plants have crossed above the path, the young foliage becomes inaccessible and is in close proximity to older leaves in the neighbouring row so preventing selective spraying. Consequently, to reduce whitefly numbers growers tend to resort to fogs which are more damaging to parasites. Another

Figure 14. Photograph showing a Guernsey tomato crop grown in peat modules and trained in a modified Guernsey arch pattern.

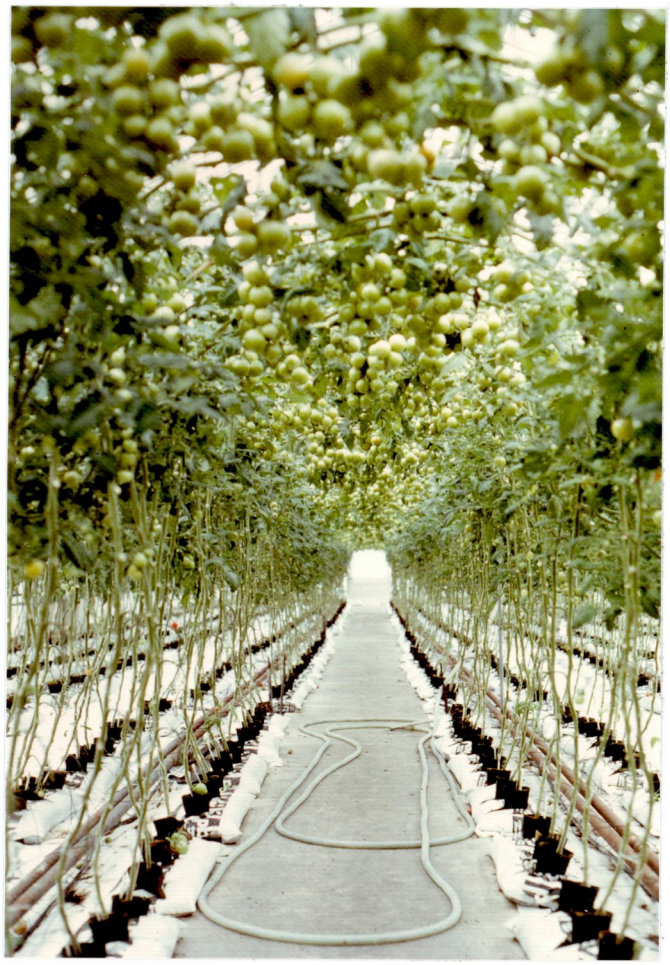
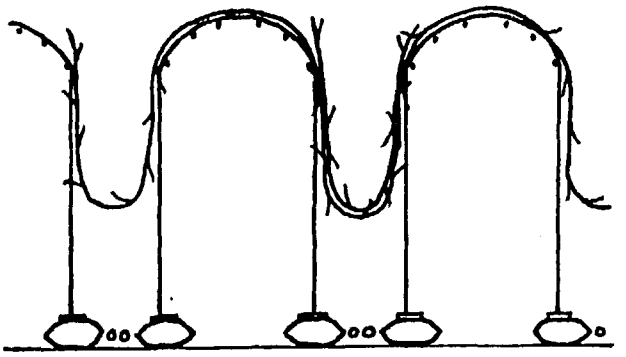
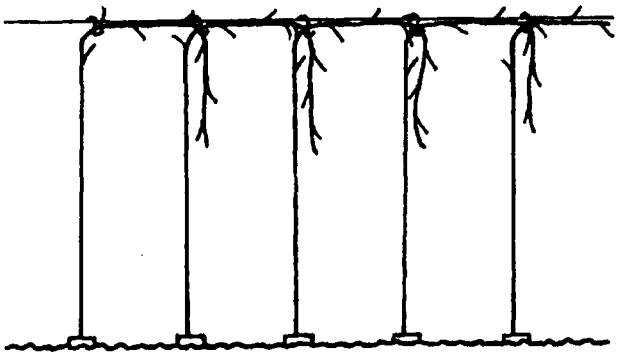


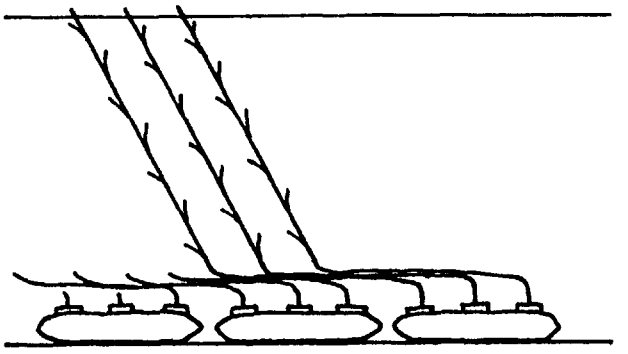
Figure 15. Diagrams to illustrate tomato training systems.



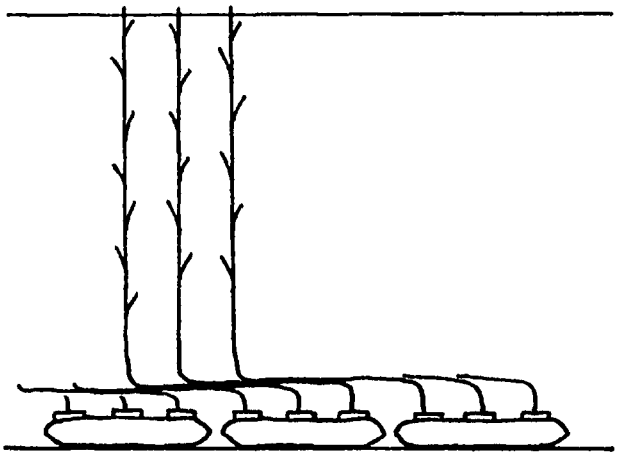
Modified Guernsey arch



Dutch hedge



Low-wire layering



High-wire layering

(After Dempster, 1980)

disadvantage of the Guernsey arch is the difficulty of assessing whitefly numbers when the tops of the plants are obscured by older foliage. When the plants are overhead it is also difficult to see adult whitefly fly up against the sun. One further consideration is the lack of penetration of sunlight through the dense canopy of the arched system compared to a layered crop, which could reduce temperatures and so restrict parasite dispersal (see Section 2.2.2).

The way in which the training pattern affects deleafing, and hence biological control is discussed in Section 3.2.1.

The use of different growing media (peat modules, border soil or NFT) indirectly affects biological control in two ways; through secondary pests, and in the effectiveness of systemic insecticides.

Soil sterilization, by steaming or methyl bromide, kills overwintering pupae of pests such as tomato moth (Laconobia oleracea L.) and tomato leafminer (L. bryoniae). With peat culture or NFT, the need for conventional sterilization is eliminated, and the floor of the glasshouse is usually wholly or partly covered with white polythene which excludes weeds and helps reflect light back into the crop. However, other measures are necessary to eliminate pests such as leafminer. In Guernsey, the usual practice is to treat the glasshouse floor with γ-HCH before laying down polythene at the start of the season. Recent evidence suggesting that this treatment is disadvantageous to subsequent biological control is discussed in Section 4.3.

Peat culture and NFT also differ from border soil in the effectiveness of systemic insecticides, such as oxamyl (Vydate), applied to these different growing media (see Section 4.2).

3.2 DELEAFING

3.2.1 Introduction

Tomatoes are deleafed both to remove senescent foliage and to increase air circulation through the crop so as to reduce disease incidence. Increased penetration of sunlight into the canopy also hastens fruit ripening. The amount of foliage removed depends on the training pattern employed and on preferences of individual growers. The need to modify deleafing procedures and to keep more foliage than usual on the plants to preserve unemerged black parasitized scales was recognised early in the development of biological control systems. Woets (1973) suggested that delaying deleafing for just a few days might be sufficient, or alternatively keeping deleafed foliage on the paths for a few days should allow Encarsia to emerge in the glasshouse (Scopes & Ledieu, 1979).

Parr (1973 a,b) considered that the introduction of the layered training system encouraged excessive deleafing and depletion of black scales. Raising the crop wires increases the amount of foliage which can be left on the plants, hence high-wire layering should favour biological control (Samways, 1978; Scopes & Ledieu, 1979).

In Guernsey, growers have always tended to deleaf severely and the need to modify this procedure for biological control was explained in Advisory Notes (HAS, 1977 b, 1978 h, 1979 e). Formerly, only 3-4 feet of foliage was thought sufficient to maintain cropping, and severe deleafing was encouraged to remove immature whitefly pupae (HAS, 1975 a). Later, more foliage (4½-5 feet) was considered necessary to optimize crop potential (HAS, 1981 g). However, at least 6 feet of leaves are required to allow completion of Encarsia development and emergence on the plant (HAS 1978 h, 1979 f, 1980 j, 1981 c).

Removal of leaves adjacent to the paths to give access to the fruit, whilst leaving more foliage inside the double rows, was encouraged. Growers were instructed to keep leaves bearing black scales and to redistribute them to areas of poorer establishment in the crop, or to place them on the paths or pipes for a few days to allow parasites to emerge (HAS 1978 g,h, 1979 d, 1980 g,h). In my own experience many growers have difficulty in seeing whether black scales have emerged or not and the HAS (1980 d,g) encouraged them to use a lens. Berendt (1980) recognised the importance of apparently trivial matters, such as poor eyesight, in compounding problems of biological control management.

Glasshouse experiments were conducted at GCRI to investigate the effects of three deleafing regimes on biological control, and to assess the benefit of keeping foliage on the paths after deleafing. Plants were severely and lightly deleafed and a compromise pattern was employed where leaves on the outside of double rows were removed to give access to the fruit, while keeping foliage lower down inside the double row to preserve immature black scales.

3.2.2 Materials and Methods

A glasshouse compartment (9.6 x 8.5 m) was planted with four double rows of Sonato tomatoes in border soil on 30th March, 1979. There were 17 plants per row, running N-S, and each double row was taken as a plot with treatments assigned as follows (plots numbered 1 to 4 from east to west):

1) Control, no deleafing;
2) High deleafing, all ripening fruit trusses exposed;
3) Low deleafing, no ripening trusses exposed;
4) Half-and-half, outside leaves removed to expose ripening fruit, inside leaves left lower down.

Figure 16. Photographs showing three deleafing regimes.

(a) High deleafing



(b) Low deleafing



(c) Half-and-half deleafing



The deleafing regimes are illustrated in Figures 16 a,b and c. The experiment was conducted at programme temperatures.

The biological control interaction was initiated by placing four banker plants around the edge of the glasshouse at planting.

These were removed one month later (2nd May) and clear polythene screens (approximately 2.2 m high) were hung along the paths to separate the plots and minimize the migration of insects between them (after Stacey, 1977 a). The tops of the plants were sprayed with half-strength Pynosect (3ml e.c./l) to reduce excessive whitefly numbers on 19th April and 14th May. Extra Encarsia were introduced on 20th April and, when the bankers were removed, any unemerged black scales were distributed through the plots. The crop was sprayed with iprodione (Rovral) for Botrytis on 17th May.

Three plants were labelled in each plot for sampling, one each in the north, central and southern section of the plots. Each week the tops of these plants were tagged to indicate the age of the leaves as they grew. The numbers of black scales were counted weekly from early May until mid-July. Weekly deleafing started on 15th May. Leaves removed from the sample plants were used to record the numbers of black and white scales and percentage emergence at the time of deleafing. Leaflets bearing any unemerged black scales, or a sample of them if numbers were high, were placed on moist filter paper in closed petri dishes and incubated at 20°C. The numbers emerging daily were recorded for up to a fortnight (some weekends excepted), after which time any unemerged scales were regarded as inviable and discarded.

At the end of the experiment, on 14th August, as an indication of the degree of whitefly control achieved, the numbers of white scales were counted on the four leaves immediately above

the uppermost one bearing black scales on each sample plant and on five other randomly selected plants in each plot. By this time, plots 3 and 4 had been deleafed up to leaf 45 and the high deleafing in plot 2 was up to leaf 50. (Leaves were numbered upwards from the first leaf immediately above the cotyledons.)

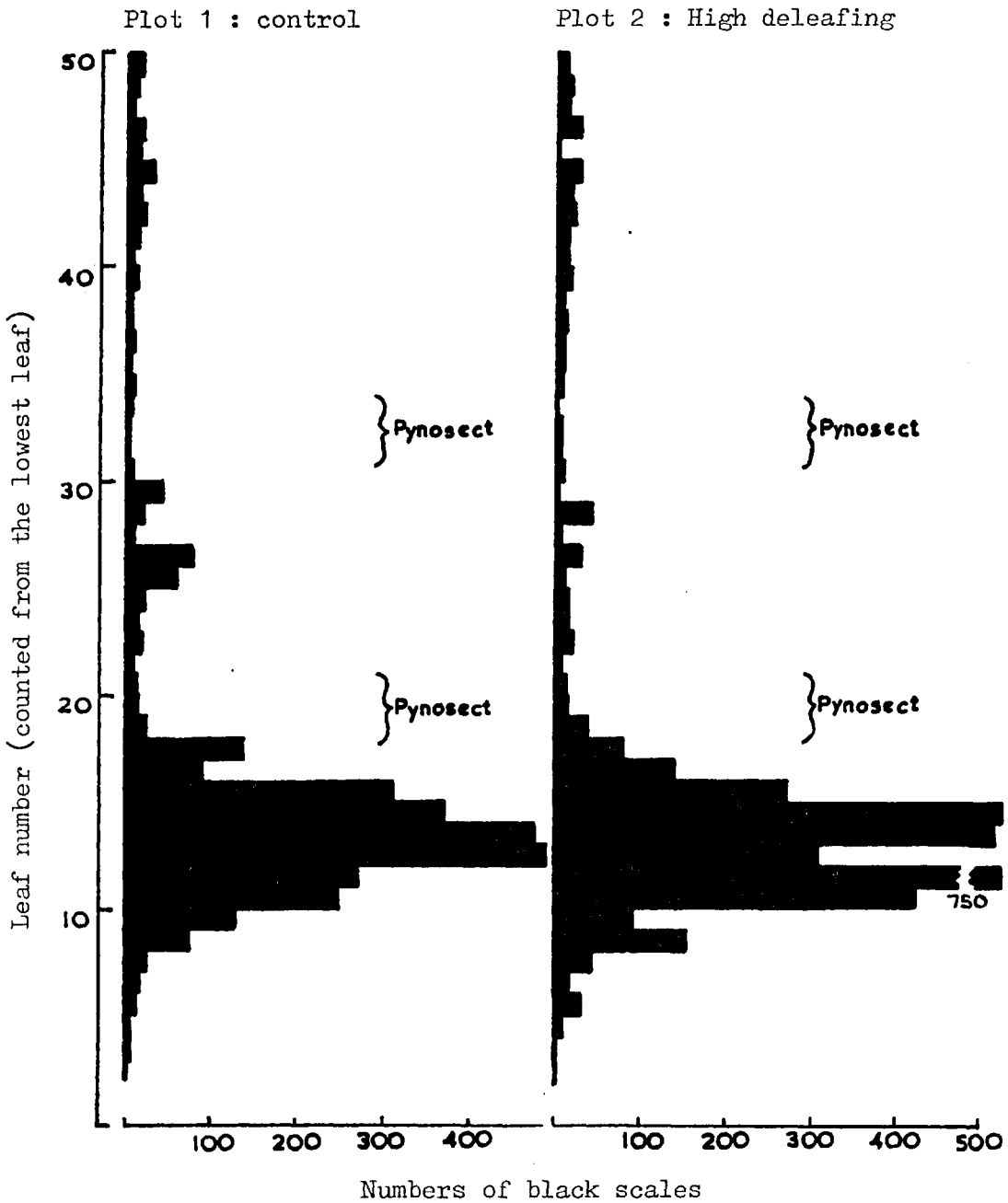
3.2.3 Results and Discussion

Unfortunately, in my absence, the crop was planted for training on a low wire layering pattern, rather than on a Guernsey arch. Consequently, in treatments where foliage was not removed (especially in the control, plot 1) counting black scale numbers on the lower leaves was difficult as the plants were 'dropped', and leaf damage caused some loss of scales as dead foliage was removed.

One point that became apparent as the experiment progressed was that, on an individual leaf, numbers of black scales increased gradually to a peak, usually three or four weeks after they first appeared, and then, if not deleafed, numbers began to decline as empty pupal cases fell off. It is known that unparasitized whitefly pupal cases are very fragile and soon break up after the adults have emerged, but I can find no comment on the disappearance of emerged black scales. Undoubtedly, the melanization process strengthens the pupal case which remains intact when detached from the leaf surface, but my observations throw doubt on the merits of a final, end-of-experiment, retrospective black scale count as used by Ledieu (1979) to provide an accurate record of parasite numbers earlier on.

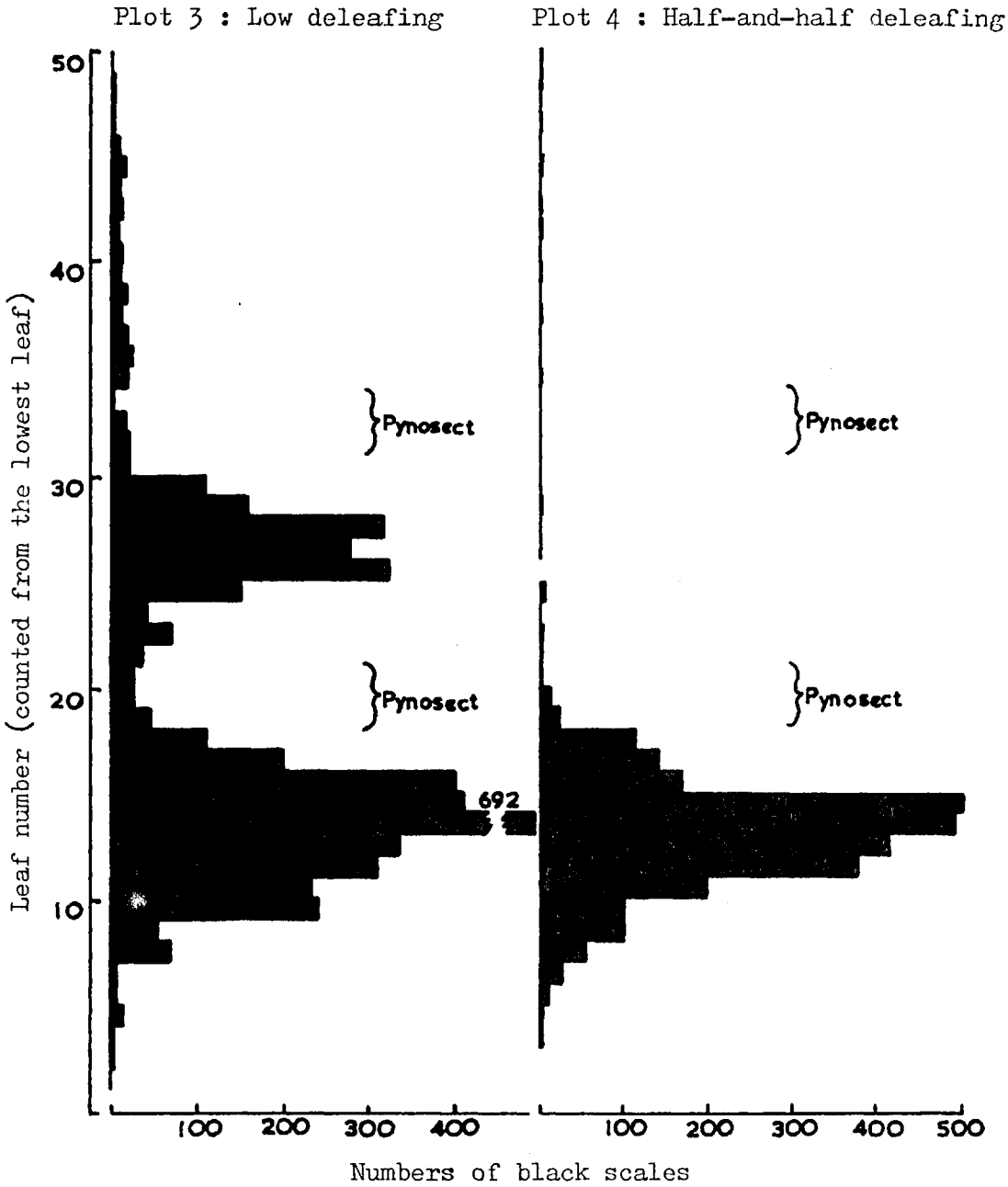
Black scale numbers. Figure 17 illustrates the pattern of black scale development in each deleafing regime. The histograms show the mean maximum number of black scales on each leaf (up to leaf 50) of the sample plants in each plot. Recording the maximum number of

Figure 17. Pattern of mean maximum black scale numbers up the plant in each deleafing treatment.



Continued ...

Figure 17 continued.



black scales allows for the disappearance of some, explained above, and hence reduces discrepancies that would appear if final assessments were used.

No record of unparasitized scales was made during the weekly counts, and for the same reason (disappearance of empty pupal cases) the proportion of black and white scales at the time of deleafing is not a meaningful comparison of the degree of parasitism between treatments.

The brackets indicate the zone of foliage at the top of the plants at the time of the Pynosect sprays. All treatments show the build up of whitefly numbers which necessitated the first corrective Pynosect spray and the resurgence in numbers prior to the second which is evident in treatment 3. By the end of the experiment the pattern of black scale numbers did not vary greatly.

Several factors should be considered when looking at the Figures. Firstly, the biological interaction was initiated from banker plants and not from controlled numbers of whitefly and Encarsia; secondly, the two Pynosect sprays altered the natural progression of the pest-parasite interaction; thirdly, the experiment proceeded during the summer months when conditions are more favourable for Encarsia, and hence whitefly suppression would be more effective than during cooler, duller winter months when deleafing could be expected to have more effect on the success of biological control.

Parasite emergence. Encarsia emergence before deleafing (derived as a mean figure for estimated percentage emergence on each leaf at the time of its removal (Table 10) clearly shows that high deleafing allows only half as many Encarsia to mature (40.1% in plot 2) compared with a more conservative regime (83.6% in plot 3).

Table 10. Mean percentage emergence of Encarsia in the crop before deleafing.

Plot	Treatment	Mean % emergence per plant Plant no.: 1	2	3	Overall treatment mean
2	High deleafing	43.1	32.4	44.8	40.1%
3	Low deleafing	75.0	89.7	86.0	83.6%
4	Half-and-half	86.1	81.8	74.8	80.9%

There is little difference in the proportion of parasites emerging between the half-and-half and low deleafing regimes; both patterns result in twice as many Encarsia emerging before deleafing as in treatment 2. This difference may, in fact, be greater since observations suggested that black scales tended to fall off the leaf after emergence where deleafing was delayed.

Parasite incubation. From Table 11 it can be seen that 50% emergence occurred in 4 days with the high deleafing and half-and-half pattern and in 5 days under the low deleafing treatment. 75% emergence occurred within 6 days in plots 2 and 4, but was not achieved in plot 3, where almost 29% of the scales failed to emerge. This probably reflects the fact that since more scales emerge in situ, a greater proportion of those immature black scales are inviable. To allow a similar proportion of the parasites in plot 2 to emerge as in the other treatments (80%), deleafed foliage would have to be kept on the paths for at least 5 days to allow 67% of the scales to mature. This is based on development rates at 20°C and would take longer at glasshouse programme temperatures. Clearly this would be inconvenient in a commercial crop, although it is practised in the Netherlands.

Whitefly control. After the Pynosect sprays, biological control was adequate in all treatments and no great differences in numbers were apparent by mid-August. The experiment could not be

Table 11. Emergence of parasites from black scales on deleafed foliage after incubation at 20°C.

(Totals from three sample plants per plot)

Plot	Treatment		Days of incubation 1	2	3	4	5	6	7	8	9	10	11	12	13	Unemerged scales	Total No. scales
2	High Deleafing	No. scales emerged	287	317	242	213	209	176	109	33	25	16	10	3	1	240	1881
		% emergence per day	15.3	16.9	12.9	11.3	11.1	9.4	5.8	1.8	1.3	0.9	0.5	0.2	0.1	12.8	
		Cumulative % emergence	15.3	32.2	45.1	56.4	67.5	16.9	82.7	84.5	85.8	86.7	87.2	87.4	87.5		
3	Low Deleafing	No. scales emerged	36	26	5	12	31	14	13	2	4	6				60	209
		% emergence per day	17.2	12.4	2.4	5.7	14.8	6.7	6.2	1.0	1.9	2.9				28.7	
		Cumulative % emergence	17.2	29.6	32.0	37.7	52.5	59.2	65.4	66.4	68.3	71.2					
4	Half-and-half	No.scales emerged	44	43	46	35	35	24	14	6	10	1	1			26	285
		% emergence per day	15.4	15.1	16.1	12.3	12.3	8.4	4.9	2.1	3.5	0.4	0.4			9.1	
		Cumulative % emergence	15.4	30.5	46.6	58.9	71.2	79.6	84.5	86.6	90.1	90.5	90.9				

started until March, by which time conditions for Encarsia establish- were improving. Had it been started earlier in the season, depletion of immature black scales by the severe deleafing regime may have had a noticeable effect on overall whitefly control. This has been measured in terms of the numbers of white scales developing on the four leaves above the uppermost black scale (Table 12).

Table 12. Mean number of whitefly scales on the four leaves immediately above the uppermost black scale (results from 8 plants per plot)

Plot	Treatment	Mean leaf no. of uppermost black scale	Mean number of scales	Standard deviation
1	Control	54	44.25	±31.16
2	High deleafing	55	20.63	±14.90
3	Low deleafing	53	8.50	± 6.86
4	Half-and-half	52	4.38	± 4.28

As an indication of relative whitefly numbers in each plot, these figures show that the half-and-half deleafing pattern (plot 4) achieved the best biological whitefly control. However, in none of the treatments are numbers excessive, even a mean of 11.1 scales per leaf in plot 1 is low in terms of the reproductive potential of a single female whitefly. High deleafing, (plot 2) had more than twice as many whitefly scales as low deleafing (plot 3), which is to be expected owing to the removal of a greater proportion of immature black scales from the glasshouse. The result for the unleafed control plot is perhaps surprising since all parasites matured in situ and may have been expected to result in greater percentage parasitism and lower whitefly numbers than the other treatments. However, severe deleafing also removes unemerged white scales and, by leaving all the foliage in

plot 1, all unparasitized whiteflies could emerge and maintain the population, despite the increased parasite numbers. As plot 1 was not deleafed, no record of black and white scale numbers and percentage emergence was made, but from the mean percentage emergence of unparasitized scales at the time of deleafing in the different treatments (see Table 13) it is clear that the proportion of white scales maturing increases the longer deleafing is delayed. While these figures are probably low due to the tendency for empty pupal cases to disintegrate (mentioned earlier), they may indicate the relative differences in whitefly emergence in the different treatments.

Table 13. Mean percentage whitefly scales emerged at the time of deleafing.

Plot	Treatment	Percentage emergence
2	High deleafing	11.6%
3	Low deleafing	20.1%
4	Half-and-half	16.2%

Another factor which may have increased final whitefly numbers in the control treatment is the position of plot 1 in the glasshouse. There is a trend of increasing whitefly numbers from west to east (from plot 4 to plot 1). Although no record was made of temperature differences, it could be assumed that the western side of the glasshouse, which catches the afternoon sun, may be warmer. Hence, temperatures would be more favourable for Encarsia in plot 4 than in plot 1.

3.2.4 Conclusion

Although no differences in the pattern of biological control could be ascribed to deleafing practices in this experiment, some

important factors suggested that the half-and-half deleafing pattern is a suitable compromise for commercial practice, whereby fruit is accessible for picking, while black scales are preserved on foliage lower on the inside of double rows. A similar proportion of the parasites mature in situ with this pattern as with more conservative low deleafing. If severely deleafed, only half as many Encarsia mature and foliage would have to be kept in the glasshouse for at least 5 days to leave a similar proportion of parasites in the crop.

The time at which deleafing is critical is during the period of initial parasite establishment. Then, premature removal of even a few Encarsia effectively reduces the pressure of natural enemies against the whitefly population, whereas later in the season, with a high parasite population present in the crop, removal of several hundreds or thousands of individuals by deleafing has little influence on the overall numbers remaining.

As mentioned earlier, severe deleafing was, at one time, encouraged to remove immature whitefly pupae (HAS, 1975 a). This is inadvisable as a general policy, since the damage done to biological control by removal of parasites would probably outweigh the benefits from depletion of the whitefly population. However, it may occasionally be a useful remedial measure to help reduce excessive numbers of unparasitized whitefly on individual plants or isolated patches of bad infestation. Stripping off a few heavily infested leaves, combined with a spot treatment with insecticide to kill adults at the top of the plant, and an extra introduction of parasites to the area, could well redress the balance of biological control.

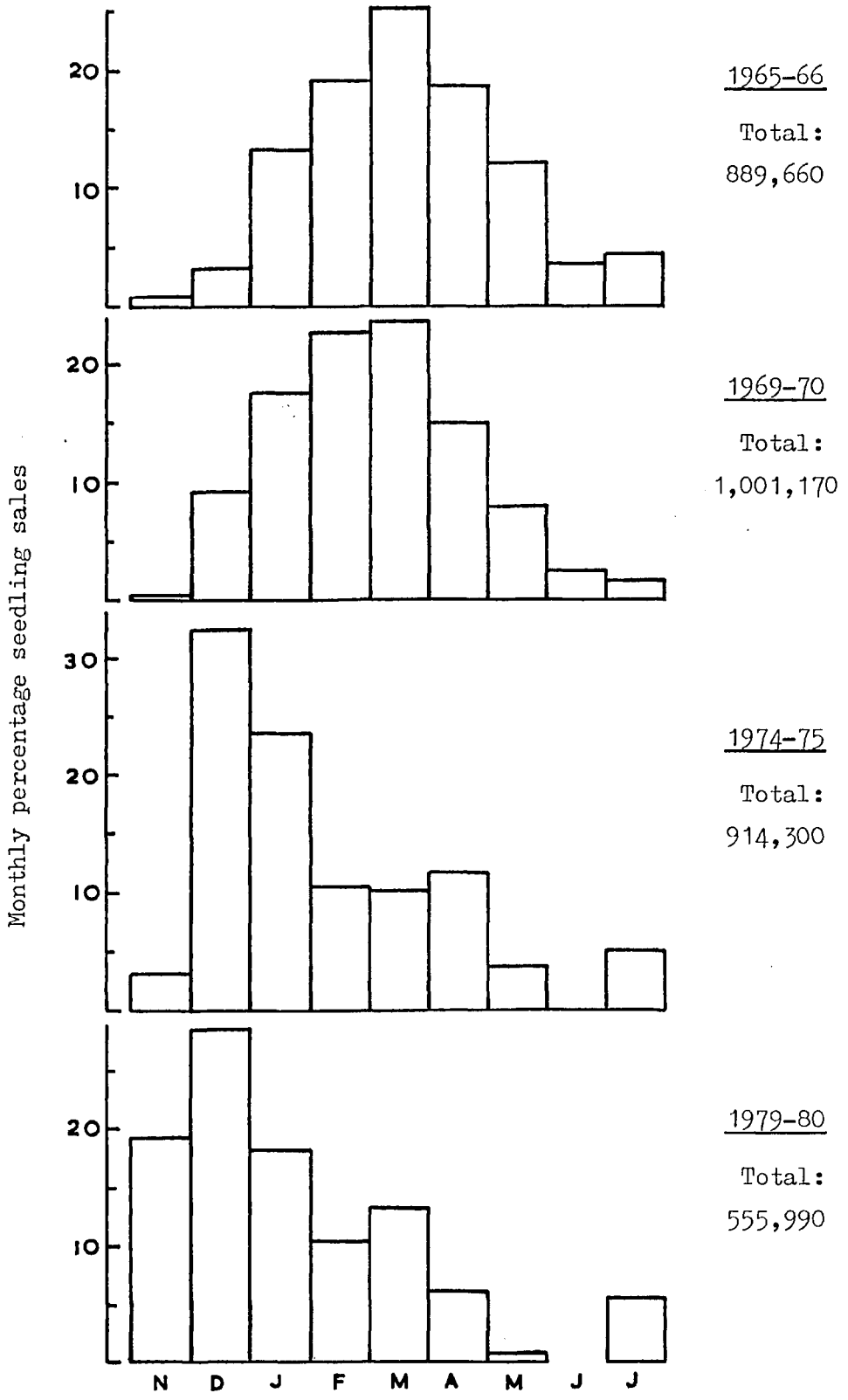
3.3 EARLIER GROWING SEASON

3.3.1 Introduction

Over the past two decades in Guernsey there has been a trend towards an earlier and extended growing season. Figure 18 shows how one major plant raiser's peak demand for tomato seedlings has shifted to earlier in the season, while Figure 19 shows the equivalent extension of tomato exports earlier and later in the year with a levelling out of the proportion of the crop sent during the summer months. Several factors have brought about this change, which in turn affects whitefly incidence due to increased pest carry-over from one season to the next.

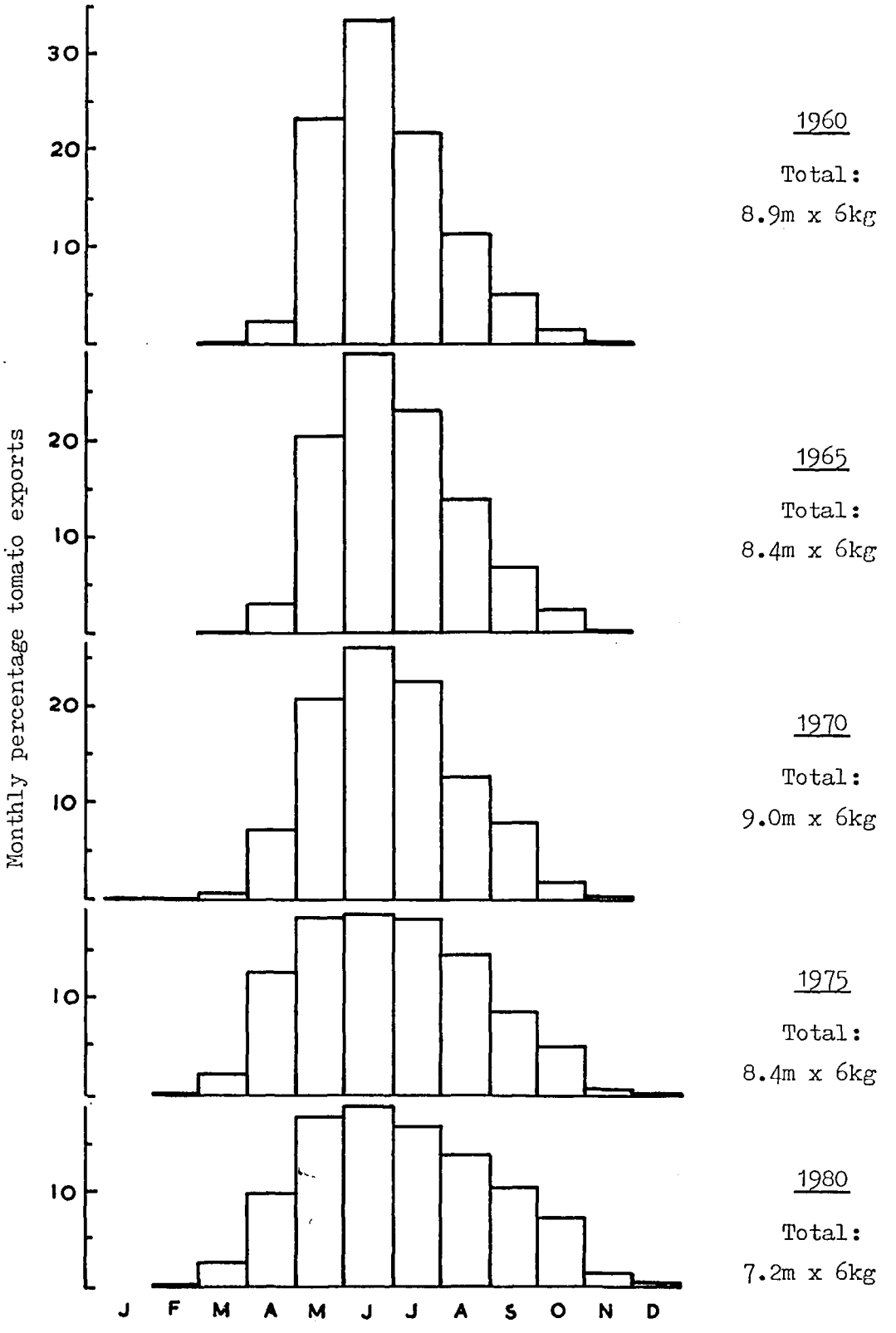
Earlier cropping is desirable in order to gain maximum benefit from high early-season prices before the UK and imported fruit comes on to the market. The switch from soil to peat culture during the 1970s has enabled growers to make a much quicker turn-round at the end of the season. Instead of several weeks of soil sterilization, the old peat modules can be cleared out, the structures washed down and new polythene and modules laid out ready to receive tomato seedlings within a week if required. Consequently, instead of a long fallow period associated with the sterilization procedures during which time most pests are starved and killed, the turn-round is now so rapid that whitefly can easily survive for a few days on plants around the glasshouse perimeter before new hosts are available inside. McClanahan (1972 b) pointed out that even a few weeds in an 'empty' glasshouse can support whitefly and act as a source of infestation. Lloyd (1921 a) recommended leaving the glasshouse fallow with the heating on for a week to kill whitefly at the end of the season, but the current economics of the horticulture industry

Figure 18. Histograms showing percentage tomato seedling sales per month for one Guernsey plant raiser.



(Data from Nicholson's Nurseries)

Figure 19. Guernsey tomato exports: shown as monthly percentages of the total exported annually.



(Data from Guernsey Tomato Marketing Board)

prohibit such measures nowadays and growers must rely on adequate end-of-season hygiene to ensure that the glasshouse is pest-free (see Section 2.1.3).

The extension of the cropping season into November creates a situation where new seedlings are sometimes raised in glasshouses next to cropping houses, as illustrated in Figure 20. Even where this practice does not occur on a nursery, seedlings may be at risk from whitefly on adjoining property. Where a grower raises his own seedlings he will be aware of the presence of whitefly as they are pricked-off and spaced out on the benches. However, if 'bought-in' seedlings have been treated for whitefly prior to dispatch from a commercial plant raiser, the grower may think he has clean seedlings and be unaware of developing whitefly until the first generation emerges, by which time the opportunity for early parasite establishment, without resort to insecticides, may have been missed. Lloyd commented on the need for legislation to stop the sale of infested plants back in 1922. This would probably be impracticable, but there is perhaps a case for obligatory information from plant raisers of the pesticide treatments applied to seedlings before their sale, to make growers aware of potential future pest problems.

3.3.2 HAS Experiments

Experiments were conducted at the HAS Experimental Station in the 1980-81 season to study the effects of early sowing and low night temperatures (see Section 3.4.2) on tomato yields. These experiments were also used to investigate how the treatments affected whitefly populations and subsequent biological control.

Sequential sowings of tomatoes were made every fortnight from 29th August to 7th November, 1980. Two glasshouses, with four large

Figure 20. Photograph showing tomato seedlings being propagated in a glasshouse (right) adjacent to a cropping house (left).



(8.4 x 8.4 m) and two small (8.4 x 4.2 m) compartments each, were used to grow the plants at different temperatures, half by NFT and half in peat modules. Assessments of the whitefly infestations in each compartment and subsequent black scale development were made periodically.

3.3.3 Results and Discussion

Earlier sowings were more heavily infested with whitefly than later sowings (Table 14). Crop inspections in subsequent months were more concerned with the establishment of Encarsia than the level of whitefly infestation, but the trend to higher infestation in the earlier sowings continued and no whitefly had been seen either in the last two plantings or in C4 by early February while only a few adults had appeared in compartment B5.

Table 14. Percentage of sample plants from each sowing date infested with whitefly (all stages counted).

Sowing Date	Compartment and no. plants sampled		% Infestation Date: 27/11	23/12
29 August	B1	12/90	16.7	16.7
	C1	"	91.7	100
12 Sept	B6	"	33.3	75.0
	C6	"	100	75.0
26 Sept	B2	24/180	12.5	4.2
	C5	"	4.2	12.5
10 Oct	B5	"	-	0
	C4	"	-	0
24 Oct	B4	"	-	0
	C3	"	-	0
7 Nov	B3	"	-	-
	C2	"	-	-

The higher infestations on the August and early September

sowings probably reflects the warmer conditions and greater whitefly activity at that time of year and hence greater 'carry-over' into seedling houses. From personal observations, this was borne out by severe sooty mould on a commercial summer-sown crop at Christmas time, where untreated patches of whitefly had built up excessively even before the first picking.

3.3.4 Seedling Infestation Experiments

Experiment 1. An experiment at GCRI in the summer of 1979 attempted to establish parasites on young tomato seedlings which had been artificially infested with whitefly at three densities.

Three glasshouse chambers (2.6 x 3.4 m) were heated to 18°C (there was no facility for differential day and night temperatures) but became considerably hotter during sunny weather. Craigella tomatoes were sown on 18th June and pricked-off into 3½" pots on 29th June. 102 pots were spaced out pot-thick on benches in each chamber. Adult whitefly were introduced five days later (3rd July) at three rates:

1) 1 whitefly per 5 plants
2) 1 whitefly per plant
3) 5 whitefly per plant.

The plants were agitated daily for the first week to ensure even infestation. Rapid plant growth necessitated spacing the seedlings out as widely as possible on 17th July. Some whitefly were already present before the artificial infestation; these were 'pootered-off' and the infested plants in chamber 1 and 2 exchanged for clean ones from chamber 3 so that any additional eggs would be in the high density treatment. Three weeks after whitefly infestation (23rd July) twice as many parasites were introduced in the form of

mature black scales (2 per 5 plants, 2 per plant and 10 per plant into chambers 1, 2 and 3 respectively).

Three destructive samples of 10 randomly selected plants per treatment were made and scales on the first four leaves were recorded as follows:

23rd July: numbers of third and fourth instar whitefly scales suitable for parasitism.

30th July and 2nd August: numbers of black, white and emerged white scales.

Experiment 2. A second experiment was done to determine the most effective rate of parasite introductions for use on artificially-infested seedlings.

The same experimental chambers and conditions were used as before, except that supplementary lighting was used from 24th August to give a 16 hour day comparable to experiment 1. Craigella tomatoes were sown on 27th July, pricked-off and 102 pots placed in each chamber on 3rd August and infested with 1 whitefly per plant on 6th August. A check on 10th August found adult whitefly on only 18% of the seedlings (5/20, 4/20 and 2/20 in chambers 1,2 and 3 respectively), so a further 80 adults were introduced into each chamber. The seedlings were spaced-out on 20th August and parasites introduced as mature black scales three weeks after whitefly infestation at three rates:

1) 2 per plant
2) 4 per plant
3) 6 per plant

Two assessments were made of the numbers of black, white and emerged white scales on the first four leaves of 20 randomly sampled plants per chamber on 13th and 19th August.

The plants grew rapidly and became very etiolated, so

plants for the second sample were chosen on the 13th August and the remainder discarded to avoid congestion. By this time most of the parasites introduced a fortnight earlier should have died and not affected the parasitism on the few remaining plants.

3.3.5 Results and Discussion

The experiment was rather unsatisfactory in several respects. Owing to premature occurrence of extraneous whitefly and Encarsia, the results cannot be wholly attributed to the experimental infestations. The transfer of infested seedlings into chamber 3 (the high density treatment) was reflected by a higher incidence of premature black scales when the plants were inspected on 26th July, (Table 15) only three days after parasite introduction (black scales were found on 17%, 14% and 55% of the seedlings in chambers 1,2 and 3 respectively). By the third sampling, on 2nd August, there was a much higher proportion of emerged whitefly and lower parasitism in chamber 3, which suggests that many scales were too old for parasitism at the time Encarsia were introduced. This was a problem overall since the whitefly developed faster than anticipated and parasites should have been introduced earlier.

By the last assessment the plants had grown very etiolated and had to be thrown out rather than being kept for further assessments. There was then slightly more parasitism and less whitefly emergence on the seedlings in chamber 2; however scale numbers were not significantly different from chamber 1 in an unrelated sample t-test.

Experiment 2 employed the intermediate rate of one whitefly per plant with different parasite densities. Analysis of variance, after square root transformation, showed no significant differences in the mean numbers of scales per plant (Table 16), despite a rather low

Table 15. Results of seedling infestation Experiment 1. (Mean scale numbers per sample seedling ± standard error of the mean)

Assessment Date	Treatment:	1) Low w.fly density 1 w.fly/5 plants 2 Enc./plant	2) Medium w.fly density 1 w.fly/plant 2 Enc./5 plants	3) High w.fly density 5 w.fly/plant 5 Enc./plant
23/7	Total scales	10.2 ± 5.58	36.6 ± 6.59	130.8 ± 25.22
30/7	Total scales	24.0 ± 9.57	51.9 ± 14.91	214.1 ± 29.87
	Black scales	1.8 ± 1.02	2.8 ± 0.89	9.9 ± 2.4
	Immature white scales	17.5 ± 6.67	44.6 ± 12.79	157.3 ± 49.74
	Emerged w.fly pupae	4.7 ± 2.93	4.5 ± 2.71	46.9 ± 10.97
	% parasitism	7.5%	5.4%	4.6%
	% w.fly emergence	19.6%	8.7%	21.9%
2/8	Total scales	46.3 ± 35.62	64.9 ± 1.01	310.4 ± 47.28
	Black scales	12.2 ± 4.12	15.4 ± 5.39	16.3 ± 6.27
	Immature white scales	27.9 ± 6.3	38.0 ± 9.07	164.3 ± 22.21
	Emerged w.fly pupae	6.2 ± 1.82	11.5 ± 4.15	129.8 ± 25.05
	% parasitism	26.3%	23.7%	5.3%
	% w.fly emergence	13.4%	17.7%	41.8%

Table 16. Results of seedling infestation Experiment 2. (Mean scale numbers per sample seedling ± standard error of the mean)

Assessment Date	Treatment	1) Low para. density 1 w.fly/plant 2 Enc./plant	2) Medium para. density 1 w.fly/plant 4 Enc./plant	3) High para. density 1 w.fly/plant 6 Enc./plant
13/9	Total scales	70.5 ± 17.39	81.7 ± 17.57	73.55 ± 17.47
	Black scales	13.35 ± 3.15	20.05 ± 6.14	29.6 ± 6.21
	White scales	57.15 ± 15.49	61.7 ± 11.94	43.95 ± 12.56
	% parasitism	18.94%	24.54%	40.24%
	no. sampled	20	20	20
19/9	Total scales	119.75 ± 31.55	56.94 ± 12.51	75.18 ± 23.92
	Black scales	56.94 ± 13.33	27.41 ± 5.58	46.06 ± 14.45
	White scales	62.81 ± 18.97	29.53 ± 7.51	29.12 ± 7.06
	% parasitism	47.02%	48.14%	61.27%
	no. sampled	16	17	17

value for treatment 2 at the second assessment. This confirms that similar numbers of eggs were laid after infesting each chamber with one whitefly per plant (plus 80 extra). There were, however, significant differences in the numbers of scales on each leaf, the small first leaf having fewer than the others, so analysis of covariance (using total scale numbers as a covariate) was used for numbers of black scales. This showed that there were significantly more black scales in the high parasite density treatment (3) at the first assessment (square root of mean black scale numbers per leaf = 1.329, 1.258 and 2.040 in chambers 1,2 and 3 respectively; 5% L.S.D.= 0.334). At that time percentage parasitism was almost twice that of the other treatments, the difference had narrowed by the time the second assessment was made and was no longer significant.

At the start of the experiments, high whitefly densities were chosen to try and create a 'banker' effect on a small proportion of the seedlings, which could then be distributed among the rest of the plants when they were stood-out in the cropping house. However, judging by the low parasitism achieved, even in favourable temperatures, and the difficulty of applying remedial insecticides to seedlings, this idea may be inadvisable and more conventional pest-in-first whitefly rates of 1 per 10 plants could be more appropriate.

Under the summer conditions of these experiments there was rapid establishment of extraneous Encarsia within a month of pricking-off, which would be acceptable where seedlings are kept on propagation benches for 4 or 5 weeks. But, establishment would not be so rapid in the autumn, when parasite efficiency is known to decline (see Section 2.2.2). Consequently, on the basis of these experiments, establishment of Encarsia on seedlings before they are stood-out would appear to be impractical.

3.3.6 Conclusion

The trend towards an earlier and extended tomato growing season results in a greater overlap of one season with the next and, consequently, greater carry-over of whitefly from cropping houses on to seedlings in nearby propagation houses. The rapid turn-around at the end of the season also increases the risk of contamination of the incoming seedlings, even if they were free of whitefly on the propagation benches. Hence, it must be recognised by growers that the likelihood of having infested seedlings is high and that remedial measures will be necessary to avoid the build up of patches of whitefly which become difficult to control later.

Lindquist & Bauerle (1972) recognised that problems of maincrop whitefly control stemmed from initial seedling infestation, where insecticidal control is difficult because of the danger of phytotoxicity, physical damage to small plants and inadequate coverage of the underside of the leaves. They recommended isolated seedling production and also evaluated the use of systemic granular insecticides on seedlings; aldicarb (Temik) was most effective for whitefly control and lack of phytotoxicity, but none of the materials tested were registered for use on glasshouse vegetables in the USA. Further tests with systemics on seedlings are currently in progress at GCRI (Hussey, pers. comm.).

Van Lenteren, Ramakers & Woets (1980) listed the avoidance of seedling phytotoxicity and flower and fruit abortion as some of the advantages of biological control. It could be expected that starting Encarsia introductions on seedlings earlier in the year, while conditions are still favourable for the parasite could achieve establishment before shortening days and dull winter weather combine to reduce parasite efficiency. However, the early tomato production

programme, whereby seedlings remain on the propagation benches for only 3 - 5 weeks (HAS, 1978 a) hardly gives time for Encarsia to establish even if whitefly were introduced on a pest-in-first basis as soon as seedlings germinate. Once plants are stood-out in the cropping house, all the problems of parasite dispersal and host-finding, which could be avoided if Encarsia were introduced on to the closely spaced plants on the benches, reappear. Further, the results were not very encouraging and so artificial seedling infestation cannot be recommended where the subsequent effectiveness of Encarsia is so uncertain, especially at a time when there is a risk of phyto-toxicity if chemicals were needed to check an excessive build-up of whitefly.

All these points emphasize the need for very thorough end-of-season clean-up procedures (HAS, 1979 h), both before, and after, pulling-out the old crop in order to assist the production of clean seedlings and so delay infestation of the new crop. Good hygiene outside the glasshouses on the rest of the nursery is also important. One of the first improvements has been the covering of all refuse skips.

3.4 ENERGY SAVING

3.4.1 Introduction

In an attempt to save fuel and ever-increasing costs, many growers are changing to lower night temperatures than are used with the normal tomato growing programme. The HAS produced appropriate cultural information (HAS, 1980 b) and set up experiments to investigate the effects of low night temperatures on tomato yields. These were also used to study their effect on the interaction of whitefly and Encarsia.

Energy saving measures reduce the efficiency of biological control agents (Smith & Webb, 1977) and research has been directed towards finding more suitable species and strains of parasites for use with lower temperature programmes, as well as more suitable tomato varieties (Ledieu, 1980; Vet, van Lenteren & Woets, 1980; Woets, Ramakers & van Lenteren, 1980). Vet (1980) in the Netherlands, studied the suitability of three Encarsia species and an Eretmocerus species as substitutes for E.formosa at low temperatures. E.pergandiella and a Californian wild strain of E.formosa showed the most promise in laboratory tests. When these parasites were tested in glasshouse experiments at GCRI, there was no evidence that they were better than the normal strain of E.formosa, and it was proposed to try and produce a suitable strain by selection and breeding (Hussey, 1981).

3.4.2 HAS Experiments

Two compartmented glasshouses at the HAS Experimental Station (described in Section 3.3.2) and two new $\frac{1}{4}$ acre blocks, which were used for banker plant trials (see Section 5.2.2), were used to study the effects of early sowing and low night temperatures ($5^{\circ}C$ and $12^{\circ}C$) on Encarsia establishment and whitefly control.

Parasites were introduced weekly from 6th November 1980 in the earliest crop or from seeing the first whitefly in later, less infested sowings. The introduction rate was one parasite per plant unless there was a heavy whitefly infestation, in which case insecticides were used first, followed by higher rates of Encarsia. The overall whitefly incidence, parasite establishment and biological control in each compartment were assessed periodically. These were mainly general visual assessments. Detailed records of the development of the pest-parasite interaction were made on one or two selected

plants in some compartments, but they did not prove to be useful in judging the effects of the low night temperatures.

3.4.3 Results and Discussion

It is evident that biological control had to be abandoned sooner or later in nearly every compartment as the whitefly populations increased (Table 17). The objective of the experiment was to determine how long Encarsia took to establish under a low night temperature programme. Consequently, to avoid harming the parasites, insufficient remedial measures were taken to restrict the whitefly population before black scales were found (especially in the early, heavily infested sowings) for biological control to ultimately be effective.

In the three earliest sowings, Encarsia introductions began after the start of Stage III and it was 12 and 15 weeks before black scales were seen on the crop. In later sowings (excluding the banker plant treatments) Encarsia were first introduced 1½-4 weeks before night temperatures were lowered for Stage III. Nevertheless, in most cases, establishment still took at least 13 or 14 weeks, partly due to lack of whitefly on the plants. The one case where black scales appeared 9 weeks after introduction was in a programme temperature regime on a conventional November-sown crop. In the blocks where banker plants were used, there was rapid establishment (in 3 weeks) where the night temperature was 12°C (East), while black scales did not appear for 6 weeks at 15°C (West) night temperatures. This occurred because whitefly were present in the east block at the time of banker plant introduction, whereas none had been seen in the west block and establishment could occur only when adult whitefly from the bankers had infested the crop. Rapid establishment, despite low night temperatures, in the east block from a February introduction

Table 17. Summary of results of biological control at different sowing dates and low Stage III night temperatures.

Sown	Stage III Duration	Stage III Night temp. (NFT soln. temp)	Compartment	Level of w.fly inf. in Nov/Dec	Insecticide treatments (after 1st intro.)	Date & rate of 1st Enc. intro. (nos. per plant)	Date of 1st black scales (weeks after 1st intro.)	Result of biological control
29 Aug	17 Oct - 17 Jan	5°C (20°C) 12°C	B1 C1	Moderate High	1 x Resmethrin 2 x Pynosect	6 Nov (9,7,1 then 3/pl)	29 Jan (12) 17 Jan (12)	Abandoned 26 Feb Abandoned 24 March
12 Sept	4 Nov - 9 Feb	5°C (20°C) 12°C	B6	Moderate High	2 x Pynosect	13 Nov (1,1 then 3/pl.)	26 Feb (15) 26 Feb (15)	Abandoned 26 Feb
26 Sept	21 Nov - 20 Feb	12°C (20°C) 12°C	B2 C5	Low Low	(Resmethrin to tops 11 Feb)	13 Nov (1/pl)	6 Feb (12) 6 Feb (12)	Abandoned 9 March
10 Oct	9 Dec - 11 Mar	12°C (20°C)	B5	None	(Resmethrin to tops 27 Feb)	26 Nov (1/pl)	16 Feb (13)	Abandoned 29 May
		12°C	C4	None	(Resmethrin to tops 11 Feb & 9 Mar)		26 Feb (13)	Abandoned 5 June
24 Oct	30 Dec - 28 Mar	12°C (20°C) 12°C	B4 C3	None None	- -	19 Dec (1/pl)	none by 7 Apr 23 Mar (14)	Abandoned 29 May Abandoned 16 June
7 Nov	19 Jan - 28 Mar	15°C 15°C	B3 C2	- -	- -	23 Dec (1/pl)	24 Mar (13) 26 Feb (9)	Abandoned 29 May Abandoned 16 June
17 Oct	24 Dec - 25 Mar	12°C	East block	None	1 x Vydate 22 Jan	16 Feb (6 bankers each)	9 Mar (3)	Abandoned 13 June
31 Oct	19 Jan - 14 Mar	15°C (plus thermal screen)	West block	None	1 x Vydate 3 Feb		3 Apr (6)	Continuing in August + Pynosect spot treatments.

emphasizes how parasite performance improves once daylength increases. Establishment was very slow from nearly all the November and December introductions, when daylength was shortening.

It has been calculated (Hussey, in litt., 1981) that, with a threshold of 8°C, whitefly development from egg to adult requires about 463 day-degrees of thermal energy. With a 10-hour day and 14 hour night, reduction of Stage III temperatures from 20°C day/ 16.5°C night to 20°C day/12°C night reduces the effective day-degrees per day from 10 to 7.3. This has the effect of increasing the whitefly development time from approximately 46 days to 63 days, i.e. with low Stage III night temperatures, the life cycle of the whitefly is extended by about 2½ weeks. Thus the appearance of black scales will automatically be delayed, regardless of the effect of the lower temperatures on Encarsia.

In laboratory experiments, Madueke (1979), recorded no parasite activity at 14.5°C, with 15°C as the temperature threshold for oviposition. Thus while at programme Stage III temperatures there is some potential for Encarsia movement and oviposition at 16.5°C, albeit small, at the reduced night temperature (12°C) the parasite is incapable of functioning for the whole night period. This is a very significant proportion of its lifespan where low night temperatures may operate for 14 hours a day. Hence, the prolonged period before black scales were seen.

3.4.4 Conclusion

It may be concluded from these experiments that the energy saving measures of early sowing and low night temperatures are incompatible with biological control of whitefly by Encarsia early in the season. But, as was discussed in Section 3.2.2, earlier

sowings tend to be more heavily infested, therefore alternative control measures must be taken early on in order to keep whitefly at a sufficiently low level for subsequent control by Encarsia which should be introduced later in the season (during February) when conditions are improving.

Vydate is useful for early suppression of pests, but, as discussed in Section 4.2. its effectiveness against whitefly is short-lived when used on a peat module crop. Further research is planned at GCRI this season (1981/82) on other soil-applied systemics suitable for use on young tomatoes. Where parasite introductions are to be deferred until several months after planting the crop, use of more persistent foliar insecticides than Pynosect, such as permethrin (Ambush), pirimiphos-methyl (Actellifog) or deltamethrin (Decis), may be advisable, provided the toxic residues have time to break down before Encarsia are introduced. However, all these materials are more liable to be phytotoxic to young plants in winter conditions (HAS, 1980 f), when they are required, so great care must be taken with their use.

3.5 VARIETIES

3.5.1 Introduction

As a result of the 1979 survey in Guernsey and also individual growers' comments which suggested that biological control appeared to be worse on some varieties than others, a glasshouse experiment was set up at GCRI in 1980 to investigate this. Should varietal differences be found, it may be possible to modify biological control to accommodate them, for example by using different parasite rates or introduction frequencies.

Seven of the varieties were selected from those approved for growing in the island by the Guernsey Tomato Varieties Committee (HAS, 1979 i) (these have fruit that is firm enough to withstand transportation). The eighth variety, Sonato, is unacceptable in Guernsey, but was included for comparative purposes as it had been used in previous biological control experiments at GCRI.

3.5.2 Materials and Methods

The eight varieties used were Cudlow Cross, Eurocross BB, Gannet, Grenadier, Nemato, Sarina, Sonatine and Sonato. The seed was sown on 22nd February, 1980, planted into 9" whalehide pots and stood out in a 9.6 x 12.9 m glasshouse compartment on 31st March. An 8x8 Latin Square design was used and the plants were spaced just under 1 m apart. Programme tomato growing temperatures were used.

Five whitefly per plant were introduced as mature pupae on 2nd April. Two Encarsia introductions were made, each at a rate of 15 black scales per plant, on 14th and 28th April. There were no barriers to prevent transfer of insects from one plant to another, as it was hoped that they would redistribute themselves according to varietal preferences. In the Latin Square design no plant had the same combination of varieties positioned around it.

Three counts were made of the numbers of adult whitefly on the top five leaves of each plant on 3rd April (soon after their introduction), 21st May and 28th May. The first black scales were seen on 2nd May, 2½ weeks after the first parasite introduction. The numbers of black and white scales (emerged and unemerged) were counted after removing the leaves. The first six leaves were recorded on 28th-29th May, and thereafter the next two leaves per plant, up to leaf 24, were counted every few days from 3rd June until 18th July. By this time, the pattern of biological control did not appear to be changing,

so it was decided to terminate the experiment. A final count of scales at the tops of the plants on leaves 31-36 was made at the end of July. The plants were stopped at truss 12 at the end of June.

3.5.3 Results and Discussion

The varietal results are illustrated in Figure 21, while data are given in Appendix 4 and mean scale numbers for the whole plants are shown in Table 18.

Table 18. Overall mean numbers of scales for each tomato variety.

Variety	White scales	Black scales	% parasitism
Cudlow Cross	1362.71	511.60	72.7%
Eurocross BB	1429.69	564.90	71.7%
Gannet	1457.52	610.64	70.5%
Grenadier	1448.52	636.02	69.5%
Nemato	999.60	446.78	69.1%
Sarina*	(1493.01) 778.99	(684.14) 528.59	(68.6%) 59.6%
Sonatine	1236.51	640.89	65.9%
Sonato	1211.14	489.01	71.2%

* Figures for Sarina in brackets include scale numbers on the discrepant plant (see text); the second set of values are means for the remaining 7 plants.

One of the Sarina plants had noticeably more scales than the other seven of that variety, especially on the upper leaves. After analysis of variance, a plot of the residuals against the fitted values showed this plant to be far beyond the normal scatter of points, so the data were reanalyzed omitting scale counts for this plant and substiuting estimated values for it, and for missing values where one of the Cudlow Cross plants had died early in the experiment. The difference in results for Sarina including and excluding the discrepant plant are indicated in the results. No explanation for the extremely

Figure 21. Histograms to show mean total scale numbers and percentage parasitism per six-leaf section per tomato variety.

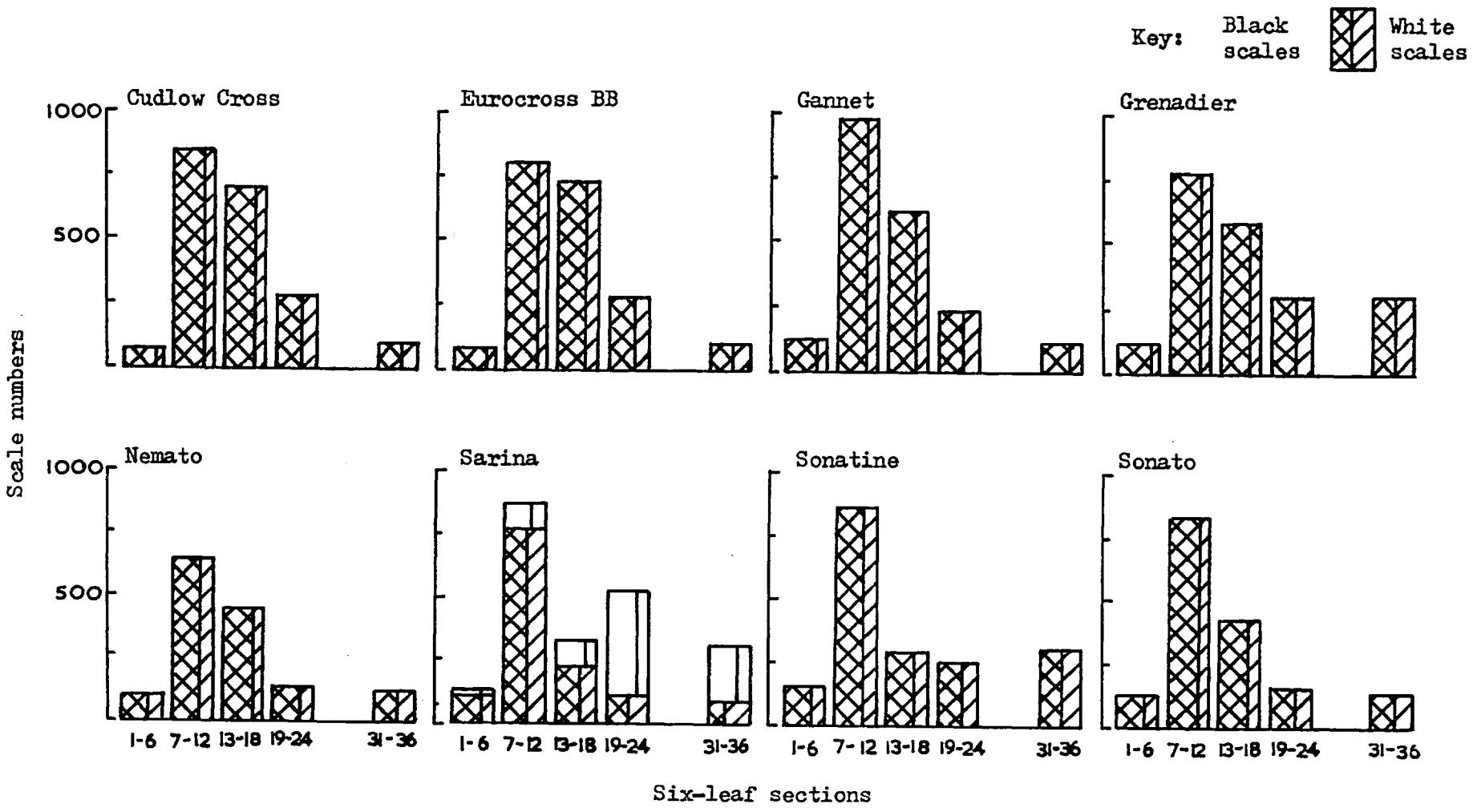
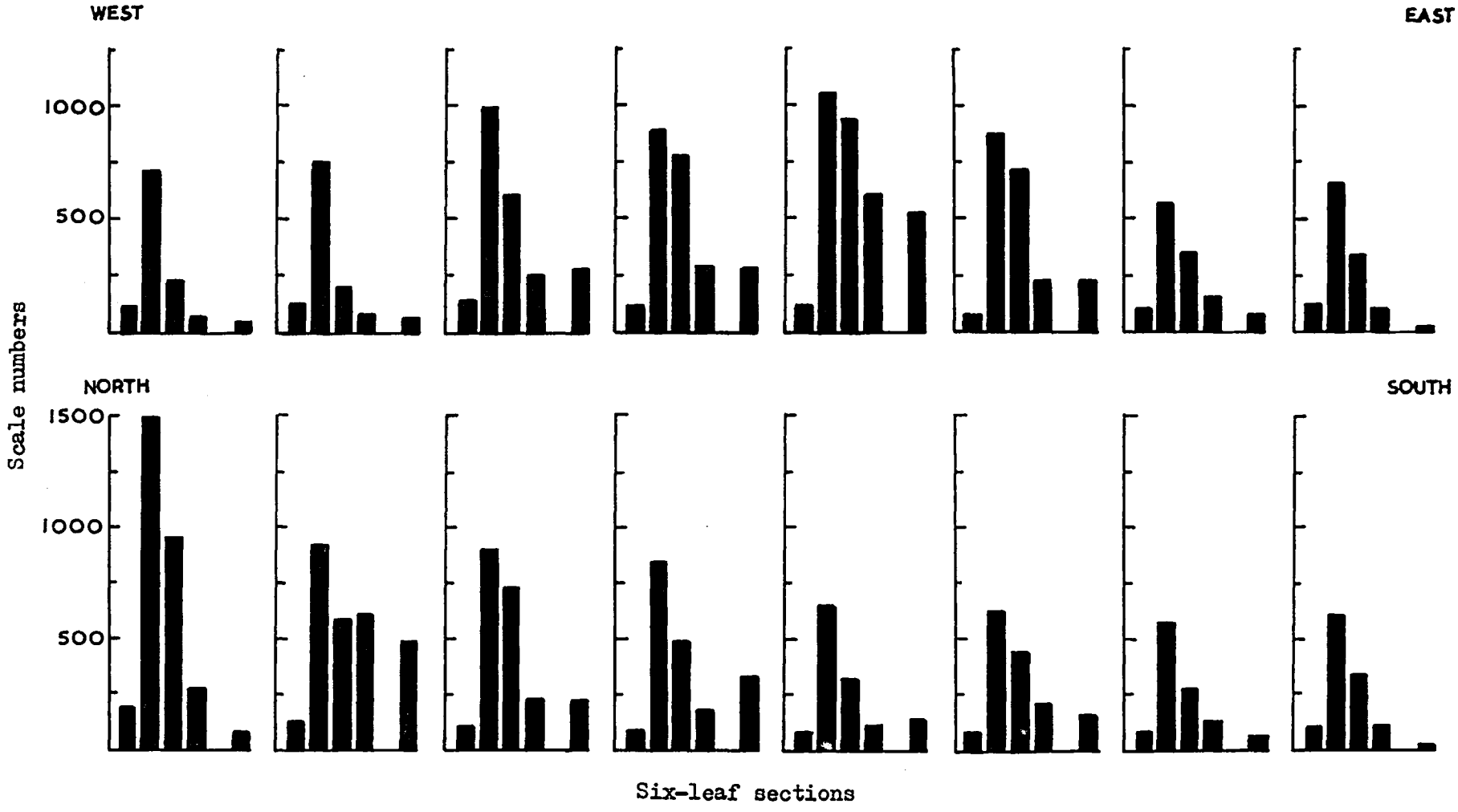


Figure 22. Histograms to show the positional trends of mean scale numbers per six-leaf section per plant in each row across the Latin square.



high numbers of scales on the one plant can be provided.

During the experiment, there was a trend of decreasing numbers of whitefly scales from north to south along the rows, and more towards the centre of the W-E rows. Figure 22 illustrates these trends, which tend to reflect the distribution of adults at the start of the experiment. To simplify the results, Tables 19 and 20 show the mean numbers of adults and scales, respectively, on each plant in each quarter of the Latin Square plot (including the discrepant Sarina plant in the SW quarter).

Table 19. Mean numbers of adult whitefly per plant (on the top five leaves) in each quarter of the experimental area.

Assessment date

3 April

5.19	8.19
2.44	3.75

NORTH

21 May

WEST

3.69	4.53
0.75	2.19

EAST

28 May

0.56	1.07
0.75	1.19

SOUTH

The pattern of most adults in the NE quarter and fewest in the SW (Table 19 - at least for the first two counts) is reflected by the pattern of total scale numbers (Table 20). Possible explanations for this distribution are, firstly, that the door of the glasshouse was in the NE corner, and although it was screened with polythene to prevent draughts, it may have allowed the entry of extraneous whitefly. Secondly, although temperature was not monitored in separate areas of the glasshouse, it may be assumed that the southern

part would be warmer, which could, perhaps, account for the uneven distribution of whitefly only three days after their introduction and therafter throughout the experiment. Adults at the warmer end of the glasshouse may have been more active and flown off the plants soon after emerging and been lost from the experiment.

Table 20. Mean total scale number per plant in each quarter of the glasshouse for each six-leaf section of the plant.

Leaf section		NORTH		
1 - 6		142.0	125.1	
		104.4	86.9	
7 -12		1026.3	1040.8	
		625.6	611.6	
13 -18	WEST	594.6	795.1	EAST
		303.4	392.6	
19 -24		197.9	403.1	
		136.8	159.1	
31 -36		237.1	331.6	
		78.8	123.1	
		SOUTH		
Total		2197.9	2695.6	
		1249.0	1373.3	

Table 21 shows the results of analysis of variance, with and without the discrepant values for Sarina. The positional trends noted above are highly significant in both analyses (except for a lack of column effect in one of the results for percentage parasitism, but the varietal effect on scale numbers is insignificant unless the

discrepant values are omitted, which makes interpretation difficult. Since the pattern of scale numbers and parasitism over the different leaf sections (Figure 21 and Appendix 4) appeared similar for the different varieties, it was decided to analyse overall scale numbers to determine any varietal effects on the whitefly and parasite populations.

Table 21. Analysis of variance (F ratios) of scale numbers and percentage parasitism over the whole plant. (Figures in brackets include values for the discrepant Sarina plant, others exclude it).

	Row effect (W-E)		Column effect (N-S)		Varietal effect	
Total scale nos.	(6.738***)	15.543***	(5.161***)	14.767***	(0.650NS)	2.738*
White scales	(7.629***)	9.772***	(8.297***)	12.419***	(1.854NS)	2.267*
Black scales	(6.200***)	16.376***	(4.225***)	13.909***	(0.485NS)	3.533**
% parasitism	(4.824***)	4.854***	(0.881NS)	0.996NS	(4.172**)	7.316***

Levels of significance: *** $P<0.001$, ** $P<0.01$, * $P<0.05$
NS Not significant

Although least significant differences (L.S.D) are not a strictly accurate measure of where the differences between varieties lie, they do provide a guide to the trends of scale numbers of the different varieties. No one variety has significantly more or less scales than the others, as is shown by the rankings and L.S.Ds given below for the results omitting the discrepant Sarina plant (varieties with no significant differences between them are underlined). The values for mean scale numbers shown here vary slightly from those in Table 18 since they were calculated as means for each whole plant in the analysis of variance, rather than as the sum of means for each six-leaf section of the plant.

Total scale numbers (5% L.S.D. = 439):

Grenadier	Gannet	Eurocross	Sonatine	Cudlow	Sonato	Sarina	Nemato
2048	2068	1960	1877	1870	1700	1457	1431

Total white scales (5% L.S.D = 137)

Sonatine	Grenadier	Gannet	Sarina	Eurocross	Cudlow	Sonato	Nemato
641	636	611	567	522	511	489	440

Total Black scales (5% L.S.D = 324):

Gannet	Grenadier	Eurocross	Cudlow	Sonatine	Sonato	Nemato	Sarina
1457	1448	1407	1359	1236	1211	991	890

From these rankings it can be seen that Sonato, Sarina and Nemato had fewer scales than the other varieties, while Grenadier, Gannet and Eurocross had more. The pattern of counts of both black and white scales was similar, except for Sonatine which had relatively more white scales than black, reflecting the lower percentage parasitism seen in Table 18. Sarina also had less parasitism than the other varieties when the discrepant plant is omitted from the analysis. The ranking and differences for parasitism in the varieties are given below (figures in brackets include the discrepant result, which also alters the estimate for the missing Cudlow plant).

% parasitism (varieties with no significant differences between them are underlined)

Cudlow	Sonato	Eurocross	Grenadier	Gannet	Nemato	Sonatine	Sarina
70.65 (10.75)	70.56	70.44	69.34	69.05	68.69	64.43	62.23 (60.22)

5% L.S.D. (with discrepant Sarina result) = 4.386

5% L.S.D. (without discrepant Sarina result) = 3.927

Harbaugh & Mattson (1976) found little difference in parasitism on 12 tomato varieties that they studied, despite large differences in the whitefly populations. This is apparently true for most of the varieties in this experiment, except Sonatine and Sarina which have a lower percentage parasitism. As mentioned before, the inexplicably high numbers of scales on one Sarina plant confuses the results and makes their interpretation difficult. Nevertheless, either analysis shows Sonatine and Sarina to have significantly less percentage parasitism than the other varieties, although the differences in scale numbers are only significant when the discrepant values are omitted, hence it is impossible to say whether the effect is real or not, without repeating the experiment (a measure for which there was insufficient time and space during this project).

3.5.4 Conclusion

The reduced parasitism on Sonatine may be important in the light of the findings of the 1979 survey (Section 1.10.2) which indicated that biological control was worse on this variety, but there is no obvious reason for Eurocross also to appear to be a less satisfactory variety for biological control. 'Grenadier had higher scale numbers in this experiment and was also shown to have unsuccessful biological control in half of the crops of that variety in the survey.

No examination of the varieties was made for differences in leaf structure which may affect parasite performance and preliminary experiments on varietal preferences by whitefly were inconclusive. In any case, a commercial crop is normally a single variety so no choice of host plant is available. In the past, experiments have shown little or no resistance to whitefly in commercial tomato varieties

and have demonstrated the difficulty of carrying out this type of investigation (Curry & Pimental, 1971, a,b; Harbaugh & Mattson, 1976; de Ponti & Hogenboom, 1980).

This is not to say that tomato variety may not indirectly affect biological control. With smaller, more open-leaved varieties it is possible to retain foliage below the picking height. This is beneficial not only to the crop (HAS, 1981 d) but also to biological control. Reduced deleafing allows more parasites to emerge into the crop (see Section 3.2) and the smaller leaved varieties permit more sunlight, and hence radiant heat, to penetrate through the crop canopy and could thus enhance Encarsia dispersal (see Sections 2.2.2 and 3.1). It was noticeable that more light penetrates through a crop of the new variety Dawn (E4884) (first used on a wide scale in Guernsey in 1980) compared to Grenadier (formerly the most common variety).

4 CHEMICAL FACTORS CONTRIBUTING TO THE GUERNSEY PROBLEM

4.1 INTRODUCTION

The use of natural enemies to control major tomato pests such as whitefly and red spider mite can lead to problems with control of other pests and diseases (Raiskinmäki, 1980). Ledieu (1980) reviewed the subject of secondary pest control in an integrated programme and cited three main problem areas:

1) The change in pesticide usage (using selective rather than broad spectrum materials) can result in a resurgence of minor pests such as tomato moth (L. oleracea) and leafhopper (Zygina pallidifrons Edwards);

2) Lack of information on the biology of pests retards the development of control measures based on cultural practices or specialised selective techniques;

3) Changing cultural methods have themselves increased pest problems, such as the cessation of soil sterilization when using NFT or peat culture.

There is a shortage of selective chemicals suitable for integration with natural enemies and, as mentioned in Section 1.8, the need for insecticidal control of pests such as tomato leafminer (L. bryoniae) and now the serpentine leafminer (L. trifolii Burgess) currently restricts the use of biological control where they occur (Woets, 1974, 1976; Zucchi & van Lenteren, 1978). Leafminer parasites are being assessed for biological control (Zucchi & van Lenteren, 1978; Hendriske & Zucchi, 1979) but until this becomes commercially feasible, cultural control techniques must be used to exclude the

pest from the new crop with the object of avoiding the need to control it later by non-selective chemicals (Hussey, Stacey & Parr, 1975).

Other research is directed towards finding aphid parasites and predators (Scopes & Hall, 1979; Markkula & Tiittanen, 1980). Bacterial control of caterpillars with Bacillus thuringiensis Berlinger, is established practice (Morgan & Ledieu, 1979; Burges, 1981) and the use of the entomophagous fungus, Verticillium lecanii Zimm, shows promise for control of aphids and whitefly under suitable conditions (Hall & Burges, 1979; Hall,1981 a,b). However, the use of biological control agents is more critical than pesticides and the situation could well become too complex for growers to manage on their own.

Selective insecticides tend to have only limited markets and it is usually uneconomic for companies to develop new materials. Now there is increasing resistance to the few insecticides that are available, such as the aphicide, pirimicarb (Scopes & Hall, 1979; Ledieu, 1980). Consequently, broader spectrum materials may need to be used more frequently, but in a manner least damaging to natural enemies.

In Guernsey, the granular systemic insecticide, oxamyl (Vydate) is widely used in glasshouses, so investigations were carried out to find out how it may best be employed without affecting Encarsia. Recent queries about the effect on natural enemies of γ-HCH applied to the glasshouse soil beneath polythene sheeting for leafminer control, led to experiments to study the consequences of this practice on biological whitefly control by Encarsia.

4.2 VYDATE

4.2.1 Introduction

Vydate is DuPont's trade name for oxamyl, a systemic insecticide and nematicide which came into widespread use in agriculture and horticulture during the 1970s. There are two formulations: liquid (Vydate L), used as a foliar spray, and granules (Vydate G), applied dry to the soil and then watered in. The latter method was approved for use on glasshouse tomatoes in 1976 (HAS, 1976 a; ACAS, 1977) and is now widely used in Guernsey, often as a general clean-up procedure for leafminer, red spider mite, whitefly and other pests before harvesting commences. The HAS issues regular guidelines for its usage, which is controlled by licence in Guernsey to avoid contamination of water supplies (HAS, 1977a, 1978b, 1979b).

The use of Vydate in conjunction with Encarsia has been been a subject of debate in the island. Early in the development of biological control it was considered that, where Vydate was used on the young crop, the first parasite introduction should be delayed until two weeks after the second application (HAS, 1977 a,b). In Ireland, Dunne & Donovan (1977) found that two Vydate applications reduced excessive whitefly numbers to a sufficiently low level for subsequent biological control to be established from April introductions of parasites. They considered that integration of Vydate with Encarsia could ensure the success of biological control. However, in Guernsey, by the 1978-79 season, early parasite introduction, at the time of standing out the plants, was considered to be very important with a fortnightly introduction schedule even where Vydate was to be used (HAS, 1978 h,i, 1979 k). In cases

where parasite introductions were to start following the Vydate treatment, a delay of two weeks after the last application was recommended (HAS, 1979c). Some growers who used the chemical where parasites were already established found that parasitism declined, perhaps as a consequence of the Vydate treatment (HAS, 1979 h). This led to doubts about the wisdom of using parasites before Vydate and, by the 1980 season, growers were again advised to defer introductions until two weeks after the chemical treatment (HAS, 1980 d). The interval was reduced to only one week in the following season (HAS, 1981 a,b). The initial use of Vydate was encouraged where red spider mite and especially leafminer were troublesome, as they are difficult to control without harming Encarsia once it is established.

Laboratory and glasshouse experiments were done at GCRI on the effects of Vydate on whitefly and Encarsia. The initial publicity literature for Vydate claimed up to six weeks protection of tomatoes from whitefly by two applications of the granules. However, this did not appear to hold true under Guernsey conditions, so an experiment was done to test the protection time from whitefly of tomatoes grown in peat modules following treatment with Vydate. In a second glasshouse experiment a study was made of the effects of treatment on an established whitefly-Encarsia interaction, and in a third experiment in the laboratory, the mortality of Encarsia feeding on honeydew from scales on treated plants was examined.

4.2.2 Materials and Methods

a) Whitefly Survival

A 9.6 x 8.5 m glasshouse chamber was used for a crop of

Sonato tomatoes in peat modules. The seed was sown on 30th July 1979 and seedlings planted out into four double rows of peat modules (three plants per bag, five bags per row) on 28th August. The crop was grown at programme temperatures. Six young aldicarb-treated cucumber plants were suspended above the crop to act as trap plants for extraneous whitefly. These were replaced periodically.

Three rates of Vydate (10% a.i.) were applied, 0.5g, 1.0g and 2.0g per plant, plus an untreated control. Each double row received one rate of Vydate; the first dose was applied to all rows (except the controls) on 3rd September and one row per plot received a second dose on 17th September.

The effect of the treatments was determined by caging adult whitefly at the tops of the plants (where they naturally feed) for three-day intervals and recording subsequent survival. Initially it was intended to record oviposition and subsequent scale development, but this proved impractical, largely because extraneous whitefly sometimes laid eggs on the leaflets before the experimental whitefly were caged on them.

Ten adult whitefly (inactivated by holding them in gelatine capsules over ice) were put in each perspex pill-box cage (Figure 23) and one was attached to an upper leaflet of every Vydate-treated plant and one in three of the control plants (one plant per module). Survival was recorded three days later and fresh whitefly were then caged on a leaflet higher up the plant. Once survival in a particular treatment had returned to the control level the number of replicates was reduced from 15 to 5 to save time.

Survival was recorded rather than mortality because the adhesion of dead insects to the cages would have necessitated

Figure 23. Perspex pill-box cage used to confine adult whitefly at the tops of Vydate-treated tomato plants.



Figure 24. Method of collecting honeydew from whitefly scales on Vydate-treated tomato plants.



laborious cage-cleaning every three days to be sure of the origin of the carcasses at each assessment. Also, difficulty in handling the whitefly meant that there was an average of ten per cage (some escaped and others had too many) so it was considered to be most meaningful to record the numbers of live adults on the treated plants relative to survival on the control plants. The experiment continued until the effects of the Vydate had apparently worn off five weeks after the first application, in which time the cages had been changed 12 times.

b) Whitefly-parasite Interaction

Sonato tomatoes were sown on 8th October 1979 and three seedlings were planted in each of six peat modules on 19th November. At this time the bags were in a small (4.2 x 2.2 m) glasshouse awaiting the vacation of the large (9.6 x 12.9 m) compartment where the experiment was to take place. Prior to planting, the seedlings had each been infested, while still on the propagation bench, with approximately 55 adult whitefly on 9th November.

On 3rd December, three peat modules were spaced down each side of the large glasshouse to give the maximum distance between them and minimise insect carry-over from one treatment to another. On the same day 325-350 mature black parasitized scales were introduced to each bag of three plants. The temperature was maintained at 18°C day and night in both glasshouses, so a temperature boost to 22°C was given for two hours at midday for the first four days after the Encarsia introduction to ensure good dispersal of the parasite to their host targets.

Vydate (10% a.i.) was applied at a rate of 1.0g per plant. The first module was treated five days after the Encarsia

introduction and the rest were treated sequentially at five-day intervals, leaving the sixth module as an untreated control.

Weekly whitefly assessments were made from early December until mid-January. Adults at the tops of the plants were counted. One leaflet was removed each week from every third leaf up each plant for microscopic examination to determine the numbers and viability of each developmental stage.

c) Honeydew Toxicity

Each week from early January 1980, Sonato tomato seedlings in 6" pots were infested with whitefly for up to 24 hours. Two weeks later, when second to third instar larvae had developed, three plants each were treated with the following rates of Vydate (10% a.i.): 1.0g, 0.67g, 0.33g and 0g per plant. The plants were then kept in the laboratory under lights for 16 hr per day.

Small 6cm petri dishes were suspended beneath leaflets well infested with scales to collect the honeydew (Figure 24). Collections were made over three 24 hour periods following the Vydate treatment. Three samples were collected from each plant. The experiment was repeated six times.

Ten freshly emerged adult Encarsia were confined on the collected honeydew in each dish and held in a dark incubator at 21°C. The mortality of the parasites was recorded every 24 hours for three days.

4.2.3 Results and Discussion

a) Whitefly Survival

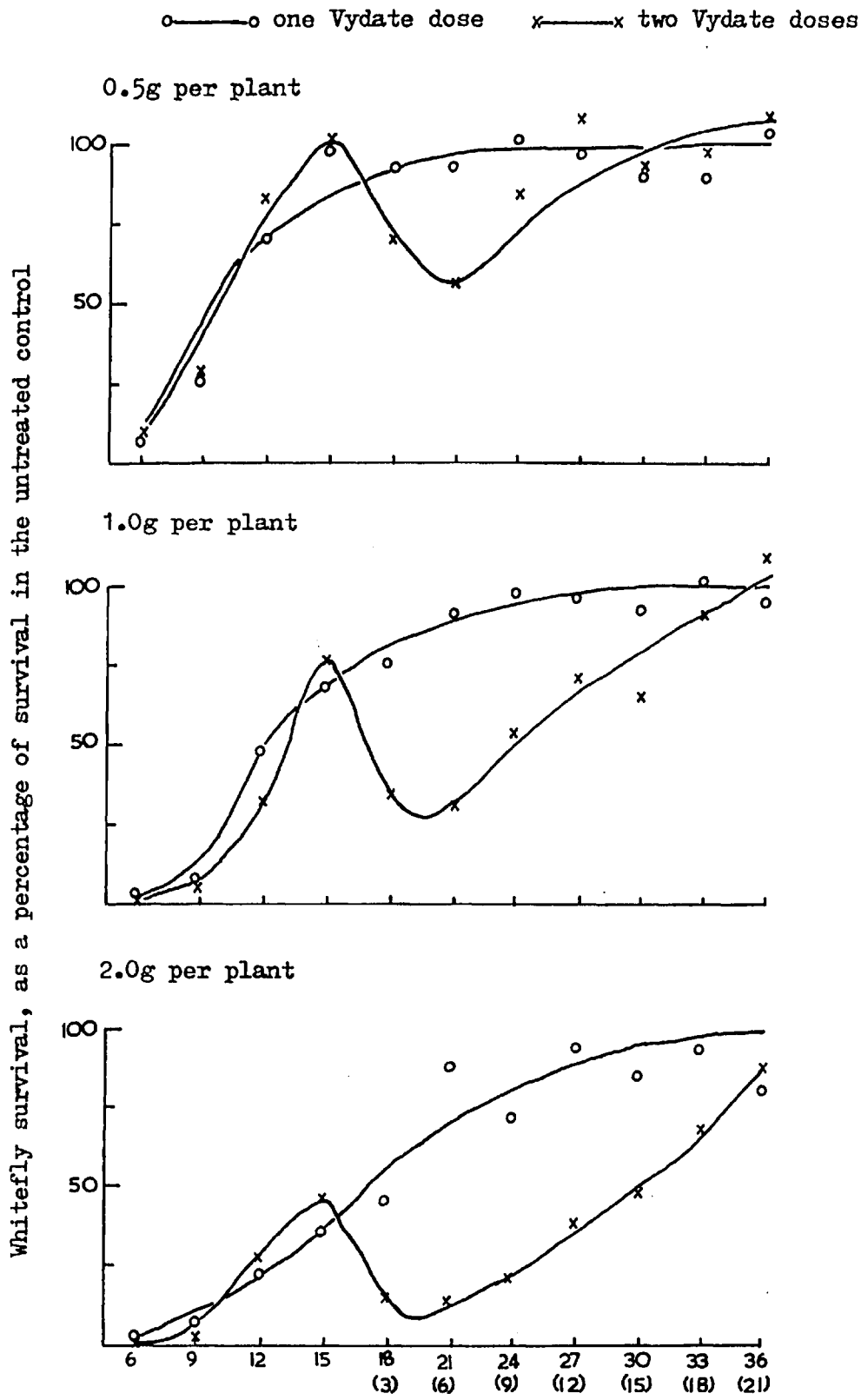
The results are given in Table 22 and Figure 25. The raw data are given in Appendix 6. It can be seen that the higher

Table 22. Mean numbers of whitefly alive after caging ± 10 adults at the top of Vydate-treated tomato plants at 3-day intervals

Days after 1st dose:	*	6	9	12	15	18	21	24	27	30	33	36
Days after 2nd dose:						3	6	9	12	15	18	21
Vydate dose/plant												
0g		9.1	9.0	9.0	8.3	9.8	8.9	7.8	8.0	10.1	9.3	8.6
1 x 0.5g.		0.7	2.4	6.4	8.3	9.2	8.4	8.0	7.8	9.2	8.4	9.0
2 x 0.5g		0.9	2.6	7.5	9.2	7.0	5.0	6.6	8.7	9.5	9.2	9.4
1 x 1.0g.		0.3	0.9	4.4	6.2	7.5	8.2	7.7	7.8	9.4	9.6	8.2
2 x 1.0g		0.2	0.5	2.9	6.4	3.4	2.7	4.2	5.7	6.7	8.5	9.4
1 x 2.0g		0.2	0.7	2.1	3.0	4.5	7.9	5.7	7.6	8.7	8.8	7.0
2 x 2.0g		0.1	0.1	2.4	3.8	1.4	1.2	1.6	3.0	4.9	6.4	7.5

* Day 3 assessment lost through problems of condensation on the cages, which were then modified

Figure 25. Survival of adult whitefly feeding at the tops of tomato plants treated with different rates of Vydate.



the Vydate dose, the longer the time taken for survival to return to the control level, i.e., the longer the protection to the plant. The second application affected the whitefly for a further period although at the low rate (0.5g per plant) more than 50% survived.

Table 22. Time taken for whitefly survival to reach 50% and 100% of untreated control level after one (and two) doses of Vydate

Vydate dose	Days to 50% survival	Days to 100% survival
1 x 0.5 g	9-10	22-23
2 x 0.5g	9-10 (-)	15-16 then 30-31 (15-16)
1 x 1.0g	12-13	26-27
2 x 1.0g	13-14 then 23-24 (8-9)	35-36 (20-21)
1 x 2.0g	16-17	35-36 (20-21)
2 x 2.0g	29-30 (14-15)	36+ (21+)

The period of effectiveness for each dose of Vydate is summarised in Table 23. At the normal rate of 1.0g per plant half the whitefly survive after 12-14 days by which time the second application is due. This gives a further 8-9 days protection, making a total effective period (under 50% survival) of approximately three weeks. Doubling the dose rate to 2.0g per plant only extended the effectiveness by 4-7 days and with the greater risk of phytotoxicity at this rate it would not appear to be worthwhile.

When Vydate was first brought on to the market, the manufacturers claimed up to six weeks protection of soil-grown tomatoes by two doses of 1.0g per plant and in experiments a single dose

prevented whitefly infestation for four to six weeks (Stacey & Parr, 1977). However, different growing media affect the performance of systemic soil-applied insecticides and in this case the use of peat modules reduced the effectiveness (defined as under 50% survival of adult whitefly) of Vydate to only about three weeks. Hence, most Guernsey growers cannot expect to have a full six weeks protection from reinfestation by the standard application of Vydate on a peat-grown tomato crop.

b) Whitefly-parasite Interaction

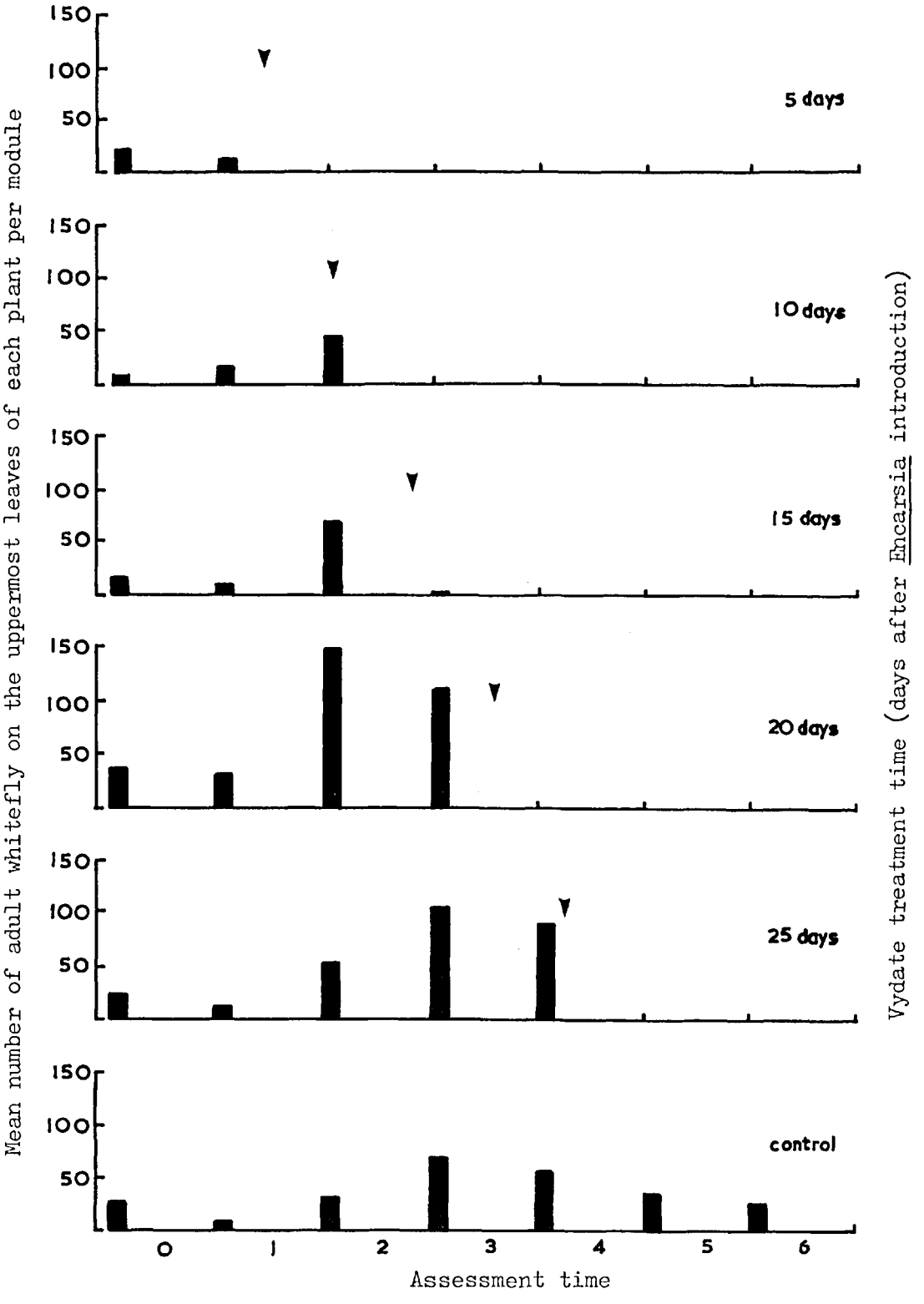
Table 24 shows the mean number of whitefly adults at the top of each plant per treatment date each week after transferring them to the large experimental glasshouse (starting 3½ weeks after the initial infestation).

Table 24. Mean numbers of adult whitefly at the top of each plant per Vydate treatment time.

Vydate application, days after *Encarsia* introduction	Days after *Encarsia* introduction						
	0	7	14	21	28	35	42
5	21.0	10.3	0	0	0	0	0
10	8.7	10.3	45.0	0	0	0.3	0
15	16.7	10.7	70.0	3.7	0	0	0
20	36.0	30.7	150.0	113.3	0.3	0	0
25	24.7	11.6	55.0	106.7	91.7	0	0
Control	26.0	8.7	32.3	70.0	58.3	36.7	26.7

These results are illustrated in Figure 26. The numbers of whitefly increased after the second assessment, by which time the first generation, from eggs laid by the introduced

Figure 26. Histograms to show mean numbers of adult whitefly at the top of each plant, relative to the time of Vydate application (▼).



whitefly, would have been emerging. Application of Vydate killed the adults within about one week and there was little or no reinfestation, either from neighbouring plots or from the lower leaves where pupae that had ceased feeding by the time the plants were treated continued to mature and hatch.

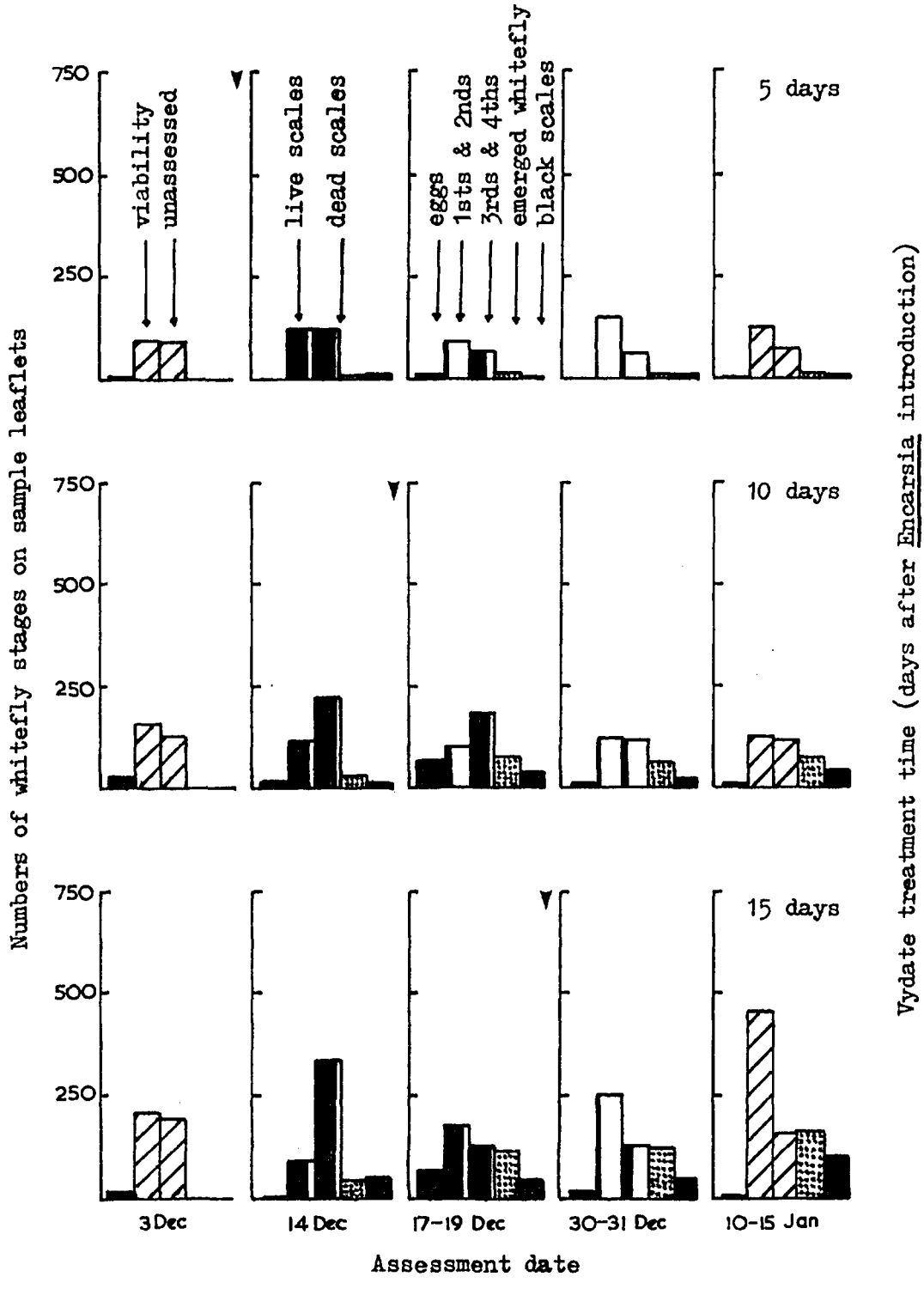
The counts of numbers and the viability of whitefly stages on sample leaflets from every third leaf up the plants are shown in Appendix 5. They have been summarized in Table 25 and Figure 27. Although no record of viability was made at the first assessment (3rd December), it can be assumed that most scales were alive as no Vydate treatment had yet been made. At the last assessment (10th - 15th January) I had a broken arm and was unable to manipulate the leaf samples enough to be able to assess mortality: however, it can be assumed that most scales were dead in the treated plots and alive only in the untreated control.

In Figure 27 scales have been shown as small (first and second instars) or large (third and fourth instars), the height of the bar represents the number of scales and the width of the black and white portions is proportional to the number of live and dead scales. As mentioned in Section 3.2.3, empty whitefly pupal cases tend to fall off the leaf, so actual numbers of emerged whitefly were probably greater than shown, but the figures give an indication of the relative numbers of offspring produced in relation to the time of Vydate treatment. Similarly, although counted separately, unemerged and emerged black scales are shown as a single bar. A few dried-up dead black scales were seen, but on the whole it was assumed that once the scale was black it was sufficiently mature to complete its development despite the Vydate treatment.

Table 25. Summary of counts of whitefly stages (and percentage viability) from leaflet samples taken from every third leaf up the plants at intervals before and after Vydate application.

Whitefly stage:		Eggs	1sts & 2nds (% alive)	3rd & 4ths (% alive)	Emerged pupae	Black scales
Days after Enc. intro. of Vydate applic.	Assessment date					
5	3/12	7	97 (?)	93 (?)		
	14/12	3	122 (73.8)	123 (96.7)	7	11
	17/12	17	93 (4.3)	70 (67.1)	17	4
	30/12	0	156 (0)	65 (4.6)	7	8
	10/ 1	1	129 (0)	74 (0)	9	8
10	3/12	28	158 (?)	124 (?)		
	14/12	10	111 (80.2)	225 (96.4)	31	10
	17/12	70	102 (33.3)	172 (89.5)	77	40
	30/12	7	121 (9.1)	119 (13.4)	58	26
	10/ 1	8	127 (?)	121 (?)	77	47
15	3/12	11	208 (?)	192 (?)		
	14/12	3	92 (72.8)	334 (96.7)	39	48
	19/12	69	177 (74.0)	126 (96.8)	111	40
	30/12	13	254 (4.7)	126 (37.3)	124	48
	15/ 1	4	458 (?)	153 (?)	159	99
20	3/12	62	275 (?)	133 (?)		
	14/12	11	263 (85.9)	374 (98.4)	14	1
	19/12	50	322 (77.0)	234 (94.9)	109	20
	30/12	192	393 (12.0)	319 (68.7)	150	51
	15/ 1	7	1588 (?)	245 (?)	144	103
25	3/12	22	164 (?)	187 (?)		
	14/12	13	183 (91.8)	198 (98.5)	38	24
	19/12	61	251 (72.1)	235 (88.1)	66	16
	30/12	206	224 (67.4)	306 (73.9)	105	33
	15/ 1	15	826 (?)	186 (?)	122	131
Control	3/12	6	141 (?)	107 (?)		
	14/12	8	124 (87.9)	202 (99.0)	32	14
	20/12	45	98 (80.6)	150 (94.0)	26	39
	30/12	150	121 (52.1)	155 (85.8)	74	14
	11/ 1	82	379 (?)	280 (?)	129	138

Figure 27. Histograms showing the age structure and viability of the whitefly population relative to the time of Vydate application (▼).



Continued ...

Figure 27 continued.

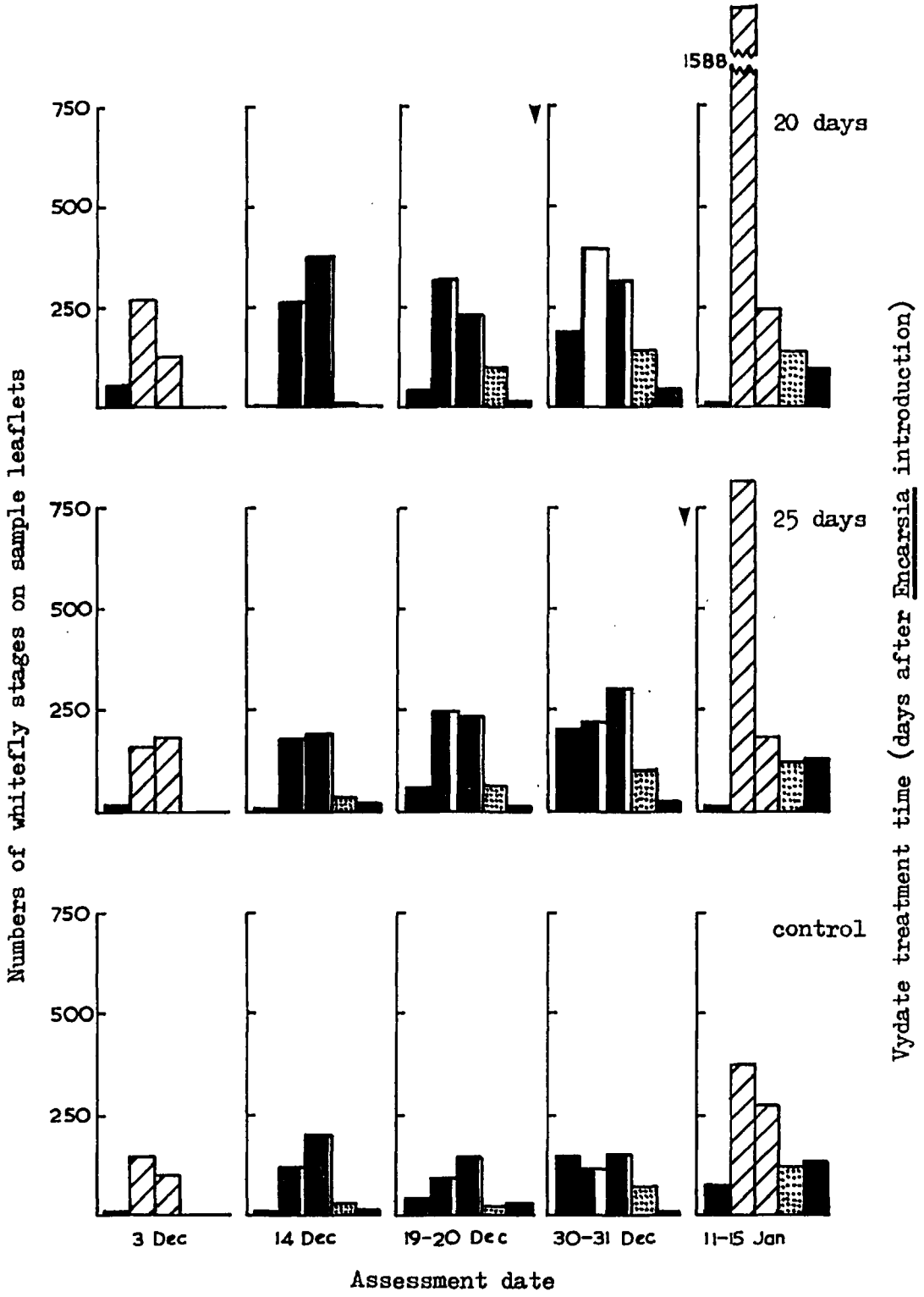


Figure 28. Photograph of an unmelanized 'black' scale (left) showing the adult Encarsia visible within the host pupal case.

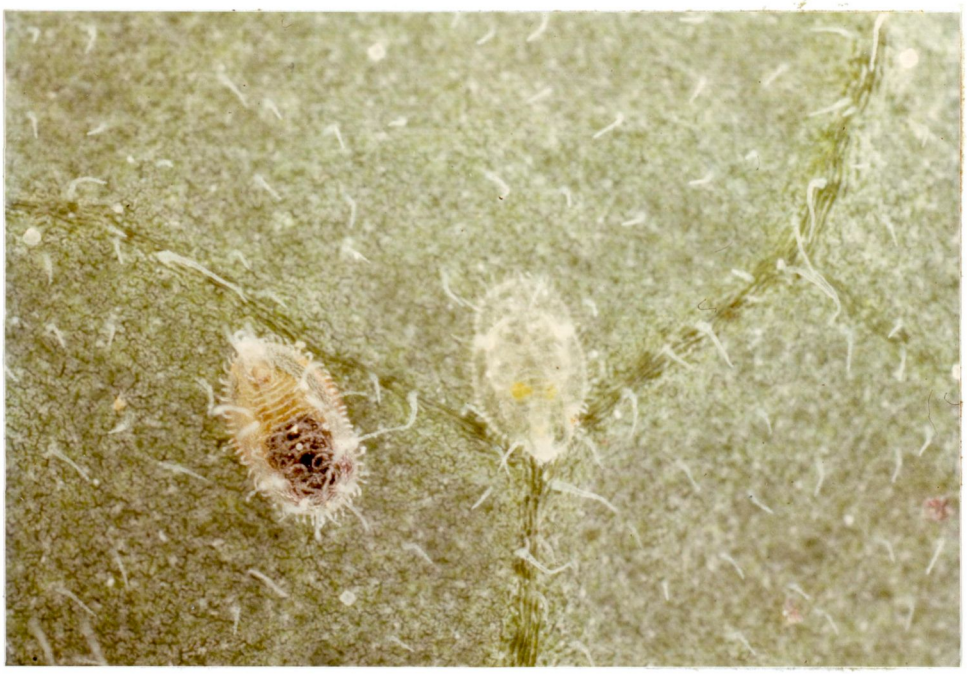


Figure 29. Photograph showing the D-shaped exit hole of the parasite from an unmelanized 'black' scale (right) compared to the normal T-shaped slit after whitefly emergence (left).



Several unmelanized 'black' scales were noticed, as shown in Figure 28. The mature parasite could be seen through the pupal cuticle which remained clear, or only slightly brown at the edges. These parasites emerged normally, as can be seen by the D-shaped exit hole in the clear pupal case, shown in Figure 29, compared to the normal T-shaped whitefly exit hole. The subsequent parasitic efficiency of the Encarsia was not followed up, but it would appear that the Vydate treatment may have disrupted the melanization which causes parasitized scales to blacken, without harming the parasite. Clear 'black' scales are occasionally found in Encarsia cultures and Hoogcarspel (pers. comm.) found them to be more common where the leaf tissue has dried up or the scale is situated on a necrotic piece of leaf. They were certainly more abundant than usual on the Vydate-treated plants.

From Figure 27 it is clear that the earlier Vydate is applied, the fewer scales survive and hence there is less parasitism. Smaller scales succumb quicker than larger ones. That a greater proportion of the third and fourth instars survived was probably due to the fact that once scales stop feeding and pupate they are immune to the effects of the systemic insecticide and continue to mature. However, the offspring would die when they started feeding. The very large numbers of scales at the last assessment of the 20- and 25-day treatments, reflects the large numbers of adults present before the application of Vydate (see Figure 26).

From these results it can be seen that Vydate disrupts a whitefly-parasite interaction since it kills the host scales

necessary for Encarsia to oviposit and reproduce. The longer the application is delayed, the more chance there is of parasites surviving, owing to the wider age range of whitefly stages available, some of which may happen to survive on an inefficiently treated plant.

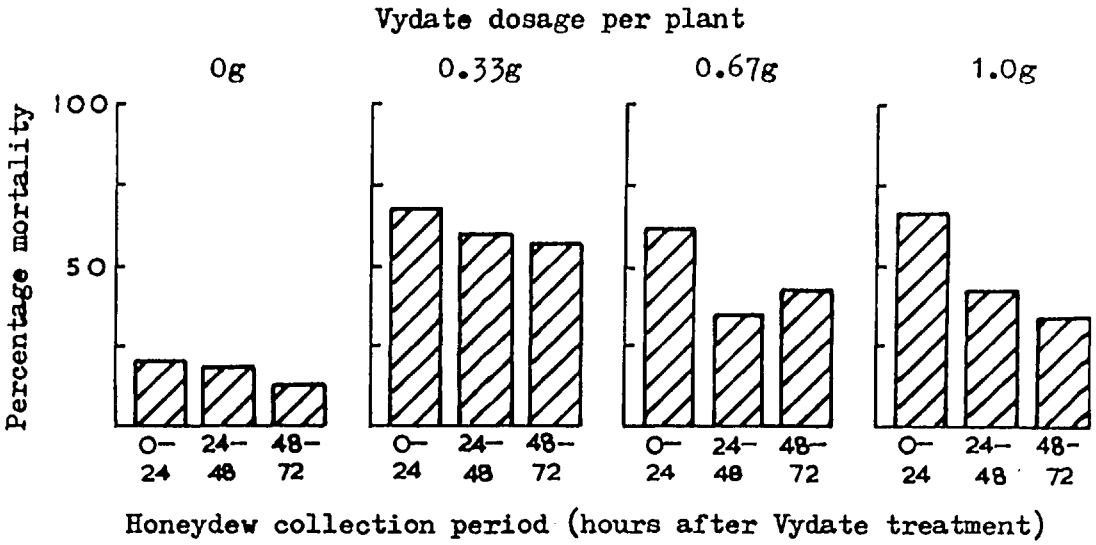
c) Honeydew Toxicity

The mean percentage mortality of Encarsia caged on honeydew collected from whitefly scales on plants treated with different rates of Vydate is given in Table 26 and Figure 30. The raw data are given in Appendix 7.

Table 26. Cumulative percentage mortality of Encarsia over 3 days when caged on honeydew collected from whitefly scales on tomato plants treated with Vydate (means of 3 collections per plant, 6 replicates per treatment)

Collection period:	0 - 24 hrs			24 - 48 hrs			48 - 72 hrs		
Assessment time (hrs):	24	48	72	24	48	72	24	48	72
Vydate dose/ plant									
0g	7.9	21.4	32.1	4.7	18.3	33.7	7.6	12.9	19.9
0.33g	40.6	70.0	89.4	32.3	64.6	82.3	35.5	56.8	77.6
0.67g	33.1	67.5	84.3	14.4	34.3	54.7	23.5	48.1	56.8
1.0g	39.1	69.5	89.7	18.8	46.4	63.0	20.7	35.2	46.4

Figure 30. Histograms to show mean percentage Encarsia mortality as an average of the three days' assessments for each collection period.



Clearly treatment of plants with Vydate results in mortality of Encarsia feeding on the honeydew, i.e. the toxicity of the insecticide is transmitted along the food chain. This was a proviso noted by Parr & Scopes (1971) when they advocated the use of systemics as the best means of chemical integration with natural enemies. It is interesting that there was greater mortality from the lower dose (0.33g per plant) and that, at higher doses, mean mortality was less on later honeydew collections. In some replicates there was little or no mortality from the second and third days' collections, although the first 24 hours' collection was highly toxic. This suggests that the scales were rapidly killed by the high dosage of Vydate and stopped excreting by the second or third day, while they could survive the low dosage and

continued to excrete honeydew which was lethally contaminated for several days after the treatment. Thus the foliage becomes coated with a toxic deposit.

Either way Encarsia suffer. At a high dose rate their hosts are killed and their source of food and oviposition sites is eliminated; at lower dose rates host scales may survive, but the honeydew produced is toxic to the parasites, as are, possibly, the scales' body fluids upon which Encarsia host-feed. A preliminary experiment produced no indication that the parasites could distinguish clean from contaminated honeydew, and the matter was not pursued as it is not relevant since the whole crop is usually treated with Vydate.

Having observed these results it was hoped to quantify both the amounts of honeydew collected and the levels of Vydate residues present. During the experiment a reduction in honeydew deposition in the later collection periods from some of the high dosages was observed, but no record of quantities of honeydew per replicate was kept. Subsequent efforts to make droplet counts and measurements of honeydew collected were unsuccessful. Similarly, there is insufficient equipment at GCRI to analyse Vydate residues. Further effort to this end was considered unwarranted, having proved the objective of the experiment, i.e. to show that the honeydew excreted by whitefly scales on Vydate-treated plants is toxic to Encarsia.

4.2.4 Conclusion

The experiments show two effects of Vydate treatments. Firstly, where the crop is grown in peat modules, the standard two

doses of 1.0g per plant protects it from reinfestation by whitefly for only about three weeks. Secondly, the insecticide disrupts the whitefly-parasite interaction in two ways; by killing host scales and by producing toxic honeydew. Stacey & Parr (1977) claimed that the systemic action of Vydate had no effect on Encarsia, but their method of assessing this was unspecified.

Two of the experiments (a & c) employed a range of Vydate dosages. These were intended to represent the range that may result from inefficient application or watering in. Figure 30 shows how granules have stuck to the stem of the plant and not been watered into the soil; the plant has therefore only received a fraction of the intended dose. Also, when treating a large area a plant may easily be missed or be dosed twice. The state of the plant at the time it is treated also affects the uptake of the chemical. In sunny weather rapid transpiration results in rapid uptake, while granules applied to wet soil in dull weather will not be taken up as efficiently.

Consequently, it can be assumed that the actual dosage per plant will not be uniform throughout the crop. Pockets of whitefly may survive on inadequately treated plants and, if unnoticed, will be difficult to control later on. If parasites were present at the time of treatment host scales would be killed on properly treated plants and toxic honeydew produced by scales would kill them on plants where the dosage was inadequate. Hence the disruption to the establishment of Encarsia observed on some Guernsey nurseries.

Having shown that it is best to defer parasite introduction until after Vydate treatment, the question is, how soon should introductions start ? If whitefly were present at the

Figure 31. Photograph showing how Vydate granules have stuck to the tomato stem and not been watered into the soil.



treatment time, not all the scales are likely to have been killed and it is therefore desirable to have Encarsia present to parasitize survivors on inadequately treated plants as soon as possible. Contaminated honeydew from scales kills parasites in contact with it and consequently, a large proportion of parasites introduced soon after Vydate applications are likely to perish while searching for surviving hosts. It is therefore preferable to make more frequent introductions in the initial period after treatment and weekly, half-rate introductions are recommended. In this way, if most of the first parasites die through contact with toxic honeydew, it is only a short time before more are introduced and their chances of survival improve as the effects of Vydate wear off. If fortnightly introductions are made and the first parasites all perish, there could be a much longer period without adults present, during which time surviving whitefly may develop and hatch to initiate the next generation of pests.

Since Vydate has been shown to be effective against adult whitefly for only about two weeks on a peat module crop, where there was a whitefly population prior to treatment, parasite introductions should be started within a fortnight of Vydate application. Weekly, half-rate introductions would be advisable for the first two or three weeks until the harmful effects of the chemical have dissipated and normal fortnightly introductions may be used. Alternatively, if the crop is treated with Vydate while weather conditions are still unfavourable for Encarsia establishment, introductions could be delayed for a longer period, but a preliminary insecticide treatment may be necessary before the parasite is used if whitefly numbers have built up. Where no whitefly were present on the crop when

Vydate was applied, introductions should start as soon as the first adult whitefly are seen in the normal way.

4.3 γ-HCH

4.3.1 Introduction

In the literature, leafminer taxonomy is confusing, but is clarified by McClanahan (1980a). Most American research refers to the vegetable leafminer, L.sativae Blanchard (formerly L.munda Frick), while the tomato leafminer, L.bryoniae (formerly L.solani Hering) is common in Europe. The life history of the pest was described by Hussey, Stacey & Parr (1975) who noted that although L. bryoniae is widespread and serious in the Netherlands and Channel Islands, in the UK it is only a localised problem in southern England. Lane (1977) attributed an outbreak in Kent to reduced pesticide usage because of biological control. With the current mobility of people and plants, it is perhaps surprising that this situation has remained unchanged since the early days of glasshouse pest research when leafminer was noted to be common on tomatoes in the Channel Islands but only infrequent and sporadic in England (Speyer, 1939; Speyer & Parr, 1945).

In Guernsey, γ-HCH is applied to the soil before laying down polythene at the start of the season to kill leafminer adults emerging from pupae in the soil and prevent them infesting the new crop. Section 3.1 explains how most of the tomato crop is grown in peat modules and consequently, soil sterilization, which formerly killed the pupae, is no longer normal practice. A newly stood-out tomato crop is shown in Figure 32.

Figure 32. Photograph of a newly stood-out tomato crop in Guernsey.



Although a heavily infested tomato crop looks unsightly, there is evidence suggesting that no direct yield loss occurs until the density of mines is extremely high, beyond that normally found in practice. This applies to both L.sativae (Lindquist, 1974; Levins, Poe, Littell & Jones, 1975) and L. bryoniae (Ledieu, 1981 c) which is mainly confined to the older leaves which contribute little to the fruit swelling. Schuster, Jones & Everett (1977) found that yields from tomato plots treated with foliar sprays of oxamyl to control L. sativae were lower than the untreated, more heavily infested plots. They suggested that the detrimental effects of the insecticide sprays outweighed any benefit from the reduction in the leafminer population.

An early attack of leafminer can be serious because larvae mining in small tomato seedlings may kill the terminal shoots (Speyer & Parr, 1950; Hussey, Read & Hesling, 1969). Hence the need to control early-season infestations in Guernsey and the Netherlands. On older plants control is necessary since damaged leaf tissue is susceptible to secondary fungal infections, especially by Botrytis.

Formerly, chemicals used for leafminer control included γ-BHC or nicotine smokes, demeton-S-methyl, diazinon, dimethoate and parathion (HAS, 1970, 1971, 1972 b,c, 1973 b, 1974 a). Nowadays permethrin (Ambush), deltamethrin (Decis) and pirimiphos-methyl (Actellifog) are used (Woets & van Lenteren, 1979; HAS, 1980 k, 1981 f). However, all these materials are highly toxic to Encarsia and Phytoseiulus and so chemical control of leafminer is incompatible with biological control, even in an integrated programme. Vydate is commonly used in Guernsey and provides good early-season control of L. bryoniae; its effects have been discussed in Section 4.2.

Where natural enemies are used, hand-picking of mines has been recommended for early leafminer infestations (Woets, 1974; HAS, 1980 g) with Pynosect against the adult flies. However, early researchers were of the opinion that, owing to the short duration of the larval stages, leaf-picking was useless as a means of control and may even do more damage than mining by the larvae (Speyer, 1939; Speyer & Parr, 1945).

In the Netherlands, neglect of L. bryoniae in the early years of biological control led to an increase in its incidence (Woets, 1978b, Ramakers & van Lenteren, 1980). The incompatibility of broad-spectrum chemicals for leafminer control with natural enemies has reduced the use of Encarsia (Woets & van Lenteren, 1979; van Lenteren, Ramakers & Woets, 1980) and this problem is regarded as a serious threat to biological control on tomatoes in the Netherlands. Much effort is being put into the development of alternative leafminer control by various species of parasites (Zucchi & van Lenteren, 1978; Hendrikse & Zucchi, 1979; Koppert, 1979; van Lenteren, Ramakers & Woets, 1979; Woets, van Lenteren & Ramakers, 1980). In the UK L.bryoniae is uncommon, but L. trifolii, recently identified on tomatoes and chrysanthemums, does pose a serious new threat since it is a notifiable pest and must be eliminated with insecticides (Gould, pers. comm.1980 (Harpenden); Wardlow, 1981).

Early experiments with soil-applied γ-HCH (formerly γ-BHC) and DDT for leafminer control were aimed at preventing pupation by larval contact with the insecticide (Speyer & Parr, 1949, 1950). They were not very successful, but it was found that treatment just before emergence commenced was effective. This is

now the standard method of preventing leafminer infestation in Guernsey (HAS, 1979 h, 1980 m). However, owing to a mistake in the recommended dose rate, five times the necessary amount of γ - HCH has been used in the island for several years (HAS 1972 a, 1980 c).

The foliar application of γ-HCH is known to have long-term deleterious effects on biological control (HAS, 1980 d), but, only recently, were doubts expressed about the effect of soil-applied γ-HCH on Encarsia. It had been assumed that the physical barrier of polythene would protect the parasite from the contact action of the insecticide. However, in cucumbers it was found that where soil-applied γ-HCH was used for thrips control, Phytoseiulus were killed on the plants above by a vapour action, the mortality being proportional to the dosage and the height of the predators above the soil.

Two glasshouse experiments were done at GCRI at the start of the 1981 season to determine whether γ-HCH under polythene sheeting affected the dispersal of Encarsia introduced into tomato crops.

4.3.2 Materials and Methods

Experiment 1

Three 9 x 9 m glasshouse compartments were used to test the effects of two rates of 80% γ-HCH emulsion on the dispersal of Encarsia, compared to an untreated control. The two rates used represented the incorrect high dosage formerly recommended in Guernsey (5 fl oz in up to 50 gallons of water per 100 x 30 ft., i.e. equivalent to 70 fl oz per acre) and the revised lower rate that

is now used (1 fl oz in up to 50 gallons of water per 100 x 30 ft, i.e. equivalent to 14 fl oz per acre) (HAS, 1972 a, 1980 b). Treatments were as follows:

i) High dose: 1.4 fl oz 80% Gamma-col in 1 gallon of water;

ii) Low dose: 0.28 fl oz 80% Gamma-col in 1 gallon of water;

iii) Control: no treatment.

The temperature regime was 11°C nights (16°C Stage III in ii and iii), 20°C days, venting at 23°C, with NFT root warming to 25°C at Stages III and IV.

The insecticide was applied with a knapsack sprayer on 12th December, 1980. As the glasshouse was already partially laid out for a nutrient film technique (NFT) experiment and had polythene on the floor, the chemical was sprayed under the polythene on which the NFT troughs were to be placed, avoiding the exposed polythene on the paths. The tomato plants were stood out and the heating turned on the following week. Parasite dispersal studies were made fortnightly from 18th December until early March, 12 weeks after treatment.

Portions of tobacco leaf bearing large numbers of mature black scales ($\pm$ 1500 - 3500) were put in three covered trays and incubated overnight at 25°C before releasing them at the centre of each compartment. The trays were placed on a large flower pot (about 9" from the floor) and the covers were removed carefully to avoid disturbing the emerged Encarsia. A tomato trap plant (decapitated above six leaves for ease of handling), heavily infested with third instar whitefly larvae, was placed in each quarter of the glasshouse compartments; two near the release point ($\pm$ 2.25 m in the NW and SE) and two further away ($\pm$ 5.0 m in the NE and SW). The trap plants

were placed out at least 24 hours before parasites were released so that any kairamones from the honeydew could build up around them and attract the Encarsia. Great efforts were made to keep the crop plants free of whitefly. A few inevitably escaped from the trap plants and by the end of the experiment there were a few scales on the crop, some of them parasitized. At this stage the trap plants were checked for Encarsia which were removed prior to each introduction.

The numbers of parasites on each trap plant were counted one and three days after their release. The plant was carefully lifted up and inverted to count the Encarsia on each leaf without disturbance. At the second count all the parasites were pootered off and the plants were removed to another glasshouse to await black scale development. The release tray was recovered and counts of unflown and unemerged Encarsia were made to estimate the effective number which had dispersed into each compartment.

Experiment 2

Two 16 x 16 m glasshouse compartments were used to test the effect of the high dose rate of γ-HCH emulsion on the dispersal of Encarsia under conditions closer to those in Guernsey. 4.9 fl oz 80% Gamma-col in 30 gallons of water (equivalent to 78 fl oz per acre) was applied to the soil of one compartment with a watering can on 5th January 1981. Polythene sheeting was laid down the next day and plants stood out on peat modules in both glasshouses on 7th January. The crop was grown at programme temperatures (see Appendix 1). The control compartment had a thermal screen.

Parasite introductions were made fortnightly from 12th January in the same way as Experiment 1. There were eight trap

plants per compartment; four near the release point (± 4 m away) and four further away (± 9 - 10 m away). Recording continued until early April, 13 weeks after the treatment.

4.3.3 Results and Discussion

Experiment 1

A detailed record of parasite numbers is given in Appendix 8. A summary of the results is shown in Table 27 and Figure 33.

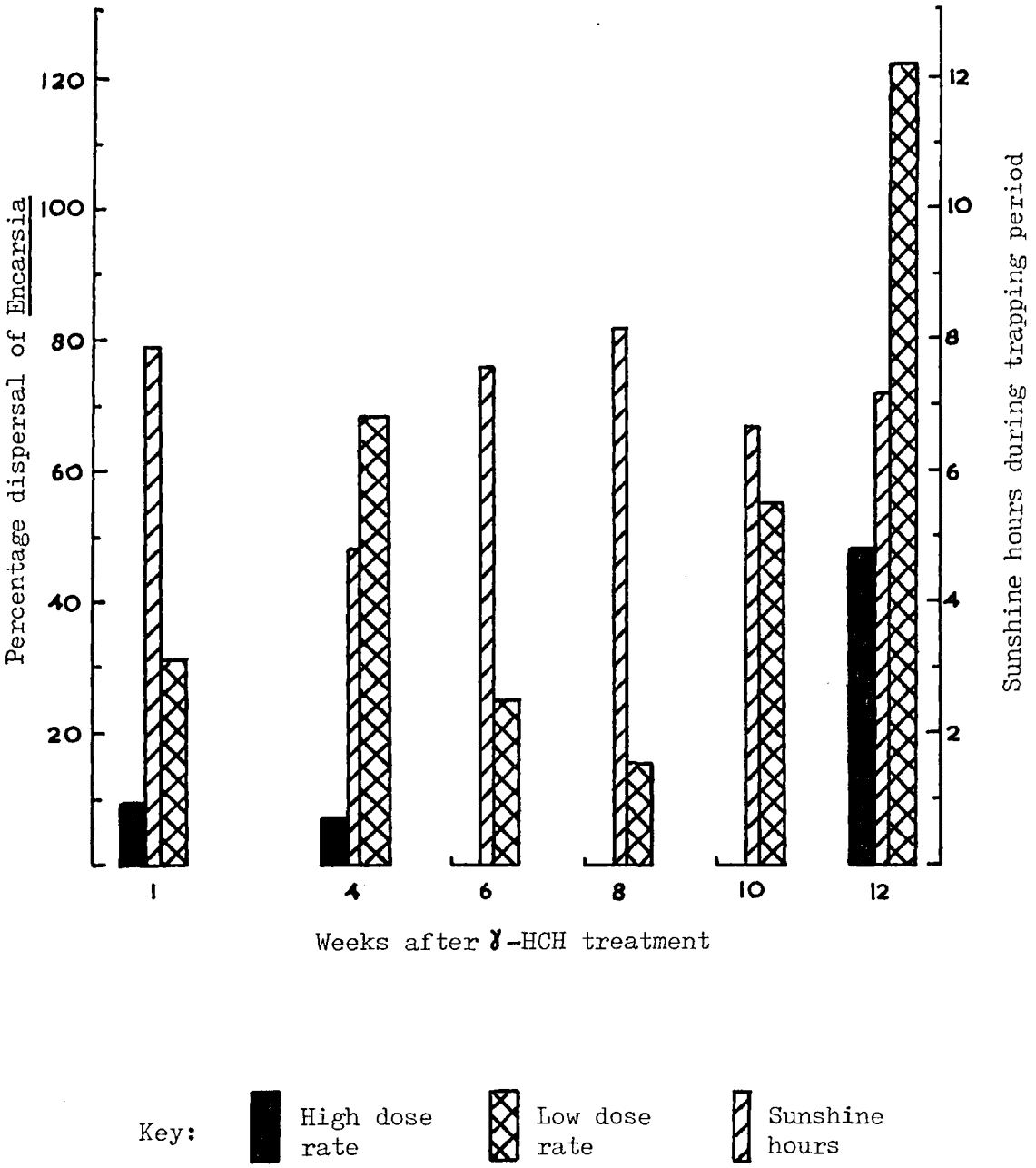
Table 27. Total numbers of Encarsia counted on four trap plants per γ-HCH treatment and numbers of black scales subsequently developed.

Weeks after treat.	High Dose				Low Dose				Control			
	Prelim. count	Day 1	Day 3	Black scales	Prelim. count	Day 1	Day 3	Black scales	Prelim. count	Day 1	Day 3	Black scales
1		3	6	7		3	30	75		9	64	258
4		6	5	104		7	48	701		2	70	796
6		0	0	31		0	2	3		3	8	103
8		0	0	9		0	2	118		4	13	204
10	(0)	0	0	22	(9)	5	11	547	(8)	5	20	361
12	(9)	10	13	531	(8)	8	33	587	(9)	5	27	496

There was no apparent relationship between the position of the trap plants in relation to the release point and the numbers of Encarsia counted. The histograms show the number of parasites recovered after three days as a percentage of the number counted on the trap plants in the control compartment for that introduction. This allows for differences in the numbers of parasites which dispersed from the release tray each time. These were sometimes rather low if the black scales were not sufficiently mature when used.

Since sunshine is known to affect dispersal, the total

Figure 33. Histograms to show Encarsia dispersal in γ-HCH Experiment 1 as a percentage of that in the untreated control.



sunshine hours recorded at the GCRI meteorological site during the trapping periods are also shown in Figure 33. This ranged from 4.8 to 8.2 hours, and although some days were sunless, there was at least 3 hours sunshine for one day in each period (see Appendix 10a). Therefore, it was assumed that there was adequate sunshine to stimulate flight and the differences in parasite dispersal can be attributed to the γ-HCH treatments.

Clearly, the high dosage severely reduced Encarsia dispersal and even after 12 weeks it was less than 50% of the control. At the lower dose rate there was always some dispersal, but it did not match the control level for 10 weeks.

The numbers of black scales that developed on the trap plants do not provide an accurate indication of parasitism by the experimental Encarsia since extraneous parasites were present both before release and after, in the holding glasshouse, and these distort the results.

Experiment 2

The individual trap plant counts are given in Appendix 9 and are summarised in Table 28.

Table 28. Total numbers of Encarsia counted on eight trap plants in the γ-HCH treatment and control glasshouses and numbers of black scales subsequently developed.

Weeks after treat.	High Dose				Untreated Control			
	Prelim. count	Day 1	Day 3	Black scales	Prelim. count	Day 1	Day 3	Black scales
1		1	0	47		6	34	321
3		0	0	0		7	21	25
5		0	0	51		4	87	869
7	(0)	0	0	28	(27)	12	44	853
9	(0)	0	2	33	(3)	5	35	471
11	(0)	1	21	1009	(9)	11	60	1347
13	(0)	6	29	815	(10)	37	84	2212

Figure 34. Histograms to show Encarsia dispersal in γ-HCH Experiment 2 as a percentage of that in the untreated control.

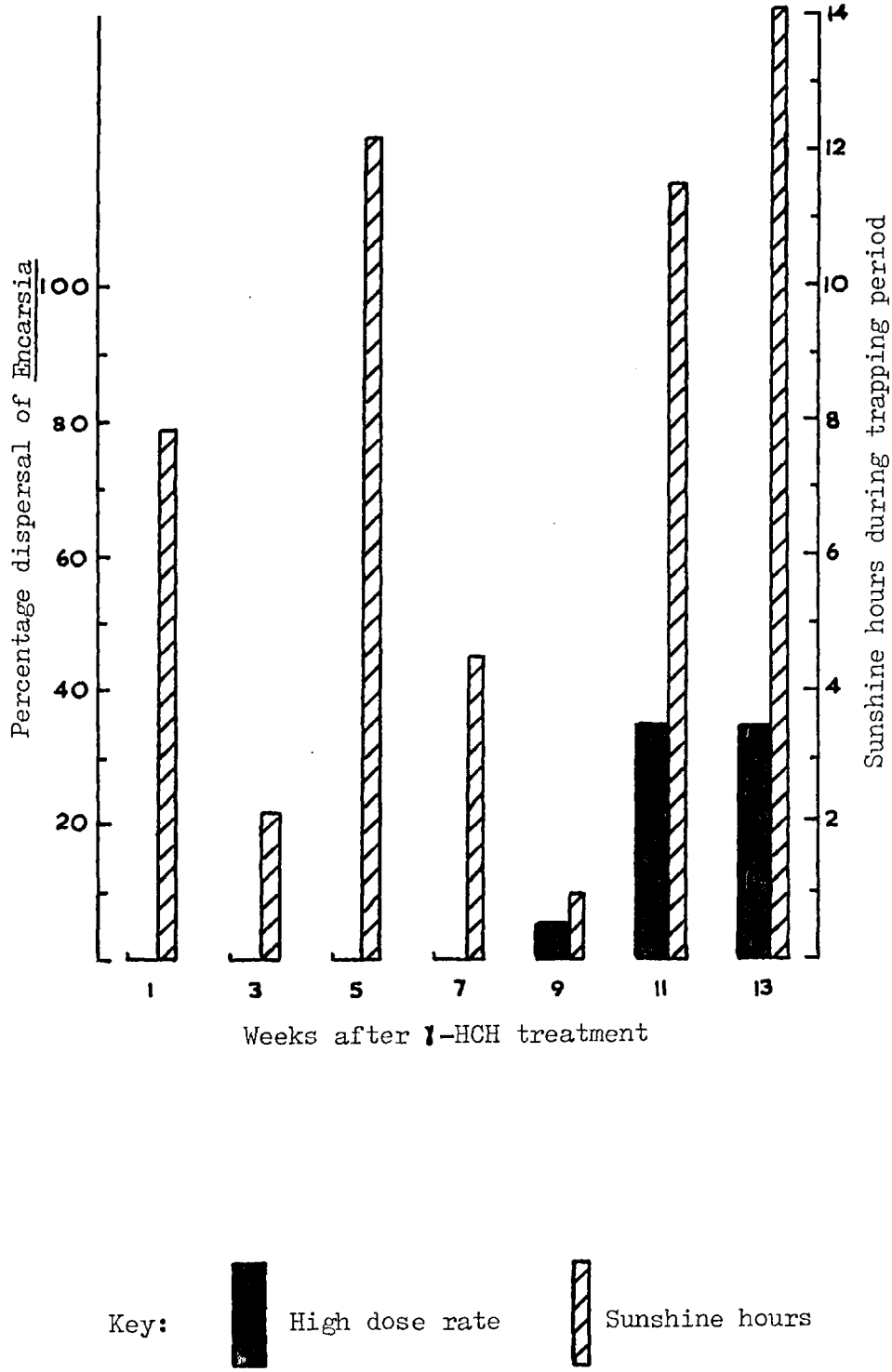


Figure 34 shows clearly how dispersal in the γ-HCH treatment was totally inhibited for seven weeks and only reached a third of the control after 13 weeks. Sunshine hours were more variable than in Experiment 1, but only two of the trapping periods had less than 3 hours every day (see Appendix 10b).

4.3.4 Conclusion

These experiments demonstrate that the application of γ-HCH under polythene sheeting disrupts the dispersal of parasites for several weeks. This is particularly apparent at the higher dose rate and may well explain some of the failures of Encarsia to establish on Guernsey tomato crops early in the season.

The correct lower dosage, now recommended, still disrupts dispersal, but not as severely as hitherto. Assuming that the use of γ-HCH is necessary for leafminer control in the island, I suggest that Encarsia introductions should be delayed until about two months after it is applied, to allow the worst of the fumigant effect to wear off.

The actual mechanism of the effect was not investigated in detail, but it can be assumed to be a fumigant action, presumably from insecticide around joins in the polythene (the areas that growers are advised to concentrate on when applying the chemical). At the start of the experiments, dead Encarsia were seen on the floor around the release tray. In Experiment 1 this may have been due to contact with γ-HCH spilled on the paths (which were already covered with a layer of polythene) but it is likely that fumigant action initially caused the parasites to fall to the floor rather than flying away from the tray.

4.4 PYNOSECT

The use of Pynosect (pyrethrum/resmethrin) in integrated control programmes was explained in Section 1.7.3. For several years this material has been used for spot-treatments and corrective sprays to restore the balance of biological control when whitefly numbers become excessive. It is also useful for control of leafhopper (Z. pallidifrons) which is becoming more common with reduced pesticide usage.

During the 1979-80 banker plant trials in Guernsey (see Section 5.2) a half-strength Pynosect (3.5 ml/l) spray was used on 21st December to reduce the numbers of adult whitefly at the tops of the bankers at the HAS. Three days later, extra black scales were introduced to try and improve the level of parasitism. On inspection the following week, large numbers of dead adult Encarsia were found on the leaves.

In an attempt to explain this unexpected mortality, further persistence testing was done at GCRI. Previous results showed Pynosect to be harmless to adult Encarsia four days after spraying (Ledieu & Helyer, 1979; Morgan & Ledieu, 1979) and that the insecticide was safe for integration with natural enemies. Pyrethrum and synthetic pyrethroids such as resmethrin (the active ingredients of Pynosect) undergo rapid photolytic degradation in sunlight, unlike some newer persistant materials such as permethrin and deltamethrin.

By keeping the sprayed test plants in subdued light, Pynosect continued to kill adult parasites for up to 30 days (Ledieu, 1981 a) indicating that the phytolytic breakdown of the

pesticide had been slowed down. Thus, although quite suitable for integration with natural enemies under sunny summer conditions when breakdown is rapid, Pynosect would appear to be more persistent and harmful under dull conditions early in the season. There were only three hours of sunshine in the three days after the Guernsey spraying, hence the high residual toxicity.

This is the time when chemical integration with Encarsia is most needed to assist establishment, so an alternative insecticide is required. Ledieu (1981a) tested rotenone and bioresmethrin. Rotenone was unsuitable as it killed adult whitefly only by direct contact action and it also caused leaf-scorch. Bioresmethrin was effective in killing whitefly and its short residual period was not increased by low light. It is, therefore, a suitable alternative to Pynosect for integration with natural enemies early in the season (Ledieu, 1981 a); however, at present it is only available as an amateur product (Fisons Combat Whitefly Insecticide).

When chemicals are integrated with parasites it is important to avoid spraying the area of parasite activity on the lower leaves, even where sublethal doses are used. Perera (1977), studying Pynosect, found that although the dose may not be toxic, parasitism declined more where there was a uniform, rather than a patchy, deposit on the leaf. He also showed how the toxicity of the insecticide changed with plant species. A dose that was not toxic to Encarsia on leaves of Phaseolus vulgaris was lethal on tomato . This emphasises the importance of testing pesticides for each specific situation, rather than extrapolating from other results.

5 EXPERIMENTAL METHODS OF BIOLOGICAL CONTROL ATTEMPTED IN GUERNSEY

5.1 INTRODUCTION

As biological whitefly control in Guernsey using conventional dribble introductions of Encarsia has been unreliable, other systems were tested experimentally in the island. The timing of parasite introductions in relation to the use of Vydate is discussed in Section 4.2. In this Section the use of banker and mini-banker plants is examined.

5.2 BANKER PLANTS

5.2.1 Introduction

The term "banker plant" was coined by Hussey (1967) to describe a method of Phytoseiulus introduction on cucumbers. One plant per hundred in the crop was heavily infested with red spider mite which were allowed to reach a fairly high density before predators were introduced. By the time control was regained, several thousand predators had built up on each banker, ready for redistribution to other parts of the crop. The same principle was applied to whitefly control on tomatoes and the banker plant system of Encarsia introduction (described in Section 1.7.1) was developed (Parr & Stacey, 1976, 1977 a; Stacey, 1977 a; Scopes & Ledieu, 1979).

Trials at GCRI and on commercial nurseries in the UK produced good results (Stacey, 1978) and this method of whitefly control has since been used regularly at GCRI. Freuler & Paccaud (1980) reported comparable control with bankers and conventional

introductions, with bankers providing more lasting control through the season. Although the initial production of bankers requires facilities to raise a few plants separately from the rest of the crop and careful planning of the insect introductions, once in the crop, bankers require less labour than regular dribble introductions.

Banker plants were first raised in Guernsey for the 1979 season. They were not entirely suitable, but results encouraged further trials, and the production of bankers was described for any growers who wished to use them (HAS, 1979 *g*). Unfortunately, a large scale commercial trial the following season was a failure owing to incorrect production of the bankers and failure to control leafminer. Since then they have only been used experimentally.

5.2.2 Materials and Methods

1979

Two 25 x 10 ft glasshouses were used to raise 80 tomato plants (variety J96 - chosen for its compactness), in 9" whalehide pots, for banker plants. They were grown at 18°C with supplementary lighting for 16 hours daily. Initially they were on benches but these were removed once the plants were tall enough.

The 6 - 7 leaf plants were infested with whitefly (100 pupae per plant) on 20th November 1978. *Encarsia* were introduced three weeks later on 11th December (200 black scales per plant). It had been planned to use the bankers around 15th January 1979; however, owing to production problems they were not put out until the last week in January.

The heating system in the glasshouse proved inadequate during the cold winter and there were problems with ventilators blowing open. Consequently, the temperature was too low and whitefly

and Encarsia developed only slowly. A Pynosect spray was applied on 12th January to reduce whitefly numbers and supplementary Encarsia were added on 14th January. Owing to insufficient attention to nutrition, the tomato plants became very 'hard'. Whitefly failed to colonise the upper leaves, with the result that the pest-parasite interaction did not progress up the plants as it should and fewer parasites than usual ultimately matured on each banker. Many of the plants were, therefore, unsuitable and only about 30 were finally used. They were introduced at a rate of one per 50 x 30 ft (1500 sq ft) on five commercial nurseries and at the HAS.

1980

Bankers were produced, under the guidance of GCRI, by a commercial company to treat their 30 acre nursery and to supply plants for use at the HAS. The intention was to have bankers ready for very early introduction, at the time of standing out the new crop. One small cropping house was cleared out early, in late August, 1979, and benching installed to raise 600 banker plants. The production schedule was as follows:

17 September 1979:	100 whitefly pupae introduced per plant (at 6 - 7 leaf stage);
8 October :	200 Encarsia (black scales) introduced per plant:
22-27 October:	first black scales due to appear on bankers;
8-12 November:	Encarsia due to start emerging, bankers ready for use after Pynosect treatment against adult whitefly.

1981

Banker plants were produced at the HAS for use in two glasshouses there and in one of the treatments in the mini-banker trial project (see Section 5.3). The production schedule was as follows:

17 November 1980: Tomato seed sown;

29 December: 25 6-7 leaf seedlings infested with 150 whitefly pupae each;

21 January 1981: 200 black scales per plant introduced;

4 February: first black scales due on bankers;

25 February: Encarsia due to start emerging on bankers, adult whitefly on the youngest leaves to be killed with resmethrin and plants introduced into the glasshouses (previously treated with Vydate to contain early whitefly).

In fact, the programme proceeded more rapidly than anticipated and the plants were placed out on 16th February. Earlier (11th February) resmethrin applied to the tops at a reduced rate had been ineffective in killing whitefly, so a second spray was applied on 16th February. Six bankers were used in each of two $\frac{1}{4}$ acre glasshouses at the HAS and a further six at the mini-banker trial site.

All these trials were visited periodically (about once a month) to make visual assessments of their progress. There was not time for detailed numerical recording of insect populations. The results given are, therefore, brief summaries of the situation in each case and specific points are discussed in more detail.

5.2.3 Results and Discussion

1979

The results on the five commercial nurseries are shown in Table 29. They largely reflected the condition of the bankers used. The failures at sites 3 and 5 occurred for contrasting reasons. In the former, there were too many unparasitized scales on the bankers which emerged and caused an excessive infestation of the crop. In the latter, there were too few unparasitized scales and whitefly never spread to the crop, any scales developing on crop plants in the vicinity of the bankers were rapidly parasitized so that Encarsia exterminated its host. These examples emphasize the care required to ensure the correct balance on the bankers and the rigorous selection of only the best plants for use. Had site 5 been infested with whitefly when the bankers were introduced succesful establishment may have been achieved, but introduction of excessive numbers of whitefly on the bankers must always be avoided.

At site 1 too few bankers were used and at least six, and possibly eight, plants should have been introduced into 12,000 sq ft. Had more bankers been used, they may have been able to control the existing whitefly population, which was at a low level in late January. Instead bad patches of whitefly developed, especially at the corners of the glasshouse. These areas always tend to be more prone to whitefly, but were also furthest from a banker.

The best results were at site 4 where an ideal low level interaction developed throughout the crop after an initial Pynosect fog to kill adult whitefly already present prior to banker plant introduction. At site 2 the grower was pleased with the results. The glasshouse used had fewer whitefly than the rest of the nursery,

Table 29. Results of 1979 banker plant trials on commercial nurseries.

Site no.	Area sq.ft.	No, bankers used	Banker intro. date	Previous *Encarsia* intros.	Biological control result
1	12,000	4	23 Jan	11 Jan 16 Jan	Insufficient establishment on the crop, despite adding extra parasites in late March. A Pynosect HV spray in June had been delayed too long and some bad patches of whitefly developed.
2	3,300	2	1 Feb	12 Dec	Banker house best on a nursery with a history of bad whitefly. Very good establishment of *Encarsia* on a fairly heavily infested crop. One Pynosect spot treatment used. Problems with leafminer and leafhopper. *Phytoseiulus* controlled red spider.
3	4,800	3	1 Feb		Unsuccessful. Insufficient parasitism on bankers resulted in excessive whitefly infesting the crop. The bankers were sprayed with Pynosect and extra *Encarsia* added in mid-March, but fogging was necessary from late May.
4	2 x 5,100	2 x 3	1 Feb		Good. A few whitefly and parasites established throughout the crop. No need for any other control apart from preliminary Pynosect fog,while in untreated houses fogging was necessary from mid-June.
5	2 x 8,000	2 x 4	1 Feb		No whitefly or parasites ever became established on the crop which remained uninfested. There were insufficient unparasitized scales on the bankers for whitefly to spread into the crop.

which was badly infested. Nevertheless, there was still a high whitefly population (unacceptable to many growers) and correspondingly many parasites, reflecting the numbers of whitefly present before banker plants were introduced.

At the HAS, two bankers introduced into a 3000 sq ft glasshouse on 30th January initiated good establishment around the bankers, which gradually spread into the rest of the crop as expected. Compartmented glasshouses had one banker per chamber (900 sq ft). The results of these eight treatments reflect both the condition of the bankers used and the temperature regime of the crop. Good bankers at programme temperatures produced reasonable results, but there was little spread in cooler glasshouses (12°C nights) and bankers with insufficient parasitism created bad patches of whitefly, despite the addition of supplementary Encarsia.

1980

This project was a failure. The banker plants had too great a proportion of unparasitized scales and consequently, succeeded only in infesting the crops with large numbers of whitefly, which neither the Encarsia from the bankers, nor supplementary introductions were able to control. Ultimately the project was abandoned and insecticides were used to clean up the nursery and the HAS glasshouses.

There were two reasons for the failure. Firstly the glasshouse used for raising the bankers was not adequately sterilized after the previous tomato crop so that the young banker plants became infested with leafminer. Initially the mined leaves were hand-picked, but it was then decided to spray the lower leaves with dioxathion

(Delnav) on 30th October. This material has a residual toxicity to Encarsia of at least two weeks, during which time whitefly scales surviving on the treated foliage would be unparasitized. Hence, the critical pest-parasite interaction was unbalanced. Secondly, the plants were produced too early for the new crop and had to be kept in the production house for a couple of weeks before being distributed. Instead of killing adult whitefly as the first generation of Encarsia commenced hatching, which normally coincides with introducing the bankers, this treatment was delayed until the plants were moved into the crop. In the meantime the whitefly were able to lay far too many eggs on the young foliage. These developed and were not all parasitized so that, three to four weeks after introducing the bankers there was an upsurge in the number of adult whitefly maturing. The tops of the bankers were sprayed with Pynosect in late December and they were then decapitated to try and remove the developing whitefly. However, by this time the situation was out of control and the project was abandoned.

A second batch of banker plants was successfully raised at the HAS during January and February to gain further experience with the production technique.

1981

The treatments and results of the trial at the HAS are summarized in Table 30.

In the east block the combination of earlier whitefly, low night temperatures and poorer banker plants led to failure and the project had to be abandoned in early May, when whitefly numbers became excessive. In the west block, not only was the crop

Table 30. Results of 1981 banker plant trial at the HAS.

	East Block	West Block
Temperatures:	Low night temperatures (12°C)	Programme temperatures (15°C nights) with thermal screen
Vydate applied:	22 Jan	3 Feb
Bankers introduced: (6/house)	16 Feb	16 Feb
Whitefly present before introduction:	A few	None
First black scales seen: (weeks after *Encarsia* introduction)	9 Mar (3 weeks)	3 Apr (6½ weeks)
Subsequent treatments:	Supplementary *Encarsia* added - 16 Apr. Pynosect fog - 5 May	Pynosect fog - Sept
Summary of the quality of the bankers used in each house: (Scale counts made in May)	Only 2 plants had adequate scales (mean of 100+/leaf, up to leaf 30). 2 had insufficient parasitism (mean of less than 70%/leaf, up to leaf 30).	Adequate scale nos. (mean of 100+/ leaf, up to leaf 30) on 3 (almost 4) plants. All had good parasitism (mean of 70%+/ leaf, up to leaf 30).

apparently free of whitefly until mid-February when bankers were introduced, but the plants used tended to be of better quality than those in the east side of the glasshouse. Additionally, the programme temperatures assisted the development of the pest-parasite interaction in the expected manner. Control was adequate for most of the season and Pynosect fogs were only used from September.

5.2.4 Conclusion

Trials of banker plants in Guernsey during the past three years have produced results varying from complete failure to good whitefly control. In each case, however, the results have apparently been explicable. The failures have resulted from poor quality banker plants or unfavourable conditions such as low night temperatures. The successes have followed the use of satisfactory bankers where only low initial whitefly infestations existed.

The 1979 and 1980 trials emphasized the care required in achieving a well balanced pest-parasite interaction on the banker and the critical timing needed to achieve sufficient parasitism to avoid introducing excessive numbers of whitefly into the crop. Nevertheless, with sufficient experience, good banker plants can be produced. It may well be advisable to over-produce to a greater extent than in 1981 at the HAS, and to select only the best plants. Alternatively, where parasitism is good, but overall scale numbers are low, the density of bankers in the crop could be increased.

It was unfortunate that the 1980 trial was unsuccessful. The firm involved had hoped to develop bankers commercially had the programme succeeded. It was unwise to have experimented on such a large scale in the first year, without previous experience of the

technique. An extra year of development may have paid future dividends. In the event there is now no commercial interest in banker plant production in Guernsey. It is unlikely that individual growers would use the method owing to the extra facilities required and their lack of experience with the parasites. This is unfortunate as banker plants, when used correctly, do appear to afford a useful method of biological control in the island. In the UK, there are no commercial growers using bankers, principally because it has not been strongly advocated, in order to avoid undercutting the commercial parasite rearing companies (Hussey, pers. comm.).

5.3 MINI-BANKERS

5.3.1 Introduction

The classical theory of biological control involves artificial creation of a balanced pest-parasite interaction in the crop. In this way a controlled low density pest population is maintained and any invasion of pests from outside is absorbed and contained by natural enemies already present. Growers are reluctant to use the system as they resist the idea of infesting their crop themselves. Banker plants involve the simultaneous introduction of pest and parasite as an existing, high density interaction on a few plants raised elsewhere. Results with bankers look encouraging, but their production is not easy and requires additional facilities unavailable to most growers.

The concept of 'mini-bankers' was an attempt to overcome the inconvenience of banker plant production, while maintaining the benefit of a known, controlled pest-parasite interaction. It is very similar to the classical 'pest-in-first' method of whitefly infestation

followed by three timed parasite introductions, except that the insects are always introduced on to the same plants rather than being distributed randomly through the crop. This is intended to avoid the problems of parasite dispersal early in the season and to ensure that Encarsia find their target host scales. Also, the name 'mini-banker' would meet with less grower-resistance than the term 'pest-in-first'.

It was decided to try mini-bankers in Guernsey and compare them with conventional bankers and chemical whitefly control. A suitable site was found at a nursery where there were four identical $\frac{1}{4}$ acre glasshouses. One had been used for raising seedlings for the rest of the nursery, and this was allocated to the chemical treatment in case other early-season pests were present. Two rates of mini-bankers were used: a low density of one plant in 48 and a high density of one plant in 12. Bankers were not introduced until late February, when environmental conditions for Encarsia should have begun to improve; Vydate was used as necessary for early pest control.

5.3.2 Materials and Methods

The four glasshouses were treated as follows:

1) Chemical whitefly control;
2) Mini-bankers at a rate of 1 in 48 plants;
3) Mini-bankers at a rate of 1 in 12 plants;
4) Banker plants after Vydate.

The tomato seed for the crop (variety E4884) was sown on 13th November 1980 and the plants were stood out in late December. The crop was grown at programme temperatures.

1) In the chemical treatment there was a low level of whitefly and red spider mite present early in the season for which Vydate was

applied on 9th February. Thereafter, deltamethrin (Decis) was applied as necessary to control whitefly.

2 & 3) the schedule for the mini-bankers was as follows:

29 December 1980: Mini-banker plants labelled and infested with 5 whitefly pupae per plant;

10 January 1981: First parasite introduction (10 black scales per plant);

2 February : Second parasite introduction (10 black scales per plant)

2 March: Third parasite introduction (5 black scales per plant).

4) The banker plants were raised at the HAS (see Section 5.2.2). A single dose of Vydate was applied on 9th February at which time very few whitefly had been found. Six bankers were introduced on 16th February.

5.3.3 Results and Discussion

The treatment and results in this project are summarized in Table 31 and discussed in more detail below.

The mini-bankers were not successful. The parasite introduction schedule failed to coincide with the whitefly development on the plants and the first Encarsia were introduced too late. Consequently, too many whitefly from the first generation matured and a high population built up. Nevertheless, Encarsia established quickly on the mini-bankers and in the lower density treatment (2) it was hoped that there was sufficient parasitism in mid-May to gain control by an integrated programme of Pynosect fogs. This was not successful and Decis had to be used. The high density mini-bankers (3) were abandoned sooner.

Table 31. Summary of treatments and results in 1981 mini-banker trial.

Treatment	Chemicals	Mini-bankers @ 1:48	Mini-bankers @ 1:12	Banker plants
Vydate used:	9 Feb	-	-	9 Feb
Whitefly in:	-	29 Dec (5/plant)	29 Dec (5/plant)	16 Feb (on bankers)
Encarsia in:		19 Jan (10/plant) 2 Feb (10/plant) 2 Mar (5/plant)	19 Jan (10/plant) 2 Feb (10/plant) 2 Mar (5/plant)	16 Feb (on bankers)
First black scales seen: (weeks after Enc. intro.)	-	23 Feb (5 weeks)	23 Feb (5 weeks)	27 Feb (east) (1½ weeks) 6 Apr (west) (7 weeks)
Chemicals vs. w.fly:	Decis - 5 Mar Decis - 1 Apr Decis - approx. monthly from June	Pynosect to tops - 1 Apr 3 Pynosect fogs from mid-May - biological control abandoned for Decis in late May	Pynosect to tops - 25 Mar Pynosect fog - 17 Apr - biological control abandoned for Decis	Pynosect fog - 26 June - biological control abandoned for Decis
Other pests:	Malathion + Decis - 1 Apr vs red spider mite	Red spider mite contained by Phytoseiulus early in season, sprayed later Caterpillar controlled by hand-picking then Dipel (B.thuringiensis).	Red spider mite contained temporarily by Phytoseiulus, out of control by mid-season. Leafhopper early on, declined without treatment.	Red spider mite from mid-June not controlled by Phytoseiulus.

The banker plants looked promising early on and there was very rapid development of black scales on the crop in the east side of the glasshouse, which had more whitefly at the time of banker plant introduction. The black scales spread up the plants well and whitefly was under good control until late June when there was a sudden resurgence of adult whitefly. Despite applying a Pynosect fog, it was decided that biological control had been lost and it was abandoned in July.

The chemical treatment in fact gave the best, and most lasting whitefly control. After one Vydate application and an early application of Decis + malthion for whitefly and red spider mite, the insecticide had to be applied only once every month or so. This illustrates how, when used properly (applied thoroughly at the correct time in the pest's life cycle), chemical control is very effective. In this project it was cheaper, since biological control failed and then had to be cleaned up chemically. However, this does not take into account crop losses through possible pesticide damage to flowers and fruit-set.

Red spider mite was very troublesome. It first occurred in the mini-banker treatments (which were not treated with Vydate) and although introductions of predators kept it under control for some time, the damage was severe by the middle of the season. This pest was first seen in the banker plant house (4) in mid-June and despite prompt introduction of Phytoseiulus, biological control was unsuccessful. The early spray of malathion with Decis in April controlled red spider mite in the chemical treatment (1).

Tomato moth caterpillar occurred in house 2. At first it was removed by hand-picking but it was finally eliminated by a spray

of Bacillus thuringiensis (Dipel). Leafhopper in house 3 appeared potentially serious on the young plants, but the population did not increase. Removal of eggs and nymphs with deleafing may have contained the pest.

Throughout the project the staff at the nursery were most cooperative and avoided deleafing the crop too severely.

5.3.4 Conclusion

This first attempt to establish a larger number of mini-banker plants in the crop, rather than bringing in a few few banker plants already bearing a pest-parasite interaction, was not a success. Consequently, it is unlikely to be tried again. The project failed because the parasite introductions did not coincide correctly with the whitefly development. This shows how difficult it is to plan parasite introductions without being able to adapt to the situation in the glasshouse at short notice. It also illustrates the dire consequences of failing to do so. When planning the experiment, the rate of whitefly development had to be estimated without being able to predict the weather, which affects the duration of the life cycle. Two Encarsia consignments (a few days apart) were produced for each introduction date, to allow for postal delays or variation in whitefly development rate. However, these were also dependent on the weather and parasite emergence failed to coincide with the appearance of third instar scales. Had a closer watch been kept on whitefly development it may have been possible to speed up the Encarsia production and dispatch, but such flexibility would be improbable where growers are dependent on commercial parasite suppliers. Had the parasite introductions been better synchronized with whitefly development, the mini-bankers might have worked, but

the risk of excessive infestation of the crop is one which growers are unlikely to take. Of the arbitrary rates used, the lower density (1 in 48 plants) is probably more realistic, for the infestation rate of five whitefly on every 48th plant (i.e. 1.04 per 10 plants) is nearer the overall threshold density for biological control (1 per 10 plants) than the higher rate of one mini-banker in 12 plants (equivalent to an infestation of 4.16 per 10 plants). Even though neither treatment was a success in this experiment, the higher rate of mini-bankers was abandoned a month sooner than the lower rate.

In this project both banker plants and chemicals gave good whitefly control early in the season. But, once the biological control began to fail, the whitefly population increased too rapidly for remedial measures using short-persistence insecticides to be effective, as too many unparasitized whitefly were hatching. Meanwhile, in the insecticide treatment, 'instant' results were achieved using more persistent materials. This highlights the two contrasting approaches to pest control; biological control is preventative, while chemical control is curative.

Of the two experimental methods of biological control tested in this trial, banker plants are probably 'safer' to use than mini-bankers. With the former, the pest-parasite interaction is established outside the cropping house and any inferior bankers can be discarded, but with the latter, the interaction is initiated in situ, and, as happened here, any imbalances are difficult to rectify. On the other hand, the principle behind mini-bankers was to avoid the need for separate facilities in which to raise bankers which then have to be moved around the nursery as large plants, thus making it a more

practical proposition for the grower. In the event, neither system is likely to be adopted by growers while there are readily available supplies of Encarsia throughout the season from commercial producers.

6 GENERAL DISCUSSION

The objective of this research project was to identify the "Guernsey factor" which caused biological control of whitefly by Encarsia to be so unreliable in the island and to suggest appropriate modifications to the technique to improve the situation. In the event, there is no single factor which can individually be blamed for past failures, rather, it seems to be a combination of features peculiar to the island and its growing practices which additively make biological control more difficult than on the mainland.

The problems were examined under the headings of physical, cultural and chemical factors and will be reviewed in the same order.

Physical Factors

The glasshouse conditions in Guernsey are unique. In an island of approximately 25 square miles (6475 ha) there is the greatest concentration of glasshouses in the British Isles, covering about 7% of the land area. There is a similar density of glasshouses in the South Holland region of the Netherlands, but covering a much larger area. Although there are some very large individual nurseries in the UK, there is nothing like the close proximity of neighbouring nurseries found in Guernsey (Section 2.1.2). Herein lies one of the island's problems. The potential for carry-over of pests from one property to another is great and few growers can consider themselves to be isolated from the influence of their neighbours' practices. Whitefly are ubiquitous in the island, and even if a tomato crop is clean at the start of the season, infestation from outside is almost inevitable as the year progresses.

With the recession in the horticultural industry many small

nurseries in Guernsey have been abandoned and become derelict (Section 2.1.3). Overgrown with weeds, they provide good sites for pests such as whitefly to multiply. Many viable nurseries also harbour whitefly in weeds around the glasshouses. If these were kept down, an important source of infestation would be reduced.

Winters in Guernsey are significantly milder than in the UK or the Netherlands (Section 2.14). Although whitefly are capable of overwintering outdoors in most of Britain, many fewer are likely to be killed by frost in Guernsey than elsewhere, so the reservoir surviving outside the glasshouses is greater and the likelihood of early infestations is increased. This is an important factor for biological control. If whitefly on seedlings and young plants are ignored and allowed to multiply, the threshold density for successful biological control (one adult per ten plants (Section 1.7.2)) is soon reached and without integration of chemicals, Encarsia is unlikely to attain control of the population. Hence, control from an early stage is necessary.

Previously, Encarsia introductions in Guernsey began very early in the season when whitefly were first seen, which often was virtually as soon as the plants were stood out in the cropping house (around late December). In the light of research described in this thesis, this practice is seen to be unlikely to succeed for two reasons; the unfavourable light, temperature and daylength conditions for Encarsia during the winter months, and the harmful effects on the parasite of the γ-HCH applied to the soil for tomato leafminer control. Whereas, in the UK the relative isolation of nurseries enables propagation of seedlings free of whitefly (provided adequate end-of-season hygiene measures are carried out) and consequently, parasite introduction is often unnecessary until later in the season (February-March). Routine early introductions have been practised in the

Netherlands, but there are problems where chemical leafminer control is necessary and this is incompatible with biological control of whitefly (Section 4.31).

Considering the climatic factors in relation to Encarsia performance, there is no intrinsic difference in the light levels or hours of sunshine experienced in Guernsey and in the UK or the Netherlands. However, Guernsey growers have been trying to use the parasites much earlier in the year and there is therefore, more dull weather and shorter daylengths during the period of initial parasite establishment. The lack of sunshine inhibits parasite dispersal while short days reduce the reproductive efficiency of Encarsia (Section 2.2.2).

Accepting, therefore, that parasite introductions are generally worthless before about February (even if temperature boosts were used to enhance dispersal in the absence of sunlight (Section 2.4) daylength conditions are still unfavourable), it is essential that adequate chemical control measures are taken to limit the growth of the whitefly population on young plants until the time that Encarsia can be used successfully. Unfortunately this is the period when the risk of phytotoxicity is greatest, and further research is necessary to find suitable insecticides besides Vydate (oxamyl) and Pynosect (pyrethrum, resmethrin) for early whitefly control.

Cultural Factors

The usual system for growing tomatoes in Guernsey is planted in peat modules and trained in a modified Guernsey arch (Section 3.1). In the UK there is a wider range of growing media, namely, border soil, peat troughs or modules and nutrient film technique (NFT) and layering is the commonest training pattern. In the Netherlands most crops are grown in border soil and trained in a Dutch hedge system. The ways in

which the growing medium and training system affect biological control are discussed below.

Soil-applied systemic insecticides function differently in different media. Thus, Vydate, which is widely used in Guernsey, is taken up rapidly by the plant and provides long-term protection against whitefly when used on border soil, but is bound to the organic matter in peat modules and is thus much less effective. Yet, it cannot be used in NFT because the toxic residues in fruit remain too high even several weeks after treatment. Thus the period between Vydate application and Encarsia introduction will depend on the growing medium (Section 4.2). The insecticide is harmful to the parasite both through direct killing of host scales and the production of toxic honeydew by scales which survive the treatment or take some time to die. Hence parasites introduced immediately after Vydate treatment are likely to perish. However, in peat modules, the effect of the insecticide against whitefly is uneven through the crop and short-lived, and parasites need to be introduced one or two weeks after treatment to parasitize remaining scales. On a border soil crop the chemical is more effective and introduction can be deferred for a further week or two to allow for dissipation of the toxic residues.

The Guernsey arch training system makes the management of biological control more difficult than in a layered crop (Section 3.1). Ideally, in an integrated control system the grower needs to inspect the tops of the plants and, if necessary, make remedial sprays of insecticides to kill excess adults without harming Encarsia beneath (Section 1.7.3). In a layered crop the tops of the plants are always accessible, but once they have crossed the wires in the Guernsey arch system, this becomes virtually impossible, except for occasional

opportunities later in the season. Hence the Guernsey grower needs to be especially vigilant and treat any patches of whitefly before the tops of the plants cross the rows.

Deleafing practices can be critical for biological control, especially during the initial period of parasite establishment. Conservative deleafing is essential to avoid discarding a large proportion of black scales before they emerge (Section 3.2). Preservation of deleafed foliage on the paths for a few days can overcome the problem of over-leafing, but is impractical for many growers. The severity of deleafing tends to be governed by the training system. High-wire layering is much the easiest system where extra foliage is to be kept on the plants, for there is no need to strip the stem in order to drop the plants on to their supporting wires each week, as there is with low-wire layering. There is a tendency for more severe deleafing with a Guernsey arch system for it is easier to trim and tie the tops of the plants where the stems of the neighbouring row are stripped and the grower can see through them to work. However, this is unfavourable for Encarsia establishment.

The other way in which the training system affects biological control is in the light loss beneath the leaf canopy of a Guernsey arch crop. The reduced penetration of sunlight would reduce its beneficial effects from radiant heat on parasite dispersal, while in a layered or Dutch hedge crop there is more penetration of, and hence more benefit from, short spells of spring sunshine to stimulate parasite dispersal.

Although there is little experimental evidence for varietal differences in biological controlon tomatoes, in terms of the development of the whitefly-parasite interaction, the form of the plant in

different varieties may indirectly affect biological control. A small, open-leaved variety would be favourable, for not only would there be more penetration of light through a less dense leaf canopy, but also deleafing need not be so severe in order to make the fruit visible for picking, so more black scales could emerge *in situ*.

The other cultural factor which has recently arisen is the of early sowing and low night temperatures at Stage III as energy saving measures. Although they may not have contributed to difficulties with biological control in Guernsey in the past, they cannot now be ignored, in the context that earlier sowing increases the likelihood of whitefly infestations on seedlings (Section 3.3), and hence the need for early control, while the reduction in night temperatures and extension of the Stage III period increases the time taken for *Encarsia* to establish (Section 3.4). In fact, the results showed that biological control was virtually impossible without chemical integration before about February and it would seem pointless to incur expense in buying parasites before then. However, whitefly must be controlled early in the season if *Encarsia* are to succeed when introduced later.

Chemical Factors

The suitability of various chemicals for integration with natural enemies applies in all locations. There are, however, certain factors which are a special problem in Guernsey. Unusually high mortality of *Encarsia* introduced after Pynosect use prompted re-investigation of the persistence of the insecticide (Section 4.4). It was found that this was much longer in subdued light than in sunlight when it is innocuous to parasites only four days after spraying. Where growers used *Encarsia* very early in the season when there was little or no sunlight, Pynosect was more persistent and therefore,

probably harmful rather than safe, and this may have contributed to the failure of biological control in some cases.

In both Guernsey and the Netherlands, tomato leafminer is a common pest. Recently in the Netherlands, its increasing incidence has resulted in a decline of biological control on tomatoes because insecticides used against it upset the action of natural enemies (Section 4.3.1). In Guernsey, where there is little soil sterilization, the standard precautionary measure for leafminer control is γ-HCH applied to the soil surface before laying down polythene at the start of the season. After suspicions were raised about the effects of this practice on Encarsia, experiments were conducted to examine the detrimental effect of γ-HCH beneath polythene on Encarsia (Section 4.3). A harmful fumigant action which reduced parasite dispersal was demonstrated. Formerly an excessive rate of γ-HCH was recommended in Guernsey which must have exacerbated the problem, but even at the correct dosage the effect lasts for almost two months, especially during the winter before venting commences and the air-changes increase. This factor provides another reason for delaying Encarsia introductions until the spring by which time the effects of γ-HCH should have dissipated.

Vydate is widely used in Guernsey (Section 4.2.1) against leafminer as well as red spider mite, whitefly and secondary pests which increase in incidence with the reduced usage of broad-spectrum insecticides and adoption of biological control techniques. The effects of Vydate on Encarsia usage were discussed earlier. In the UK leafminer is very uncommon and hence, biological control is unaffected by the use of γ-HCH. Even if the pest did occur, sterilization of border soil would eliminate the need for γ-HCH on a large proportion of nurseries.

Experimental Methods of Encarsia Introduction

During the three years of the research project, experimental methods of Encarsia introduction were examined in Guernsey. Of these, banker plants (Section 5.2) produced the most promising results, while mini-bankers (a modified pest-in-first system) (Section 5.3) were unsuccessful. However , it is unlikely that individual growers would go to the trouble of producing their own banker plants when parasites are readily available for conventional dribble introductions and the only modifications to Encarsia usage are likely to be in the timing, rates or frequency of introductions.

Alternative Methods of Whitefly Control

Various alternatives to insecticides and Encarsia formosa for whitefly control in tomatoes have been examined. These include insect growth regulators (Van de Veire, 1973; Van de Veire & Degheele, 1974; Van de Veire, Hertveldt & Aerts, 1974; O'Reilly, 1974; Lindquist, 1975, 1977; Ekbom, 1979 a), host plant resistance (Curry & Pimental, 1971 b; Clayberry & Kring, 1974; de Ponti, Pet & Hogenboom, 1975; Harbaugh & Mattson, 1976; de Ponti & Hogenboom, 1980), trap plants such as tobacco (O'Reilly, 1974), repellant plants such as African marigolds (Hills, 1959), yellow sticky traps (Webb & Smith, 1980) and alternative parasites and predators (O'Reilly, 1974; Vet, 1980; Vet, van Lenteren & Woets, 1980). Although some have reduced whitefly populations, none have been commercially viable alternatives to existing techniques.

The only promising development at present is the use of the parasitic fungus, Verticillium lecanii. This is already used for aphid control on chrysanthemums and in cucumber trials, sold as Vertalec, and now a whitefly strain of V. lecanii is being developed (Mycotal)

(Hall & Burges, 1979; Hall, 1981 a,b). As the spores require high humidity for germination, the fungus is suitable for use only in glasshouse crops, but inhibition of mycelial growth at high temperatures (above 30°C) would preclude its use in mid-summer. Trials have produced variable results for whitefly control (using the aphid strain), some unsuccessful (Ekbom, 1979 b) and others more promising (Kanagaratnum, 1980; Kanagaratnum, Hall & Burges, 1981), although repeated sprays were required since, in contrast to results with aphids, there was no natural spread of the fungus through the sedentary scale populations. Nevertheless, the whitefly strain of V.lecanii could well be a useful candidate for integration with Encarsia. Mid-season trials with Mycotal in the Netherlands have produced very promising results this year (1981) (Hussey, pers. comm.) and future developments are awaited with interest.

To summarize, therefore, the factors considered to contribute to the problems of biological control in Guernsey are:

1) The proximity of glasshouses which facilitates movement of whitefly between them;

2) Mild winters which increase whitefly survival outdoors and hence, encourage early infestation;

3) Weeds around nurseries and in derelict glasshouses which provide outdoor and overwintering host plants;

4) The early incidence of whitefly on new crops which necessitates control measures at a time when Encarsia performance is poor in dull weather and short days;

5) The Guernsey arch training system which makes management of biological control more difficult for several reasons: 1) there is a tendency for severe deleafing, 2) once the crop reaches the wires it is difficult

to see adult whitefly at the tops of the plants and to treat them selectively with an insecticidal spray, and 3) the dense leaf canopy reduces penetration of sunlight through the crop and hence reduces parasite dispersal;

6) Energy saving measures which are incompatible with the use of Encarsia early in the season. Early sowing increases the incidence of whitefly on seedlings and low Stage III night temperatures delay parasite establishment to such an extent that biological control is unlikely to succeed;

7) The use of peat modules which reduces the effectiveness of Vydate against whitefly and means that Encarsia introductions cannot be delayed for more than two weeks after the last application, unless other insecticides are used in the meantime;

8) γ-HCH applied to the soil beneath polythene sheeting which has a harmful fumigant action on Encarsia which persists for about two months when there is little or no venting in the early part of the season.

In the light of these findings, several recommendations for the use of Encarsia against whitefly on Guernsey tomatoes can be made:

1) End-of-season clean-up procedures to reduce the carry-over of whitefly on the nursery site from one season to the next. Treatment of the old crop to kill adults before removing the plants from the glasshouse is essential, as well as clearance of weeds from around the perimeter to remove overwintering hosts.

2) Close inspection of seedlings for adult whitefly, and where plants are bought-in, the supplier should be asked to give details of any insecticides used so that the grower is aware of the potential whitefly population that is unlikely to be noticed while handling the plants if

adults have been killed. Systemic insecticides suitable for use on seedlings for whitefly clean-up are currently being investigated at GCRI.

3) Encarsia should not be used before about February. Whitefly control is essential before then to keep populations at a sufficiently low level for Encarsia to succeed subsequently. Pynosect and Vydate are the most suitable materials for this purpose, but more persistent insecticides may be used, provided the risks of phytotoxicity are considered.

4) Once Encarsia introductions begin the parasites should be thoroughly distributed throughout the crop, with special attention to known patches of whitefly infestation. Fortnightly introductions of one parasite per plant have been usual in the past, but in individual cases variations may be necessary in both the introduction frequencies and rates used. For example, if whitefly are scarce a reduced rate of parasites can be used and weekly, rather than fortnightly, introductions are advisable in dull weather when many parasites may perish without having dispersed from their introduction point.

5) Whatever methods are used, regular crop inspection and awareness of whitefly and Encarsia while working in the crop is essential in order to recognise and rectify problems before biological control is lost.

6) Deleafing should not be excessive. If possible, extra foliage should be left on the insides of the double rows, and where leaves with many immature black scales are removed, they should be retained in the glasshouse for a few days.

7) Integration of suitable chemicals with natural enemies when necessary is essential, and failure to do so when adult whitefly build up, can lead to a loss of biological control that might otherwise have satisfactorily maintained.

Success, familiarity and experience with techniques will, no doubt, increase growers' confidence to judge the state of biological control interactions. However, it cannot be emphasized too strongly that biological control is a preventative rather than a curative measure for adult whitefly control and it is important to seek advice before whitefly gets out of hand rather than delay until a purely chemical programme is the only alternative. There are currently, effective chemicals available for whitefly control, to which many Guernsey growers, disillusioned with biological control, have turned. These are very effective if used properly, but are more expensive than successful biological control, both in direct material costs and also in terms of probable crop losses incurred through chemical injury to flowers and fruit-set. Long-term use of synthetic pyrethroids against whitefly is also liable to result in a resurgence of red spider mite. While these chemicals remain effective, there is less dependence on biological control, but when whitefly become resistant to them, as they have to other materials in the past, biological and integrated control will become increasingly necessary. This alone justifies the need to explain past failures in Guernsey and to determine how to obtain reliable results in the future.

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Appendix 1. Programme temperatures for tomato growing.

	Plant maturity	Temperature (°C)		
		Night	Day	Venting
Stage 0 (17-21 days)	Sowing to 7 days after pricking off	18	18	21
Stage I (21-28 days)	Pricking off to first buds visible	16.5	18	26.5
Stage II (14-21 days)	First buds visible to first open flower	15.5	18	26.5
Stage III	First open flower to first pick	16.5	20	26.5
Stage IV	First pick to end of crop	15.5	18	26.5

(From Dempster, 1980)

Appendix 2. Factors apparently unrelated to the success of biological control, as examined by the HAS 1978 survey.

The source of *Encarsia* scales;

The amount of whitefly the previous season;

The date on which *Encarsia* were first introduced;

The type of glasshouse - wood or metal;

The size of panes;

The tightness of the glazing;

Whether single houses or blocks:

The type of heating - pipes or warm air;

The form of carbon dioxide equipment;

The source of water supply - mains, well, borehole, etc.;

The growing system - troughs, modules, soil etc.;

Whether the floor was covered with polythene;

Whether the site was sheltered from, or exposed to, the wind;

Whether the site or neighbouring properties were weedy;

The tomato variety grown;

Whether the plants were bought in or raised by the grower;

The frequency and vigour of hand syringing;

Whether overhead spraylines were used;

Whether γ-HCH was used on the floor of the glasshouse;

Whether Vydate was applied to the crop;

Whether dimethoate was used on the crop;

The number of *Encarsia* introduction points in the glasshouse.

Appendix 3. 1979 biological control survey questions and answers, given as percentages of the 52 participants.

SECTION I: GLASSHOUSE DETAILS

1) Area of glasshouse Under 300' 54% 300-1000' 35% Over 1000' 12%
2) Glasshouse construction: Old wood 29% New wood 21% Metal 50%
3) Condition of glazing: Tight 65% Moderate 20% Leaky 16%
4) Site exposure: Sheltered 60% Moderate 23% Exposed 17%
5) Heating system: 4" pipes 54% 2" pipes 21% Hot air 25%
6) Ability to keep constant temperatures: Good 54% Moderate 17% Variable 29%
7) Temperature relative to programme: Warmer 15% At programme 40% Cooler 44%
8) Polythene on floor: All over 82% Not on paths 16% None 2%
9) γ -HCH used under sheeting: No 51% Yes 49%
10) CO_2 equipment: Paraffin burner outside 48% Paraffin burner inside 37% Bottled gas 6% None 10%
11) Irrigation water source: Well 29% Mains 27% Borehole 13% Other 13% Two sources 17%
12) Weeds on the site (in April): Few 42% Potentially weedy 42% Weedy 15%
13) Weeds in the glasshouse (in April): Few 63% Potentially weedy 29% Weedy 8%

SECTION II: CULTURAL DETAILS

14) Tomato variety: Granadier 54% Sonatine 10% Eurocross BB 8% Angela 6% Sarina 6% Other varieties 12% Mixed varieties 6%
15) Seedling source: Bought in from popagator 63% Raised own in survey house 10% Raised own elsewhere 27%
16) Whiteflies on seedlings: Yes 55% No 45%
17) Date of standing out seedlings*: Week 0 - 5 59% Week 6 - 10 37% Week 11-15 4%
18) Deleafing frequency (days): 7 19% 10 19% 14 44% 21 8% 30 10%
19) Leaves kept on paths (days): 4 37% 2-3 37% 0-1 27%
20) Amount of foliage kept on plants: 6'+ 4% 5-6' 63% 4-5' 33%
21) Deleafing modified for biological control: Yes 62% No 38%
22) Trimming frequency (days): 7 67% 10 27% 14 6%
23) Syringing frequency (in April): Daily 65% 2-4 times per week 23% seldom or never 12%
24) Use of overhead spraylines (in April): Daily 38% 2 -4 times per week 8% At weekends 6% None 37% Not yet 11%

-ctd-

- Appendix 3 continued -

SECTION III: BIOLOGICAL CONTROL

25) Number of years using biological control: 1 27% 2 40% 3 27% 4 2% 5 4%

26) Parasite supply: Fruit Export (cards) 52% Le Huray (tobacco) 35%
Stan Brouard (tobacco) 23%

27) Distribution of introduced parasites in glasshouse:
Throughout 83% Limited (less than 10 pieces per plant) 17%

28) Positioning of introduced parasites: On plants 83% In trays 9%
On wires, in tubes, etc. 8%

29) Frequency of assessing biological control: Frequent 27% Moderate (usually while deleafing, etc.) 45% Seldom 27%

30) Date of first parasite introduction*: Week 0- 5 20% Week 6- 10 27%
Week 11-15 25% Week 16- 20 22%
Week 21-25 6%

31) Age of crop (since standing out) at time of first introduction:
0 - 5 weeks 51% 6 - 10 weeks 25% 11 - 15 weeks 18%
16 -20 weeks 6%

32) Timing of first introduction compared to last season: Earlier 50%
Same 20% Not applicable (first season) 30%

33) Number of parasite introductions made: 2- 3 8% 4- 5 12% 6 43%
7 12% 8 14% 9-10 10% 11-12 2%

34) Date of last introduction*: Week 6-10 2% Week 11-15 0%
Week 16-20 8% Week 21-25 45%
Week 26-30 33% Week 31-35 8%
Week 30+ 4%

35) Biological control situation in April: Good 58% Moderate 25% Bad 6%
Too soon to say 12%

36) Biological control situation in July : Good 37% Moderate 14% Bad 49%

37) Had to abandon biological control: No 62% By end of April 8%
By end of May 15%
By end of June 15%

38) Any fruit wiping by July: Yes 40% No 60%

39) Used Phytoseiulus for red spider: o 86% Yes, successfully 4%
Yes, unsuccessfully 10%

40) Would the grower try banker plants if they were available ? :
Yes 50% No 29%
Maybe if trials are successful 21%

41) Would the grower like more help and advice ? : Yes, 62% No 38%

SECTION IV: CHEMICAL CONTROL

42) Used Vydate: None 35% One dose 12% Two doses 54%

43) Vydate used before or after parasite introduction: None 35%
Before25%
After 40%

-ctd-

-Appendix 3 continued -

44) Use of chemicals against whitefly in relation to first parasite introductions (by April): None 38% Before 29% After 27%
Both before and after 6%

45) Number of sprays or fogs against whitefly (by July):
None 12% 1 21% 2 or 3 13%
4 or 5 10% Many 44%

46) Insecticides used against other insect pests: Yes 67% No 33%

47) Fungicides used: Yes 75% No 25%

* Dates: The dates referred to in weeks are counted from the earliest crop surveyed which was stood out during the week November 12-18th; this is taken as week 1. The time intervals referred to are, therefore, as follows:

Week nos:	1 - 5	6 - 10	11 - 15
Dates :	12 Nov -16 Dec '78	17 Dec - 20 Jan '79	21 Jan - 24 Feb '79
Week nos:	16 - 20	21 - 25	26 - 30
Dates :	25 Feb -31 Mar '79	1 Apr - 5 May '79	6 May - 9 Jun '79
Week nos:	31 - 35		
Dates	10 Jun -14 July '79		

Appendix 4. Mean numbers of scales per six-leaf section for each tomato variety (means of 8 plants).

Leaf section:		1-6	7 - 12	13-18	19-24	31-36
Variety	Scales					
+Cudlow Cross	Black	63.29	601.71	535.25	110.29	53.17
	White	13.43	225.43	176.00	63.57	33.17
	% para.	82.5%	72.7%	75.3%	63.4%	61.6%
Euro-cross BB	Black	63.63	602.25	528.25	178.43	57.13
	White	15.25	200.88	205.38	99.14	44.25
	% para.	80.7%	75.0%	72.0%	64.3%	56.4%
Gannet	Black	93.38	712.63	439.50	145.88	66.13
	White	29.00	259.63	180.25	91.13	50.63
	% para.	80.8%	73.3%	70.9%	61.6%	69.2%
Grenadier	Black	94.38	589.38	406.75	190.63	167.38
	White	22.38	188.38	182.38	109.88	133.00
	% para.	80.8%	75.8%	69.0%	63.4%	55.7%
Nemato	Black	71.75	442.38	326.63	89.13	69.71
	White	27.88	195.63	124.13	49.00	50.14
	% para.	72.0%	69.3%	72.5%	64.5%	58.2%
*(Sarina)	Black	(88.25)	(565.63)	(233.25)	(389.15)	(216.75)
	White	(39.25)	(306.38)	(99.00)	(142.88)	(96.63)
	% para.	(69.2%)	(64.9%)	(70.2%)	(73.1%)	(69.2%)
+Sarina	Black	73.71	471.00	139.71	55.43	39.14
	White	34.71	301.86	88.71	53.88	49.43
	% para.	68.0%	60.9%	61.2%	50.7%	44.2%
Sonatine	Black	107.50	607.00	209.63	155.63	156.75
	White	48.88	260.25	84.25	96.88	150.63
	% para.	68.7%	70.0%	71.3%	61.6%	51.0%
Sonato	Black	96.38	622.50	312.50	98.88	80.25
	White	36.00	213.50	118.13	62.13	59.25
	% para.	72.8%	74.5%	72.6%	61.4%	57.5%

\+ 7 plants

* Figures in brackets include scale numbers on the discrepant plant (see text)

Appendix 5. Counts of numbers of surviving shitefly after caging ± 10 adults for three-day intervals at the tops of tomatoes in peat modules treated with different rates of Vydate.

Days after first dose:		6	9	12	15	18	21	24	27	30	33	36
Days after 2nd dose :						3	6	9	12	15	18	21
Vydate dose	Plant No											
0g per plant	2	10	6	10	9	10	14	*	6	11	8	*
	5	10	*	11	7	8	8	7	10	10	10	9
	8	9	8	9	9	9	8	8	9	11	9	9
	11	8	9	7	9	9	9	8	8	9	8	8
	14	9	*	9	8	10	7	7	8	10	11	8
	17	9	10	9	9	11	5	8	9	9	11	8
	20	9	11	10	8	10	9	9	11	11	10	10
	23	10	9	9	11	11	10	7	9	9	9	9
	26	9	9	9	7	10	8	8	6	10	10	8
	29	8	10	7	6	*	11	*	4	11	7	8

* Insects escaped

- ctd-

- Appendix 5 continued-

Days after first dose:		6	9	12	15	18	21	24	27	30	33	36
Days after 2nd dose:						3	6	9	12	15	18	21
Vydate dose	Plant No											
1 x 0.5 g per plant	1	1	4	8	7							
	2	0	0	5	10	9	9	6	8	9	8	8
	3	0	2	8	*							
	4	1	0	6	8							
	5	0	1	4	8	9	9	9	6	8	8	9
	6	0	1	8	10							
	7	2	3	4	11							
	8	0	1	6	6	11	9	7	9	10	8	10
	9	0	1	6	9							
	10	2	4	6	7							
	11	1	1	9	9	9	7	9	8	9	9	8
	12	1	2	7	11							
	13	1	3	6	8							
	14	1	7	6	8	8	8	9	8	10	9	10
	15	0	6	4	7							
2 x 0.5g per plant	1	0	2	8	11	3	2	7	10			
	2	0	1	6	9	5	5	7	9	*	9	10
	3	0	4	4	10	2	8	7	7			
	4	0	1	10	10	10	5	9	7			
	5	2	5	9	9	10	4	3	9	8	10	9
	6	2	5	10	7	7	3	7	9			
	7	0	0	4	8	6	2	5	9			
	8	*	0	10	9	6	5	5	9	9	9	10
	9	1	0	7	10	6	4	8	10			
	10	1	5	11	6	7	5	5	10			
	11	4	*	2	8	7	4	6	7	10	9	8
	12	0	3	7	9	9	9	6	6			
	13	0	*	8	10	7	8	7	11			
	14	1	4	10	9	10	4	10	11	11	9	10
	15	1	4	7	10	*	7	7	7			

* Insects escaped

-ctd-

- Appendix 5 continued -

Days after first dose:		6	9	12	15	18	21	24	27	30	33	36
Days after 2nd dose :						3	6	9	12	15	18	21
Vydate dose	Plant No.											
1 x 1.0g per plant	1	0	2	4	9	5	6					
	2	0	0	4	9	7	11	7	7	11	10	8
	3	0	1	3	*	11	5					
	4	0	1	5	5	7	8					
	5	0	0	6	8	7	8	10	7	10	10	8
	6	0	*	2	10	6	8					
	7	0	0	8	9	10	6					
	8	0	4	9	4	7	9	7	9	7	9	8
	9	0	3	3	5	7	7					
	10	0	0	5	*	7	12					
	11	1	0	4	6	11	10	7	7	9	9	8
	12	2	*	2	4	7	10					
	13	0	0	3	4	6	7					
	14	0	0	5	5	7	7	7	9	10	10	9
	15	1	0	3	3	8	9					
2 x 1.0g per plant	1	0	0	2	7	0	1	3	4	*	7	
	2	1	0	1	7	2	1	4	5	7	9	10
	3	0	1	7	5	7	2	6	6	5	7	
	4	0	0	3	6	4	4	5	5	6	10	
	5	0	0	2	8	5	3	2	9	10	10	8
	6	1	0	8	9	1	1	0	6	4	8	
	7	0	0	3	4	2	0	4	6	6	10	
	8	0	0	0	9	3	6	7	6	9	9	9
	9	0	0	2	6	2	4	6	3	5	7	
	10	0	3	8	8	7	7	3	9	5	11	
	11	0	0	0	6	2	0	5	5	7	4	10
	12	0	1	1	8	7	4	1	8	7	9	
	13	0	0	2	7	2	2	7	4	7	10	
	14	0	2	6	6	7	4	4	3	7	9	10
	15	1	0	5	5	0	2	6	6	9	8	

* Insects escaped

-ctd

-Appendix 5 continued-

Days after first dose:		6	9	12	15	18	21	24	27	30	33	36
Days after 2nd dose :						3	6	9	12	15	18	21
Vydate dose	Plant No											
1 x 2.0g per plant	1	1	1	5	1	7	9	8	10	9		
	2	0	0	0	1	2	8	4	9	9	10	7
	3	0	0	4	1	6	10	9	6	9		
	4	0	0	1	5	5	11	9	8	8		
	5	0	2	0	7	7	6	6	6	10	10	7
	6	1	3	2	7	5	9	6	7	9		
	7	0	0	5	2	4	11	4	5	8		
	8	0	1	0	3	2	9	4	10	8	8	6
	9	1	0	0	2	1	5	5	9	8		
	10	0	0	1	3	4	3	2	9	7		
	11	0	0	1	2	6	8	4	8	10	8	8
	12	0	4	4	2	5	7	5	6	10		
	13	0	0	2	5	5	10	6	7	8		
	14	0	0	3	0	5	5	5	6	10	8	7
	15	0	1	3	4	4	7	9	8	7		
2 x 2.0g per plant	1	0	0	5	3	2	3	4	5	5	7	7
	2	0	0	1	7	1	1	0	2	2	6	9
	3	0	0	3	5	2	2	3	3	3	6	9
	4	0	0	5	6	3	0	2	4	6	8	9
	5	0	0	2	3	1	0	4	2	7	8	7
	6	0	0	1	4	0	3	1	5	7	8	9
	7	0	0	0	0	3	0	0	1	7	8	6
	8	0	0	1	3	1	1	*	5	3	8	7
	9	0	0	3	5	2	0	3	4	6	8	9
	10	0	0	0	7	0	0	1	4	5	7	6
	11	1	1	4	1	1	0	2	1	5	4	6
	12	0	0	3	5	2	1	1	2	5	7	10
	13	0	1	3	3	0	2	0	3	7	5	8
	14	0	0	1	2	3	4	1	2	4	6	7
	15	0	0	4	2	0	1	1	2	1	0	4

* Insects escaped

Appendix 6. Counts of whitefly stages on leaflets from every third leaf up tomato plants treated with Vydate at five-day intervals after Encarsia introduction. (Totals from three leaflets per count)

L = live D = dead

i) 5-day treatment

Leaf	Date	Eggs	1sts L	1sts D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	4	5		12		12		3				
	14/12	0	2	1	3	0	0	1	8	0	5	7	
	17/12	2	0	1	0	1	0	1	12	6	16	2	
	30/12	0	0	10	0	0	0	1	0	9	6	5	1
	10/1	0	1	8	0	1	0	2	0	3	3	1	7
6	3/12	3	29		15		36		42				
	14/12	2	4	6	23	6	36	2	66	1	2	4	
	17/12	3	1	18	0	19	0	11	34	3	1	2	
	30/12	0	0	23	0	33	0	20	3	27	1	2	
	10/1	1	0	18	0	18	0	29	0	35	6		
9	14/12	1	46	7	12	12	4	2	5	0			
	17/12	4	0	19	0	13	0	2	1	0			
	31/12	0	0	27	0	16	0	5					
	10/1	0	0	49	1	17	0	4	1	0			
12	17/12	8	3	18									
	31/12	0	0	31	0	2							
	10/1	0	0	18									
15	31/12	0	0	14									
	10/1	0	0	0									
18	10/1	0	0	0									

-ctd-

- Appendix 6 continued-

ii) 10-day treatment

Leaf	Date	Eggs	1sts L	1sts D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	16	18		25		17		16				
	14/12	2	0	1	5	4	8	0	25	0	29	10	
	19/12	4	0	9	1	4	1	1	29	0	38	35	
	30/12	3	0	12	0	4	0	1	0	17	24	5	7
	11/1	2	2		5		3		14		77	7	13
6	3/12	12	36		79		61		30				
	14/12	4	19	5	14	7	46	7	121	0	2		
	19/12	15	4	15	1	9	3	17	115	0	39	5	
	30/12	0	0	11	0	31	0	24	15	54	34	14	
	11/1	0	10		29		36		69		64	12	15
9	14/12	4	19	0	32	5	14	1	3	0			
	19/12	10	10	12	8	11	6	0					
	31/12	0	0	19	0	7	0	3	1	4			
	11/1	2	44		15		5		4				
12	19/12	41	10	8									
	31/12	3	2	23	0	3							
	11/1	3	9										
15	31/12	1	9	54									
	11/1	3	19										
18	11/1	1	13										

-ctd-

-Appendix 6 continued -

iii) 15-day treatment

Leaf	Date	Eggs	1sts L	1sts D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	0	16		41		45		15				
	14/12	1	1	1	1	4	7	1	71	1	18	18	
	19/12	5	2	3	0	1	1	1	12	0	35	15	
	30/12	0	0	1	0	2	0	0	6	8	31	8	2
	15/1	1	8		1		4		5		48	1	33
6	3/12	11	53		98		65		67				
	14/12	2	12	3	13	8	19	6	180	1	20	30	
	19/12	9	1	10	2	4	10	3	65	0	76	25	
	30/12	2	0	5	0	9	0	7	17	26	85	30	6
	15/1	0	13		10		10		56		99	18	33
9	14/12	0	5	2	35	7	20	2	26	0	1		
	19/12	23	9	4	7	2	11	0	19	0			
	31/12	0	2	27	1	17	0	15	23	17	8	2	
	15/1	0	61		30		38		40		12	14	
12	19/12	32	93	21	17	1	4	0					
	31/12	7	1	57	0	16	0	6	1	0			
	15/1	0	87										
15	31/12	4	10	108									
	15/1	3	100		11								
18	15/1	0	148										

-ctd-

- Appendix 6 continued-

iv) 20-day treatment

Leaf	Date	Eggs	1sts L	1sts D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	43	62		71		36		6				
	14/12	2	9	6	32	4	37	2	121	2	10	1	
	19/12	11	1	15	1	7	3	4	46	1	83	16	
	30/12	2	0	0	0	2	0	2	11	7	61	33	
	15/1	1	6		5		2		8		50	4	47
6	3/12	19	57		85		78		13				
	14/12	7	23	4	29	6	43	2	139	0	4		
	19/12	6	1	7	3	6	10	6	134	0	26	4	
	30/12	11	0	26	7	40	2	29	114	15	82	18	
	15/1	0	68		37		42		69		2	8	
9	14/12	2	71	13	63	4	10	0	18	0			
	19/12	12	43	7	33	9	27	1	1	0			
	31/12	16	8	9	4	12	25	17	67	8	7		
	15/1	1	68		37		42		69		2	8	
12	19/12	11	155	15	11	8	1	0					
	31/12	18	2	73	0	62	0	17					
	15/1	0	119		75		20		2		1	1	
15	31/12	145	26	125	0	7	0	5					
	15/1	2	316		3		2						
18	15/1	5	913										

-ctd-

- Appendix 6 continued-

v) 25 day treatment

Leaf	Date	Eggs	1st L	1st D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	3	15		37		58		28				
	14/12	5	7	4	6	3	1	2	62	0	35	24	
	19/12	18	0	4	0	5	0	5	31	1	45	15	
	30/12	4	3	6	0	9	0	10	9	4	48	19	3
	15/1	0	16		0		1		7		33	10	12
6	3/12	19	29		83		92		9				
	14/12	1	7	5	34	3	25	1	81	0	3		
	19/12	16	6	19	12	11	12	19	114	2	21	1	
	30/12	26	1	17	1	12	1	45	114	2	53	11	
	15/1	0	27		26		22		42		80	38	35
9	14/12	7	66	0	48	0	9	0	17	0			
	19/12	8	35	9	41	9	39	1	9	0			
	31/12	24	4	13	3	16	2	19	66	0	4		
	15/1	2	52		21		17		67		8	36	
12	19/12	19	72	9	15	4	2	0					
	31/12	42	33		13		21		12				
	15/1	4	68		18		25		5		1		
15	31/12	110	82		11		1						
	15/1	9	148		3								
18	15/1	0	445		2								

-ctd-

-Appendix 6 continued-

vi) Control - untreated

Leaf	Date	Eggs	1st L	1st D	2nds L	2nds D	3rds L	3rds D	4ths L	4ths D	Emerged pupae	Black scales	Emerged blacks
3	3/12	1	23		28		39		16				
	14/12	6	0	3	0	3	2	1	60	0	32	13	
	20/12	7	0	5	0	5	0	3	37	2	21	35	
	30/12	6	0	6	0	1	0	1	4	0	32	12	2
	11/1	0	12		11		0		4		18	18	11
6	3/12	5	109		91		48		4				
	14/12	0	9	4	35	5	40	1	92	0	0	1	
	20/12	13	6	4	4	3	10	3	74	0	5	4	
	30/12	13	2	28	4	9	7	13	77	0	37		
	11/1	9	38		17		18		31		79	62	5
9	14/12	2	32	0	33	0	3	0					
	20/12	15	19	2	17	0	13	1	5	0			
	31/12	56	2	12	4	2	6	8	29	0	5		
	11/1	3	7		8		9		32		32	42	
12	20/12	10	30	6	3	0	2	0					
	31/12	17	19		18		10						
	11/1	10	25		9		9		26		0	4	
15	31/12	58	34										
	11/1	50	113		23		7						
18	11/1	60	103		12		128						

Appendix 7. Counts of dead (D) and live (L) Encarsia confined on honeydew collected from whitefly scales on tomato plants treated with different rates of Vydate (Section 4.2.3c)

(i) 0g Vydate per plant

Collection period (hours)		0 - 24						24 - 48						48 - 72					
Assessment time (hours)		24		48		72		24		48		72		24		48		72	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
Rep.	Sample																		
	1	2	8	7	3	10	0	2	8	7	3	8	2	3	7	4	6	7	3
I	2	2	8	8	2	9	1	1	9	2	8	4	6	1	9	2	8	5	5
	3	0	10	2	8	4	6	1	9	3	7	6	4	2	8	3	7	3	7
	1	2	8	4	6	4	6	2	9	4	6	6	4	1	9	1	9	1	9
II	2	1	9	3	7	3	7	1	9	2	8	5	5	1	9	2	8	2	8
	3	0	10	1	9	4	6	0	9	2	7	2	7	1	9	1	9	2	8
	1	1	9	*		*		0	10	1	9	4	6	*		*		*	
III	2	0	10	1	9	7	3	0	9	2	7	4	5	1	7	1	7	1	7
	3	2	8	3	7	4	6	0	11	3	8	6	5	1	9	2	8	4	6
	1	1	9	1	9	2	8	1	9	1	9	5	5	1	9	1	9	2	8
IV	2	0	10	2	8	2	8	0	10	0	10	2	8	0	10	1	9	2	8
	3	1	9	1	9	1	9	0	10	0	10	1	9	0	10	2	8	3	7
	1	0	10	1	9	1	9	0	10	0	10	0	10	1	10	1	10	1	10
V	2	0	10	0	10	1	10	1	9	1	9	1	9	0	10	1	9	1	9
	3	0	10	0	10	0	10	0	10	3	7	3	7	0	10	0	10	0	10
	1	1	8	1	8	1	8	0	10	0	10	0	10	0	11	0	11	0	11
VI	2	1	8	1	8	2	7	*		*		*		0	10	0	10	0	10
	3	0	10	0	10	0	10	0	10	0	10	0	10	0	11	0	11	0	11

* Insects escaped

-ctd-

- Appendix 7 continued-

(ii) 0.33g Vydate per plant

Collection period (hours)		0 - 24						24 - 48						48 - 72					
Assessment time (hours)		24		48		72		24		48		72		24		48		72	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
Rep.	Sample																		
	1	2	8	8	2	10	0	6	4	9	1	10	0	2	8	3	7	7	3
I	2	3	7	7	3	10	0	6	4	10	0	10	0	4	6	6	4	7	3
	3	4	5	6	3	9	0	3	7	9	1	10	0	1	9	3	7	7	3
II	1	10	0	10	0	10	0	0	10	4	6	7	3	9	1	9	1	10	0
	2	7	3	9	1	10	0	6	4	8	2	9	1	2	8	3	7	6	4
	3	5	5	8	2	9	1	1	9	6	4	7	3	1	9	4	6	5	5
	1	3	7	5	5	10	0	4	6	6	4	10	0	7	3	7	3	7	3
III	2	3	8	8	3	11	0	2	8	6	4	10	0	5	6	9	2	9	2
	3	4	6	4	6	10	0	2	7	6	3	8	1	5	5	6	4	7	3
	1	0	10	8	2	9	1	1	9	1	9	2	8	1	10	3	8	4	7
IV	2	3	7	6	4	7	3	2	8	3	7	4	6	0	10	0	10	4	6
	3	1	9	3	7	9	1	*		*		*		1	8	5	4	8	1
	1	8	2	10	0	10	0	3	7	7	3	10	0	10	0	10	0	10	0
V	2	8	2	10	0	10	0	8	2	10	0	10	0	6	4	8	2	10	0
	3	10	0	10	0	10	0	1	9	5	5	9	1	8	2	9	1	10	0
	1	0	9	0	9	1	8	*		*		*		0	11	6	5	10	1
VI	2	0	10	3	7	5	5	3	7	8	2	10	0	0	11	8	3	11	0
	3	2	9	11	0	11	0	3	6	4	5	4	5	3	7	5	5	10	0

* Insects escaped

-ctd-

- Appendix 7 continued -

(iii) 0.67 g Vydate per plant

Collection period (hours)		0 - 24						24 - 48						48 - 72					
Assessment time (hours)		24		48		72		24		48		72		24		48		72	
		D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
Rep.	Sample																		
	1	4	6	10	0	10	0	6	4	8	2	9	1	3	8	5	6	5	6
I	2	0	6	0	6	5	1	1	9	1	9	5	5	2	8	6	4	7	3
	3	*		*		*		2	8	6	4	9	1	7	3	9	1	9	1
	1	7	3	10	0	10	0	1	9	2	8	2	8	1	11	5	7	5	7
II	2	7	2	10	0	10	0	3	7	4	6	4	6	1	8	1	8	2	7
	3	8	2	10	0	10	0	0	10	2	8	6	4	1	9	3	7	3	7
	1	4	8	9	3	12	0	1	9	4	6	8	2	3	7	5	5	5	5
III	2	1	9	6	4	10	0	2	8	6	4	10	0	6	4	8	2	8	2
	3	4	6	8	2	9	1	6	4	7	3	9	1	6	3	7	2	7	2
	1	3	7	5	5	5	5	3	7	4	6	6	4	0	10	2	8	3	7
IV	2	2	8	10	0	10	0	1	9	1	9	1	9	0	9	1	8	5	4
	3	0	10	7	3	9	1	0	10	3	7	3	7	0	10	0	10	0	10
	1	6	4	8	2	9	1	2	8	5	5	8	2	2	8	7	3	9	1
V	2	1	9	3	7	8	2	0	10	3	7	9	1	1	9	5	5	6	4
	3	4	6	9	1	10	0	0	10	2	8	6	4	3	8	9	2	9	2
	1	2	7	3	6	4	5	1	9	1	9	4	6	0	12	3	9	8	4
VI	2	2	8	4	6	7	3	0	10	0	10	0	10	1	9	2	8	3	7
	3	0	9	0	9	2	7	0	11	0	11	0	11	6	4	10	0	10	0

-ctd-

- Appendix 7 continued -

(iv) 1.0g Vydate per plant

Collection period (hours)		0 - 24						24 - 48						48 - 72					
Assessment time (hours)		24		48		72		24		48		72		24		48		72	
Rep.	Sample	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L	D	L
I	1	4	6	7	3	9	1	0	10	6	4	9	1	3	5	4	4	5	3
	2	1	6	5	2	7	0	7	3	10	0	10	0	3	7	4	6	5	5
	3	2	7	7	2	9	0	5	5	10	0	10	0	1	9	5	5	6	4
II	1	3	7	9	1	10	0	5	5	6	4	9	1	0	10	0	10	0	10
	2	8	2	9	1	10	0	1	9	5	5	5	5	1	9	2	8	2	8
	3	8	2	9	1	10	0	0	10	3	7	4	6	0	10	2	8	2	8
III	1	3	7	10	0	10	0	2	8	6	4	8	2	0	10	2	8	3	7
	2	2	9	6	5	10	1	3	7	8	2	9	1	6	5	6	5	8	3
	3	8	2	8	2	10	0	4	6	4	6	5	5	4	6	5	5	6	4
IV	1	1	9	4	6	6	4	1	9	2	8	2	8	1	9	2	8	2	8
	2	7	3	10	0	10	0	0	10	0	10	1	9	1	10	1	10	1	10
	3	3	7	5	5	6	4	2	8	3	7	3	7	1	9	1	9	3	7
V	1	7	3	10	0	10	0	1	9	7	3	8	2	5	5	8	2	8	2
	2	3	5	6	2	8	0	1	9	4	6	9	1	3	7	8	2	10	0
	3	3	7	7	3	10	0	2	8	4	6	8	2	3	7	4	6	4	6
VI	1	2	8	4	6	6	4	0	10	5	5	8	2	4	6	7	3	10	0
	2	2	7	3	6	9	0	0	10	1	9	3	7	1	9	2	8	8	2
	3	1	9	2	8	6	4	0	11	0	11	3	8	0	9	0	9	0	9

Appendix 8. Numbers of Encarsia on trap plants in γ-HCH Experiment 1.

Dose rate	Weeks after treat.	Day of count	Trap plant position NE	SE	NW	SW	Total
High	1	1	0	2	1	0	3
		3	3	1	1	1	6
	4	1	0	3	1	2	6
		3	1	1	3	0	5
	6	1	0	0	0	0	0
		3	0	0	0	0	0
	8	1	0	0	0	0	0
		3	0	0	0	0	0
	10	1	0	0	0	0	0
		3	0	0	0	0	0
	12	1	5	2	1	2	10
		3	7	3	1	2	13
Low	1	1	1	1	0	1	3
		3	7	3	3	7	20
	4	1	1	1	4	1	7
		3	8	14	13	13	48
	6	1	0	0	0	0	0
		3	0	0	2	0	2
	8	1	0	0	0	0	0
		3	0	0	1	1	2
	10	1	2	0	2	1	5
		3	2	3	3	3	11
	12	1	5	1	0	2	8
		3	11	8	2	12	33
None	1	1	3	1	5	0	9
		3	7	15	27	15	64
	4	1	0	0	1	1	2
		3	12	21	20	17	70
	6	1	3	0	0	0	3
		3	5	1	0	2	8
	8	1	0	1	2	1	4
		3	2	2	2	7	13
	10	1	1	2	0	2	5
		3	3	5	3	9	20
	12	1	0	2	0	3	5
		5	5	5	5	12	27

Appendix 9. Numbers of Encarsia on trap plants in γ-HCH Experiment 2.

Dose rate	Weeks after treat.	Day of count	Trap plant position NW	nrNW	nrNE	NE	SW	nrSW	nrSE	SE	Total
High	1	1	0	0	0	0	0	1	0	0	1
		3	0	0	0	0	0	0	0	0	0
	3	1	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0
	5	1	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0
	7	1	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0
	9	1	0	0	0	0	0	0	0	0	0
		3	0	1	0	0	0	1	0	0	2
	11	1	0	0	0	0	0	0	1	0	1
		3	3	5	1	9	0	2	0	1	21
	13	1	1	0	0	1	2	1	1	0	6
		3	4	7	2	4	5	5	1	1	29
None	1	1	2	1	0	0	0	3	0	0	6
		3	2	3	2	0	0	7	12	8	34
	3	1	0	0	1	4	1	0	1	0	7
		3	0	2	3	7	1	4	1	3	21
	5	1	2	0	0	0	0	1	0	1	4
		3	5	7	5	3	24	6	18	19	87
	7	1	1	0	0	0	4	0	2	5	12
		3	5	2	5	6	9	1	3	13	44
	9	1	4	0	1	0	0	0	0	0	5
		3	6	0	3	5	2	1	6	12	35
	11	1	5	0	0	1	1	1	1	2	11
		3	17	0	4	8	10	6	6	10	60
	13	1	14	2	1	2	12	2	2	2	37
		3	18	11	8	7	27	2	6	5	84

Appendix 10a. Daily sunshine hours during γ-HCH Experiment 1.

Date					Total	Release Time
December	19th	20th	21st	22nd		
	0	3.8	3.7	0.4	7.9	12.00
January	6th	7th	8th	9th		
	0	3.4	0.1	1.3	4.8	14.00
January	19th	20th	21st	22nd		
	2.6	5.0	0	0	7.6	11.00
February	2nd	3rd	4th	5th		
	0	1.9	5.3	1.0	8.2	15.00
February	17th	18th	19th	20th		
	3.8	1.7	0.7	0.5	6.7	10.00
March	3rd	4th	5th	6th		
	0	3.8	3.2	0.2	7.2	11.00

Appendix 10b. Daily sunshine hours during γ-HCH Experiment 2.

Date					Total	Release Time
January	12th	13th	14th	15th		
	0	5.7	0	2.2	7.9	12.00
January	26th	27th	28th	29th		
	0	0	0	2.2	2.2	12.00
February	9th	10th	11th	12th		
	0	3.0	7.9	1.3	12.2	12.00
February	23rd	24th	25th	26th		
	0	4.2	0.3	0	4.5	10.00
March	9th	10th	11th	12th		
	0	0	0	1.0	1.0	12.00
March	24th	25th	26th	27th		
	0	0	8.2	3.3	11.5	10.30
April	6th	7th	8th	9th		
	1.5	4.7	4.9	3.0	14.1	12.00