A STUDY OF SOME FACTORS AFFECTING THE EFFICIENCY OF ENCARSIA FORMOSA GAHAN, AN APHELINID PARASITE OF THE GREENHOUSE WHITE FLY, TRIALEURODES VAPORARIORUM (WESTW.)

Thesis for the Degree of M. S.

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Herbert E. Milliron

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Thesis

Submitted to the Faculty of the Graduate School of Michigan State College, in partial fulfillment of the requirements for degree of Master of Science

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CONTENTS

REVIEW OF LITERATURE

The life history, habits and host plants of Trialeurodes vaporariorum (Westw.) have been given thorough treatment by several authors. Morrill (19), Hargreaves (12) and Britton (3), have contributed largely to the biology of this insect, while Weber (41), has given the most complete ecological account. Others have added valuable observations and data on the habits and control (10, 17, 29, 31, 33, 34, 40, 43).

The publications of Cockerell (5), and Quaintance and Baker (23), concern the classification of white flies.

No work on the biology of Encarsia formosa Gahan, and nothing regarding the factors which affect the efficiency of the parasite in controlling the greenhouse white fly have been published in the United States to the knowledge of the writer.

Speyer (29), of the Experimental and Research Station, Chestnut-Herts, England, has conducted research on the insect's biology. He has given a good account of the life history and habits. Various workers have been chiefly concerned with the observations of plants they believed to be repellent to the parasite and the extremes in temperature that it could endure, especially low temperatures (7, 30, 31, 33, 43). A few articles (41, 44), are more specific in the discussion of temperature as a factor affecting the

control of the greenhouse white fly by E. formosa.

The literature which treats of environmental factors that affect insect activities, particularly those of parasite and host, is extensive and demonstrates the differential effects of temperature and humidity on the biotic potential * , the host parasite balance and the

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* Sweetman (37, p. 11), patterned his definition of "biotic potential" after Graham (1933). It is "the inherent ability of an organism to reproduce and survive, within a given time, and under optimum environmental conditions." He further states that its values may be divided into a "reproductive potential" which takes into account the number of young, sex ratio, and number of generations; and into the "survival potential" which is concerned with the nutrition and protection.

Chapman (Animal Ecology, 1931, p. 194), terms the opposing value of the above as the "environmental resistance."

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varying internal changes with respect to reproduction. The conclusions reached are not specifically related to this problem but are reviewed because they are analageous.

Payne (21), found that under certain conditions of temperature and moisture, Microbracon hebetor Say was able to control its host, Ephestia kuhniella Zeller. Weber (41), experimenting with what was probably Encarsia formosa, showed that at low temperatures the rate of reproduction of the parasite is much lower than that of its host, T. vaporariorum and thus, it follows that the percentage of parasitism was low and complete control could not be expected.

Webster and Phillips (42), working with Toxoptera graminum Rond. discovered that it was able to oviposit at

slightly below 4.4°C while its principal parasite, Aphidius testaceipes Cress., was inactive below 13.3°C. The biotic potentials at that given set of conditions varied considerably and even the slightest control was out of the question.

The host-parasite balance has likewise been investigated by several workers, a few of whom are Blunk, Bremer and Kaufman (2), Barnes (1), Shelford (27), and Payne (21). The general contention is that the hosts were able to overcome their parasites at low temperatures as a result of the conditions retarding the development of the parasites. The opposite of this has been reported by Ruzicka (26), in the case of the parasites of Porthetria monacha Linn., provided a high humidity accompanies the low temperature.

In two instances noted here, the experiments of Ruzicka (26), and Hefley (13), indicate that the host in each case, was favored by lower humidities than those of its parasite, but probably many more such cases could be found.

Physical factors, whether of climate or of a host, are responsible for stimulating or inhibiting the desire for oviposition and therefore control to some extent the amount of parasitism. The summary of a few physical factors is made by Richardson (24).

Publications dealing with the mathematical treatment and the calculation of percentage of parasitism is limited. Larrimer and Noble (16), have devised a method

whereby the relative percentage of parasitism can be calculated for the parasites of the Hessian Fly, Phytophaga destructor (Say), by using a system of means and standard variation. The formula proposed by Thompson (38), and later improved by Chapman (4), does not provide a means of determining the differential action of environmental factors since the formula alone is intended to calculate the number of generations that are necessary before a parasite can entirely overcome its host, and takes into account only the values expressed by biotic potentials (See footnote, p.2).

Methods of measuring temperature and humidity (28, 11, 6), means of maintaining constant humidities in control cabinets and cages (36), and laboratory equipment (22), were reviewed, but it seemed necessary to devise special methods and procedure for the experiments discussed in this thesis.

THE GREENHOUSE WHITE FLY

Trialeurodes vaporariorum (Westw.)

Synonymy, Origin and Distribution

When Westwood described this insect in 1856, (Gardener's Chronicle, p. 852), he assigned it to Latrielle's genus Aleyrodes, which has been altered by some in spelling to Aleurodes. This genus has been divided into several genera and at various times the insect has been referred to the genus Asterochiton (23), and to the subgenus Trialeurodes (5).

Either Brazil or Mexico is thought to be the original home (5, 23), but since this is not a definitely established fact, it can only be said that the species is probably indigenous to tropical America.

The greenhouse white fly has a general distribution in both Europe and the Western Hemisphere.

Descriptions and Life History

The adult which averages about 1.5 mm. in length, has four wings and is entirely covered with white waxy powder (Fig. 2). The mouth is fitted for piercing and sucking. Males are identical in appearance except that they are smaller.

The average period which constitutes the adult stage is 30 to 40 days (10, 19, 41), and during this time each female lays an average of two eggs per day (41). Varying conditions will affect egg production which account for

the recordings of individual females from 28 to 534 eggs (10, 17, 19).

The eggs are 0.2-.25 mm. long, when first laid, are yellowish green but after 2-4 days (10, 41), they become black, (Fig. 3 and 4). This stage, depending upon the environment, requires from 6-13 days (3, 10, 19, 41).

Eggs are attached to the tissue of the under surfaces of leaves by a short petiole. It is not a common occurrence to find them on the upper surfaces of leaves or attached to the stems. When depositing the eggs, the female uses her beak as a pivot, thus, on smooth-leaved plants, one often observes perfect circles of eggs (Fig. 4). The number of eggs composing each circle varies. It ranged from 21-46 per circle on the fuchsia leaves examined by the author. Half-circles or quarter-circles are frequently found on ageratum leaves; while on such pubescent leaves as hollyhock, Nicotinia spp., tomato and similar plants, the eggs are scattered, because of the interference of hairs with the pivoting movement.

Larval instars (10, 12, 17, 19)

The remainder of the cycle is composed of four instars, the first three of which are known as the larvae; 1st, 2nd, and 3rd. The fourth stadium is often called the pupa, (Fig. 10). A few writers have recognized five separate instars, maintaining that the stadium following the third is in reality the fourth larval stage. For all practical purposes, we may assume there are four instars between the egg and imago, designating the fourth as including the immature

insect from the third molt to the time the adult emerges.

First instar (5-6 days)

The newly hatched larva is oval, flat and transparent light green in color and about 0.29 mm. long. It possesses functional legs and antennae and during the first 2-3 days moves about in search of a suitable place to settle, but seldom wanders farther than a half-inch from its egg-shell. Each lateral margin of the body is provided with 18 spines, graduated in length; the posterior ones being longest.

Second instar (4-6 days) Sedentary

After the first molt, the insect flattens out on the leaf; is more transparent than in the first stage; and is difficult to detect. Legs and antennae are vestigial. The margins of the body are finely crenulated and the marginal spines number three on each side. Dorsal bristles, one anterior and two caudal pairs, which appear at this time, are short. The insect measures about 0.39 mm. during this instar.

Third instar (4-6 days) Sedentary

This stage closely resembles the second in all respects except size (averages about 0.52 mm.).

Fourth instar (12-16 days, including the pupa) Sedentary

When newly emerged from its third molt, the larva is whitish green and closely set to the leaf surface. As it matures, it separates itself farther and farther from the leaf by submarginal, perpendicular wax rods, which are so close together they form a complete wall or palisade of striated secretion. It is always distinguished from other stages by the possession of seven pairs of long dorsal

spines or rods. The margins are evenly fringed with shorter spines. When mature, it measures about 0.75 mm.

It is from the pupa which forms inside, that the adult emerges through a T-shaped opening. This last instar is undoubtedly the most important as far as E. formosa is concerned, since the parasite almost entirely limits its attack to this stage in the white fly cycle.

The life history from the time the egg is laid to emergence of the adult requires about five weeks.

Host Plants, Habits and Parasites

The greenhouse white fly adults prefer the more tender leaves and invariably are found by hundreds on the undersides of leaves at the top of the plant where most of the eggs are deposited at any one time in the growth of the plant. Lower leaves, especially of a plant which makes rapid growth, seldom show many eggs or first and second instar larvae. Adults have been noted congregating to a considerable extent on the under surfaces of pale or chlorotic leaves, or on normal leaves under intense light. This suggests a phototropic response even during the period of oviposition.

Britton (3), has listed 58 plants upon which he has observed young stages, and many more could be added. In these experiments the host preference was in descending order; tomato Nicotiana spp., heliotrope, fuchsia, ageratum and lantana. Conditions of temperature, light and humidity appear to alter this order, however.

Weber (41), reports the greatest activity of the

greenhouse white fly is at temperatures between 25-30 C., and that the optimum for development of all stages is 30 C.

Natural parasitic enemies of the white fly are several species of fungi (25, 40, 15, 29), and several Chalcids belonging to the genus Encarsia: E. formosa Gahan, (8, 29, 7, 31, 41, 34, 32, 33, 43, 39, 44, 45, 20), E. versicolor Gir., (18), E. pergandiella How., (10), E. partenopea Masi., (29, 14), E. luteola How., (35) and Encarsia sp. (41).

THE PARASITE

Encarsia formosa Gahan

Description, Origin and Distribution

Encarsia formosa was first described by Gahan in 1924 (9), (family Aphelinidae of some authorities, or Eulophidae, subfamily Aphelininae of others).

The female (29), is about 0.6 mm. long and 0.3 mm. broad (Figs. 5 and 6). Most of the head is brown, the thorax black and the abdomen pale yellow; the legs and antennae are light brownish yellow and the wings opalescent, fringed with relatively long hairs.

Males are usually slightly larger and may always be distinguished by the dark brown or black abdomen. Since the species reproduces thelyotokously, males rarely occur, generally making their appearance after a prolonged period of low temperature.

The bionomics of the insect suggests a tropical origin. It is thought that India is the location from which the parasite spread (29, 41); however, this has not been definitely established and is likely only if a recent host association was initiated.

Within recent years, the parasite has been reported as occurring in England (7, 29, 31), Australia (39), New Zealand (20), Germany (41), Canada (correspondence with Dr. A. B. Baird of the Dominion Parasite Laboratory, Belleville, Ontario) and the United States (9). Its distribution is

is largely restricted to the greenhouse in the Temperate Zone.

Life History (29)

Egg Observations thus far indicate that only a single egg is deposited in each white fly pupa at a point anterior and just to the side of the operculum. Each oviposition requires from two to four minutes. Females, which live for about 28 days, have been observed ovipositing over a period of nine days and in this time deposited 50 or more eggs each. Tonnoir (39), reports that females of this parasite have deposited an average of 100 eggs per individual during the oviposition period.

EGG

The egg itself is large, measuring 0.08 mm. long and 0.03 mm. in diameter. It is devoid of the "neck" so often noted as a part of the eggs of chalcidoid parasites.

LARVA

The incubation period is approximately four days. Upon hatching, the young larva is dilated at the anterior end, but soon becomes elongated, and finally semi-circular. It molts three times as is shown by the number of cast-off larval skins. The total length of time necessary for these stages is unknown, but is probably 10-14 days.

PUPA

After attaining maturity, the larva transforms into a pupa which usually faces the anterior end of the white fly pupa. Pupation requires about 10 days, after which the adult emerges from the pupa and escapes from the white fly scale by cutting a circular opening in the top.

The life cycle from egg to adult is about 26-30 days. Tonnoir (39), has observed it to be as short as 20 days, intimating that it varies widely depending upon conditions of temperature.

HABITS AND ECONOMIC IMPORTANCE

Speyer (29), states that the adult parasites are able to cover considerable distances in quest of their host. Weber (41), who worked with what was probably E. formosa, concluded that even "crowded parasitized larvae" on a leaf did not induce wandering. Observations during these experiments, especially at low temperatures, confirm the belief of Weber. The parasites are more active at higher temperatures (20-30°C.) and under these conditions many can be seen deserting the lower leaves for those higher up on the plants, but they seldom fly great distances. They are not easily disturbed and often remain quiescent, even upon close examination.

Several plants are naturally repellent to the adult parasites but they are discussed in another part of this thesis.

E. formosa seems to be the most valuable of all species of Encarsia for biological control of the greenhouse white fly and has been reported with at least some degree of success, in a number of countries where it has been introduced and colonized (29, 7, 31, 43, 34, 33, 39, 44, 45, 20).

OBJECT OF THE EXPERIMENTS

The experiments attempt to determine; some of the factors which increase or decrease the total parasitism of the greenhouse white fly, T. vaporariorum (West), by E. formosa; the optimum conditions for parasitism; and the economic importance of E. formosa in an average greenhouse environment.

EQUIPMENT AND METHODS

Control Cabinet

A cabinet 4' x 5½' x 2' was converted into a control cabinet (Fig. 1). Since it was necessary to use plants, light was essential, and accordingly, two 500-watt lights were adjusted outside the cabinet, about eight inches above the glass top. Later it became apparent that regulation of the cabinet temperature required the installation of two water trays (Fig. 1), placed over the top just under the lights. These trays were equipped with glass bottoms and were kept filled with running water by means of an inlet hose connected to a water supply and an outlet hose leading into the sink.

The inside conditions of temperature and humidity were satisfactorily controlled by passing water through a copper line running across the ceiling of the cabinet. Various conditions were obtained by the relative amount, or speed of flow, of water that passed through the line. Humidity was maintained by the moisture supplied the potted plants. Thermo-

static control apparatus was installed which maintained a temperature that did not fluctuate more than five degrees. Electric coils at one end of the cabinet supplied heat.

The air currents set up by a fan disturbed the flights of both host and parasite adults from plant to plant.

The cabinet functioned satisfactorily between 18°C. and 26°C.

Greenhouse

The Entomology Greenhouse was used to conduct several of the experiments. Temperature was controlled there by thermostatic apparatus. The problem of maintaining desired humidities was the most difficult factor in attempting to determine the most ideal conditions for parasitism. The only means of obtaining various degrees of atmospheric moisture were the use of 10-15 shallow pans filled with water and placed on the steam pipes under benches, and by wetting plants and the steam pipes. Transpiration of the many kinds of plants that occupied the house assured a rather constant though lower humidity when either of the foregoing practices were performed less frequently.

Care was taken never to sprinkle the tops of plants used in these experiments.

Instruments

Temperatures were recorded continuously by thermographs and checked at intervals with accurate thermometers.

A hygrograph which was periodically checked with a sling psychrometer, was used to measure the relative humidity.

Plants Used

Tomato plants were selected at the beginning of these experiments as the most ideal plants because they were rather easily cultivated and they appeared to be the favorite greenhouse host plant of the white fly. Data were also collected from the following kinds of plants, either in the control cabinet or the greenhouse or both; ageratum, fuchsia, heliotrope, lantana, hollyhock, *Nicotiana tabacum* and *N. glutinosa*.

Method of Collecting Data

Parasitized white fly fourth stadium individuals may be detected as a usual thing 10-12 days after parasitism, since they become black (Figs. 8 and 9). Figure 7 shows the difference in appearance between an unparasitized pupa (white), and one that has been parasitized (black), after an exposure of 10-15 days. Due to the succession of white fly generations that commonly appear on a single leaf, data was never collected from a new plant until a period had elapsed equal to that required by the parasite to transform from egg to adult, and only after any initial parasitism had taken place under a normal parasite population. * In most cases, data was taken

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* (3-4 parasites per leaflet or leaf, appearing on the majority of leaflets or leaves, were the general criterion followed in regards to a normal population of the parasite).

only after exposures of from 30-60 days during which time an endeavor was made to maintain a large parasite population.

Leaflets (tomato) or leaves (other plants) were taken in a randomized manner. No attempt was made to choose those leaves showing the greatest number of blackened pupae or those with the least number.

All leaves so selected were placed under a binocular microscope and the following stages counted and recorded separately: "Parasitized, fourth stadium, "Unparasitized, fourth stadium", First to third stadia," and "Eggs". In nearly all cases a column was made also of the number of adults which had emerged as indicated by the larval skins with resemblances of a T-shaped opening. This last figure was also included in the column "Unparasitized, fourth stadium", and was tabulated separately only to indicate the thoroughness of the work of the parasite at the time counts were made. Such recording would have been of little importance, which will be pointed out later, had all larvae been of the same age.

METHODS OF CALCULATING PERCENTAGES OF EFFICIENCY

After experimenting for sometime with the various methods that might be used to arrive at a representative figure for the percent efficiency of this parasite, it was concluded that no one method is absolutely accurate, due primarily to the several peculiarities already mentioned in connection with both host and parasite.

If one were to count every stage of the host on a plant exposed for the time required for parasite establishment, he would discover that the average percentage figure obtained was anywhere from one-half to two-thirds lower than the figures tabulated under "Data". This is illustrated by the complete counts from Experiment A (see also Table I for data given below under "lower leaflets, fourth stadium only"), made in analyzing the problem.

Entire Plant, All Stages

	All Stages	Parasitized	Percent
Lot 1	2065	265	13.0
Lot 2	2101	558	27.0
Lot 3	2388	563	24.0
Lot 4	1866	381	17.0
Lot 5	970	310	32.0
Lot 6	654	159	24.0

Lower Leaflets, Fourth Stadium Only

	Fourth Stadium	Parasitized	Percent
Lot 1	546	261	48.0
Lot 2	712	554	79.0
Lot 3	669	563	84.0
Lot 4	586	379	65.0
Lot 5	505	309	61.0
Lot 6	251	136	54.0

The difference in the percentage figures is due to the much greater value of combined counts of the egg, first, second and third instars and adults; all of which are stages said to be ignored by the parasites. Because the results obtained by considering all the stages were not believed to be representative of the work of the parasite, the method was not used.

The second method considered was that of regarding only the empty larval skins from which white flies emerged, in relation to the number of parasitized individuals. One obvious drawback appeared to be that of often confusing the empty larval skin from which a white fly emerged and that from which a parasite emerged, since they frequently resemble each other. Another detriment was the unusually long time required for maturation of all the stages on a leaf, because of the overlapping generations. During the course of these experiments few leaves were found without some of the immature larval stages. Since it was advisable that many counts be made, this method alone was unsuitable, yet under conditions where

time permits its application, with moderate white fly infestations, it appears to be an efficient way of determining the value of the parasite.

The method found most applicable, especially since a number of different kinds of plants were used, was that of considering only the fourth stadium. All percentages given in the following tables were based on the number parasitized of the total fourth stadium found on the number of leaves indicated on a certain plant. It was assumed at the time counts were made that any individuals in the fourth stadium, not discolored, were free from parasitization.

Additional information, i.e. "Emerged" (adults), is often given for the purpose of indicating the proportion that the parasites have failed to parasitize. Counts were made of all stages in the case of the earliest experiment, "Experiment A", and they are included for reference in "Discussion of Data and Observations".

As was intimated previously, the method adopted is not without defects; any parasitism occurring approximately 10 days or less prior to counting would in many cases fail to show, and there is the possibility, when making hundreds of counts, that the early fourth stadium and the late third may be confused and designated in the wrong columns. In order to partially overcome the first difficulty, the exposure period was made rather long (as stated elsewhere), and series of counts at intervals were made when possible, and then totaled.

Despite the complication encountered in the collection of data, it is felt that reasonably accurate conclusions may be drawn from the following tables, because the procedure which was found most suitable was used consistently throughout the work.

DATA

Environmental factors which affect the parasite's efficiency* are interpreted in terms of the percentage of parasitism incurred on its host. In reference to most tables, therefore, the number parasitized in relation to the number unparasitized, is of prime importance. Other items such as number of "First to third instars" and "Eggs" were omitted in all tables except Table I because they apply directly to the white fly reproduction and not to the calculation of the efficiency of the parasite by the adopted method.

The data forming the basis for these interpretations are tabulated and graphed on the following pages.

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* The parasite's efficiency as used in this thesis is the effect of the parasite on the host, and it is usually thought of as the degree control accomplished.

TABLE I.

Experiment A, Four Tomato Plants

Average Greenhouse Conditions

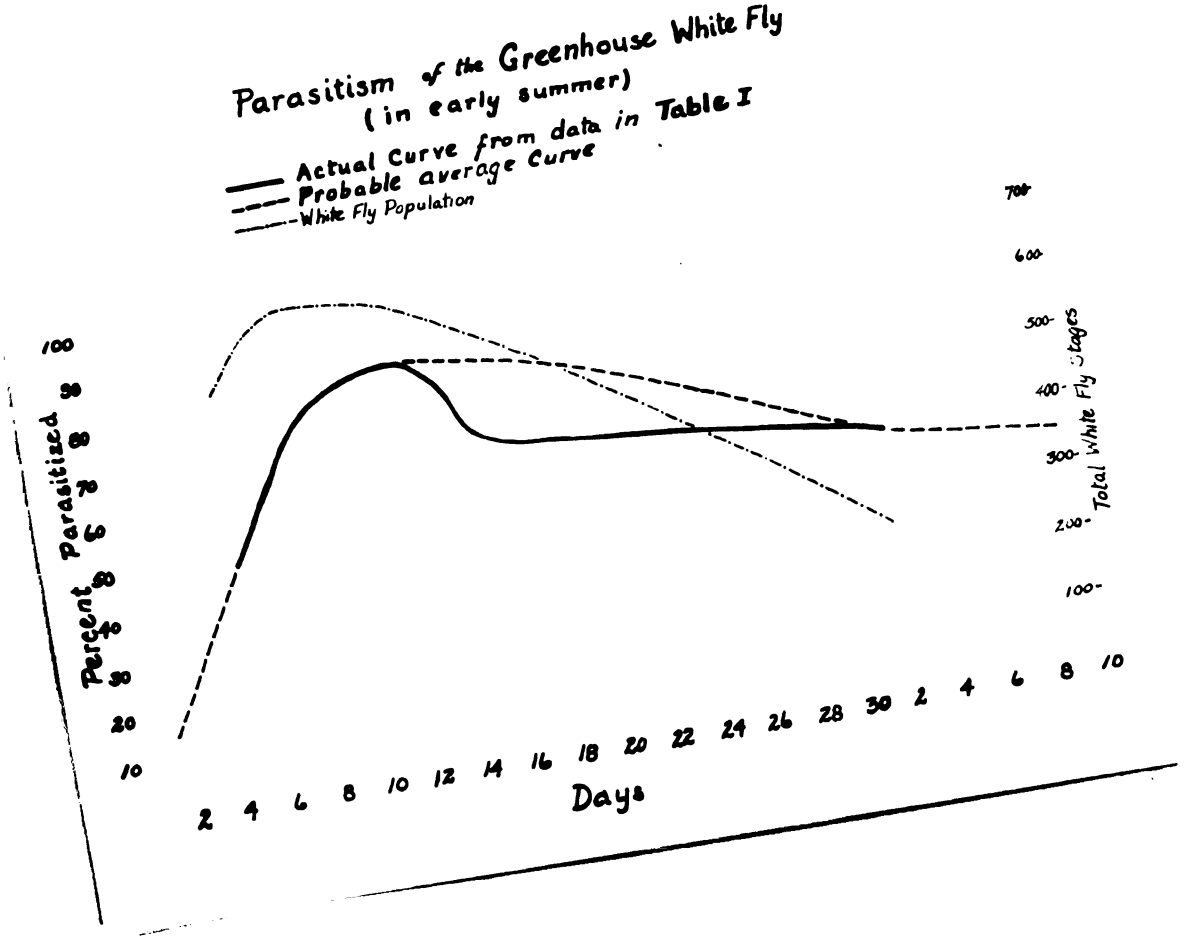
No. leaflets	Fourth Stadium		1-3 Stadia	Eggs	Percent Parasitized (Approx.)
	Parasitized	Unparasitized			
4	261	285	32	21	48.0
4	554	158	3	none	79.0
4	563	106	4	8	84.0
4	379	207	5	8	65.0
4	309	196	8	11	61.0
4	136	115	none	6	54.0
24	2202	1067	52	54	67.0

Period of Initial Exposure - about 30 days

Period between Series of Counts - 5-10 days

Conditions: Temperature - 18-26°C.

Relative Humidity - 40-90%


Parasitism of the Greenhouse White Fly
(in early summer)
Actual Curve from data in Table I
Probable average curve
White Fly Population
Percent Parasitized
100
90
80
70
60
50
40
30
20
10
Total White Fly Stages
700
600
500
400
300
200
100
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 2 4 6 8 10
Days

GRAPH I.

TABLE II.

Experiment B, Effect of Humidity (Cabinet)

Plant	No. leaves	Fourth Stadium			% Parasitized	Humidity	Temperature (°C)
		Parasitized	Unparasitized Unemerged	Emerged			
Tomato	3	249	253	11	50.0	30-40%	25
N. glut.	1	181	258	52	41.0	30-40%	25
Heliotrope	1	1680	506	104	77.0	30-40%	25
Tomato	3	184	73	4	72.0	60-70%	26
Lantana	1	54	46	2	54.0	60-70%	26
Ageratum	2	161	98	38	62.0	50-70%	26
Tomato	8	245	281	68	47.0	80-90%	21
Lantana	3	72	280	63	20.0	80-90%	21
Ageratum	1	48	70	6	41.0	80-90%	21

Exposure 30-60 days

Additional factors operating -

Cumulative effect of:

(1) Character of different plants
(2) Temperature
(3) Constant light

TABLE III.

Experiment B-1. Constant Temperature. (Cabinet)

Plant	No. Leaves	Fourth Stadium			% Parasitized	Temperature (°C)
		Parasitized	Unparasitized Unemerged	Emerged		
Tomato	7	112	246	1	31.0	18
Fuchsia	2	23	27	19	46.0	18
Ageratum	3	97	41	31	70.0	23
Fuchsia	1	66	47	31	58.0	23
Tomato	3	184	73	4	72.0	26

Exposure - 30 days

Conditions - 60-70% Humidity

Additional factors operating:

(1) Types of plants

(2) Constant light

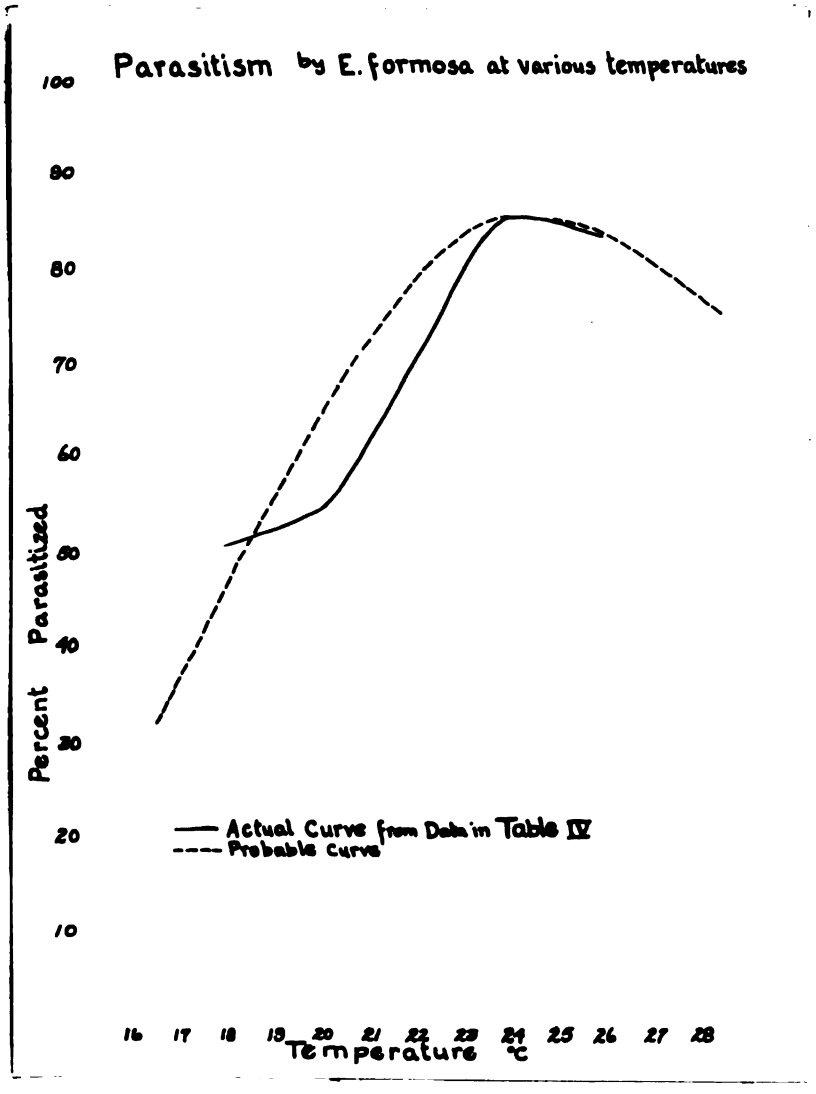
TABLE IV.

Experiment C Mean Temperatures in Greenhouse

Plant	No. Leaves	Fourth Stadium			% Parasitized	Temperature (°C)
		Parasitized	Unparasitized Unemerged	Emerged		
Tomato	5	78	72	41	52.0	18
Tomato	4	436	458	30	49.0	18
Tomato	5	521	244	36	68.0	18.5
Tomato	15	744	645	78	54.0	20
Fuchsia	2	82	22	6	79	22
Tomato	13	1025	181	56	85.0	24
Ageratum	3	389	114	3	77.0	24
N. glut.	1	114	78	11	59.0	24
Tomato	8	812	170	12	83.0	26

Exposure - 30-60 days

Conditions - Relative humidity 60-70%


Parasitism by E. formosa at various temperatures
Percent Parasitized
100
90
80
70
60
50
40
30
20
10
Actual Curve from Data in Table IV
Probable Curve
16 17 18 19 20 21 22 23 24 25 26 27 28
Temperature °C

GRAPH 2.

TABLE V.

Experiment C-1

Different Plants Subjected to Fluctuating Temperatures and Humidity (Greenhouse)

Plant	No. Leaves	Fourth Stadium			% Parasitized	Temperature Fluctuations (°C)
		Parasitized	Unparasitized Unemerged	Emerged		
Tomato	5	683	107	36	86.0	18.5-23.5
Tomato	4	138	30	9	86.0	15-27
Fuchsia	3	247	24	11	91.0	15-27

Exposure - 30-60 days

Relative Humidity - 40-70%

Observations: At temperatures of 15°C. and below, the adult parasites were sluggish.

Adult parasites were observed in the act of oviposition on individuals in the second and third instars (see "Discussion of Data and Observations".)

TABLE VI.

Experiment D

Effect of Type of Plant

(Approximately the same conditions of temperature and humidity - optimum 24-26°C. and 40-70% relative humidity. Highest percentage recorded in most cases.)

Plant	No. Leaves	Fourth Stadium			Temperature (°C)
		Parasitized	Unparasitized	% Parasitized	
Tomato	13	1025	181	85.0	24
Fuchsia	3	347	24	91.0	24 (mean)
Hollyhock					
1 (very pubes.)	1	1218	1980	38.0	24 (mean)
2 (med. pubes.)	1	1291	1437	47.0	24 (mean)
N. glutinosa	1	114	78	59.0	24
Ageratum	3	389	114	77.0	24
N. tabacum	1	75	117	38.0	25 (mean)
Bean	1	150	183	45.0	25 (mean)
Heliotrope	3	482	236	67.0	25
Lantana *	1	54	46	54.0	26

* Plant from Cabinet, others from Greenhouse.

Observations - Epidermal hairs of N. glutinosa secreted a viscous, sticky substance that appeared to be detrimental to the activity of the parasite.

Larvae of the white fly often excreted globules of "honey dew" on hollyhock, and especially on heliotrope (see Fig. 11 and

TABLE VII.

Effect of Intense Light

(500 watt bulb about 12-18" from plants)

Plant	No. Leaves	Fourth Stadium		% Parasitized	Temperature (°C)
		Parasitized	Unparasitized		
Tomato *	8	169	341	33.0	23
Tomato	4	65	41	61.0	24
N. glutinosa (See also Fig. 12)	1	734	1783	29.0	22
Fuchsia	4	372	185	67.	25

Conditions: 40-70% relative humidity

* Plant from Cabinet, others from Greenhouse.

DISCUSSION OF DATA AND OBSERVATIONS

The data presented in Table I (and plotted in Graph 1) were taken from lower leaf samples.

It is evident by studying the table that few eggs and immature stages existed on these leaves at any one time the counts were made. Likewise a gradual desertion by both host and parasite of lower leaves is indicated. There is an increase in the percentage of parasitism over a period of 10-15 days and then a gradual decline. This tendency for a build-up followed by a decrease was evident in most experiments conducted. It was, however, more marked in this experiment; probably due to the fact that the counts were made beginning in early summer when both the populations of parasite and hosts were observed to be less abundant. Otherwise, under normal conditions the high percentage should be more extended.

The activity of the parasite (figured by the parasitism) and white fly (figured on the basis of numbers present) is plotted in Graph 1. The "probable curve" is indicative of the presumed average degree of parasitism over the given time and bears no other significance.

According to Richardson (24), the humidity may or may not have an effect on the oviposition by parasites. Weber (41), has found the optimum relative humidity for the white fly to be 80%. The figures in Table II, show that the parasite is little affected by extremes of humidity between 30-90%, if one takes into consideration the compensating differences in the temperatures and the types of plants sampled.

Owing to the difficulty in controlling humidity, wide ranges had to be considered when tabulating data rather than means or constants. The most consistent high percentages occurred within the range of 50-70% except that on heliotrope, which was unusually high.

Tables III, IV and V, are concerned with the results of temperature experiments. The percentage figures obtained from the experiments conducted in the control cabinet were always lower than those in the greenhouse. This was probably due to one or more of three factors; that of intense light (Table VII), periodical operation of a fan for air circulation and the lower parasite population. The outstanding effect of lower temperatures expressed in Tables III and IV is the low percentage of parasitism, which seems to indicate a decreased stimulus for oviposition at those temperatures. At 18°C., 31-52% of all fourth stadium individuals were parasitized on tomato, while at 24°C., there was 85 per cent.

At temperatures above this, the parasitism seemed to decline. Fuchsia showed a greater percentage of parasitism than tomato at all given degrees of temperature.

Table VI indicates the parasitism under rather widely fluctuating temperatures, and at the same time demonstrates the effect of plant types. The 85 per cent parasitism on tomato and 91 per cent on fuchsia were the highest percentages obtained in any of the experiments.

Graph 2 shows parasitism at various temperatures based upon the percentages of parasitized fourth stadium on tomato, from Table IV. Similar curves could be plotted for other plants used in the experiments. The "probable curve" in this graph is

the presumed parasitism, and is similar to that in Graph 1, in derivation.

E. formosa was sluggish at temperatures below 15°C. and it is not, so far as Table V is concerned, apparent that any fluctuations below 18°C. aided its efficiency, except to lengthen the period of oviposition. Various publications (29, 33, 43, 45) have suggested the inefficiency of the parasite at lower temperatures and another (44), recommended an average greenhouse condition of not lower than 70°F., otherwise it would be useless to introduce it. Wilson (43) pointed out that successful control by the parasite depended upon temperature between 60-75°F.

Other workers (7, 31, 43), have listed eucalyptus, Nicotiana tabacum, N. virginica, regal, scented and zonale pelargonium, abutilon, pelargonium, abutilon, bouvardia and datura as repellent to the parasite. Table VI shows the parasitism on various plants under what is believed to be optimum conditions. It should be noted that the white fly upon the two species of tobacco showed considerable parasitism. Under the same conditions of temperature and humidity the percentage of parasitism appears to be correlated with such factors as; density and character of leaf pubescence and the amount and type of plant secretions. Fuchsia (smooth) displayed the highest percentage of parasitism; while tomato (medium pubescent), and ageratum (medium pubescent) displayed the next highest percentages. It is also true that the white fly larvae excreted less "honey dew" on those plants, or the excretion was eliminated in a normal way as described by Hargreaves (11); thus, very little accumulation in the form of droplets was evident. On such plants as heliotrope (Fig. 11), and lantana,

droplets of "honey dew" were large and disturbed the activity of the parasite and frequently a dozen or more adult parasites could be seen embedded in this excretion. The epidermal hairs of N. glutinosa excreted a viscous, sticky substance, (Fig. 12), that greatly impaired the efficiency of E. formosa and was responsible for the destruction of great numbers of the adults. Nevertheless, the apparent attraction of this species of Nicotiana was so great that the parasite was always found in large numbers on the leaves.

Results presented in Table VII are indicative that constant, intense light reduces the amount of parasitism. This substantiates similar observations in other experiments, but lacking additional data, it is merely suggested that light is one of the factors which affects the efficiency of the parasite. The cumulative effect of other factors operating was most difficult to adjust in working with the light factor. The representative leaf of N. glutinosa showing 29.0% parasitism is pictured in Fig. 12.

Undoubtedly the early fourth stadium of the white fly is the most frequently attacked stage. During the course of the experimental work, adult parasites were observed attacking younger stages, particularly the third stadium. And on March 11, a single female was seen attacking five different second stadium larvae within 30 minutes, averaging 2-4 minutes for each act of oviposition. Garman and Jewett (10), have observed females of a related species, E. pergandiella ovipositing in "pupae and larvae".

CONCLUSIONS

E. formosa has never controlled its host during these experiments to a greater extent than 91.0 per cent on fuchsia and 86.0 per cent on tomato.

According to the data presented here, the greatest control (percentage of parasitism) of the white fly on the majority of plants was reached between 24-26°C (under nearly constant temperatures) and between 50-70 per cent relative humidity. Widely fluctuating temperatures gave somewhat higher percentages, Table V. The parasite accomplished very little control at temperatures of 18°C or below, for at such temperatures it was sluggish.

Weber (41), has expressed the opinion that the optimum temperature for both the host and parasite is 30°C. The data and observations here recorded show that, if the percentage of parasitism is any indication of the optimum conditions of the parasite, it is lower than 30°C.

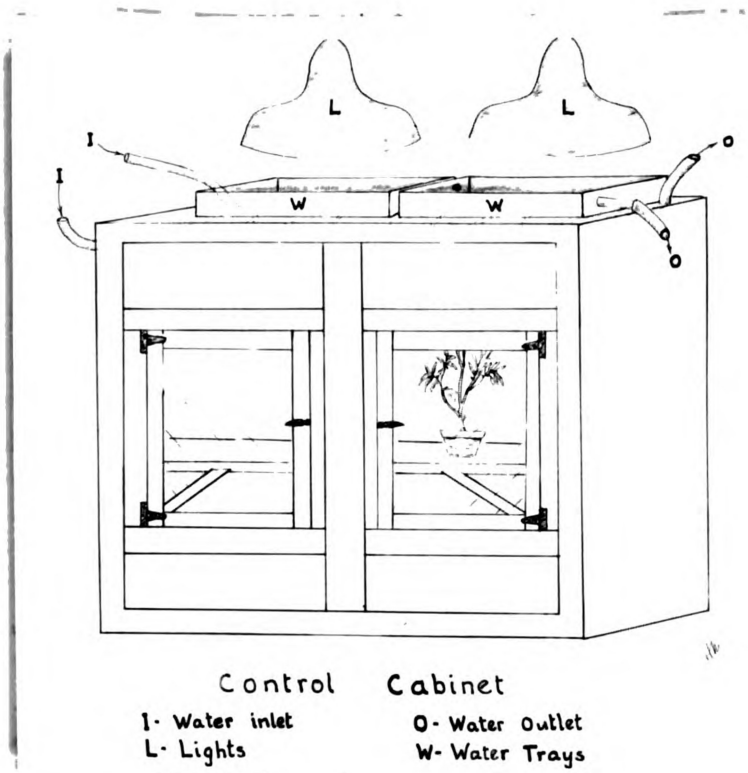
Even in an environment that seems most ideal for the parasite, and despite the fact that each generation is composed of 100 per cent females in most cases (thelyotoky), the biotic potential of the parasite is not equal to that of its host, especially during heavy infestations. Where a variety of plants are grown together, therefore, it seems unlikely that complete control can be rendered by the parasite alone, under normal greenhouse conditions.

Of the physical environmental factors affecting the efficiency of the parasite, temperature seems to be the

most important. Other factors which appear to play an important part are humidity and light.

The effect of such physical factors as character of the host plant is expressed by the degree of pubescence and the amount of excretion of both plant and white fly larvae (Table VI, and Figs. 11 and 12).

The parasite does not appear to restrict its oviposition entirely to the fourth stadium; it has been observed attacking the second and third as well.



Control Cabinet

I- Water inlet
L- Lights
O- Water Outlet
W- Water Trays

Figure 1.

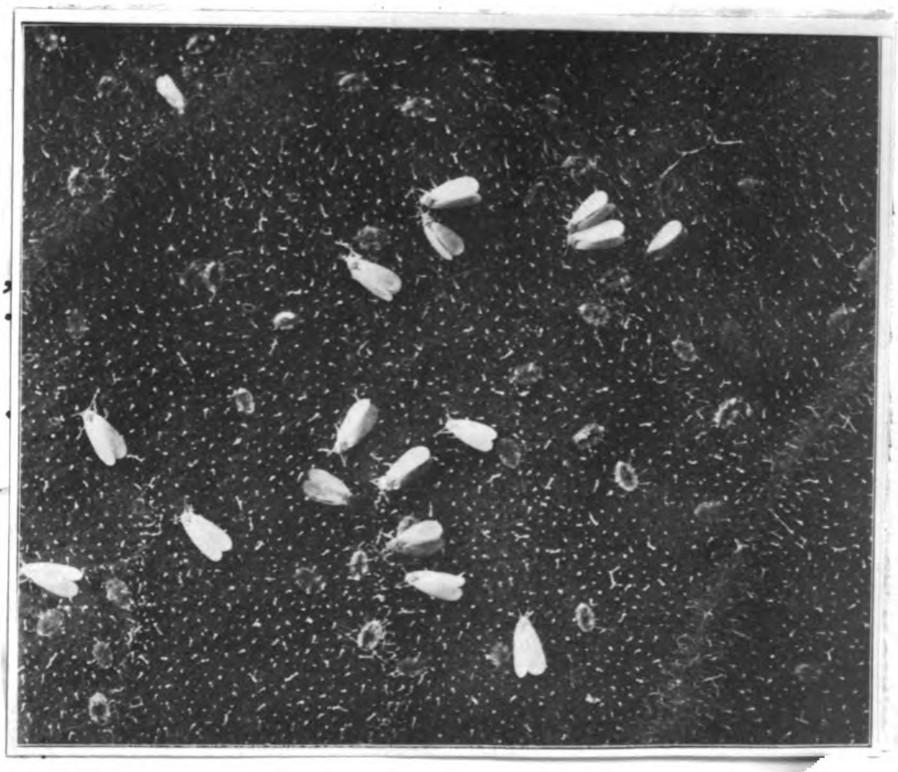


Figure 2.

White Fly Adults, Approximately 8x. (After Britton, Conn. Agr. Exp. Sta., Bul. 140).

Figure 3. White Fly Adults and Egg Circles on Fuchsia Leaf.

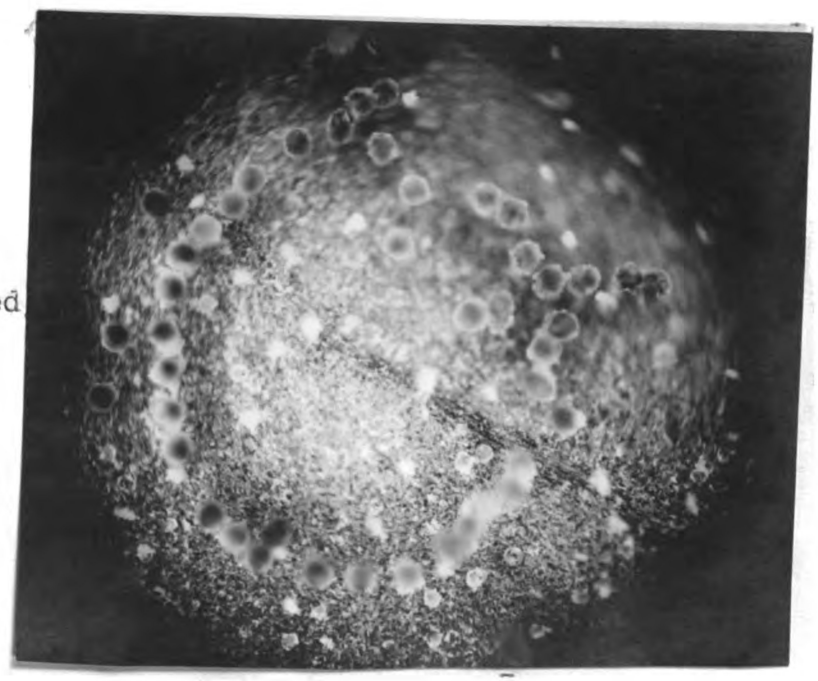


Figure 4. Circle of White Fly Eggs on Fuchsia Leaf. (Much Enlarged

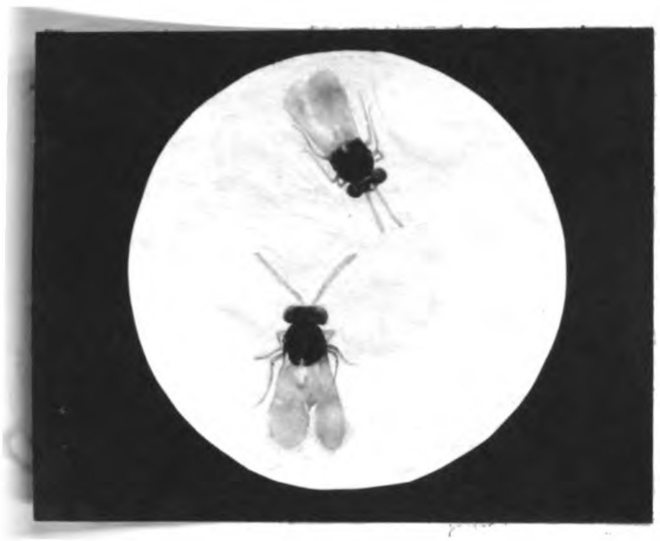


Figure 5.

Parasite Adults (Approx. 30x)

Figure 6.

Parasite Adult (Approx. 40x)

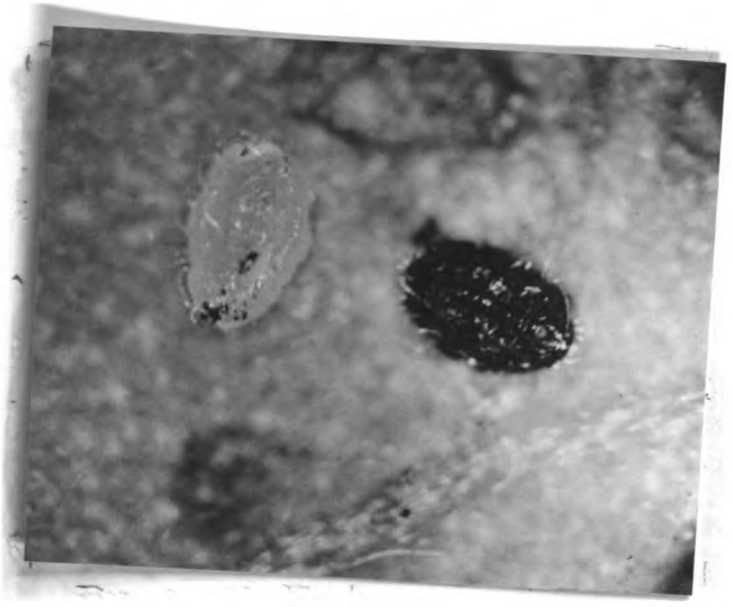


Figure 7.

Unparasitized and Parasitized White Fly Pupae (Greatly Enlarged)

Figure 8.

Parasitized White Fly Pupae (Greatly Enlarged)

Figure 9.

Tomato Leaf, Showing Parasitized and Unparasitized White Fly Pupae (About Normal Size)

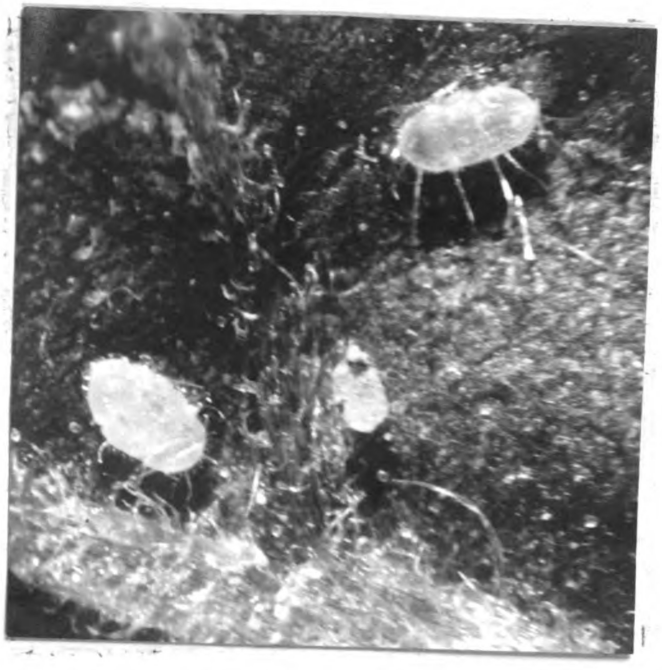


Figure 10.

Unparasitized White Fly Pupae (Enlarged)

Figure 11.

Heliotrope, Showing Pubescence of the Leaf and the White Fly Larval Excretions.

Figure 12.

Tobacco Leaf (*N. glutinosa*) Showing Relative Amount of Parasitized and Unparasitized Pupae. Note the Secretions of the Epidermal Hairs.

LITERATURE CITED

(1) Barnes, H. G. On Some Factors Governing the Emergence of Gall Midges: Cecidomyidae: Diptera. Proceedings Zoological Society, London, pp. 381-393. 1930.

(2) Blunk, H., H. Bremer, and O. Kaufman. Untersuchungen zur Lebensgeschichte und Bekampfung der Rubenfliege (Pegomyia hyoscini Panz.). Arb. Biol. Reichsanstalt. f. Land. u. Forstwirtsch, volume 16, pp. 423-573. 1928.

(3) Britton, W. E. The White-Fly or Plant-house Aleyrodes. Connecticut Agricultural Experiment Station, Bulletin 140, pp. 3-17. 1902.

(4) Chapman, R. N. Animal Ecology with Special Reference to Insects. Burgess-Brook. Inc., Minneapolis, 370 pp. (pp. 158-161). 1925.

(5) Cockerell, T. D. A. The Classification of Aleyrodidae. Proceedings of the Academy of Natural Sciences of Philadelphia, Volume 54, p. 282. 1902.

(6) Cotton, E. C. A Constant Low Temperature Apparatus for Biological Investigations. Journal of Economic Entomology, Volume 3, pp. 140-145. 1910.

(7) Davies, W. M. Trials on the Control of Certain Horticultural Pests in North Wales. Welsh Journal of Agriculture, Volume 7, pp. 332-349. 1931.

(8) Davis, G. C. White Fly Description and Illustrations. Michigan Agricultural Experiment Station, Special Bulletin 2, pp. 22-24. 1896.

(9) Gahan, A. B. In the Proceedings of the United States National Museum. Volume 65, Article 2517, pp. 14-16. 1924.

(10) Garman, H. and H. H. Jewett. The White Flies of Hot Houses. Kentucky Agricultural Experiment Station, Bulletin 241, pp. 77-111. 1922.

(11) Granfield, C. O. and Frank J. Fink. A Humidity and Temperature Control Cabinet for Growing Plants. Journal of Agricultural Research, Volume 54, number 7, pp. 503-508. 1937.

(12) Hargreaves, E. The Life-History and Habits of the Greenhouse White Fly (Aleyrodes vaporariorum Westd.). Annals of Applied Biology, Volume 1, pp. 313-334. 1914-15.

(13) Hefley, H. M. Differential Effects of Constant Humidities on Protoparce quinquemaculata Haworth, and Its Parasite, Winthemia quadripustulata Fabicius. Journal Economic Entomology, Volume 21, pp. 213-221. 1928.

(14) Hodson, W. E. H. and A. Beaumont. Fifth Annual Report of the Department of Plant Pathology for the Year Ending September 30th, 1928. Pamphlet, Seale-Hayne Agricultural College, number 30, pp., Newton Abbott, Devon. 1929.

(15) Horne, A. S. Occurrence of Fungi on Aleurodes vaporariorum in Great Britain. Annals of Applied Biology, Volume 2, pp. 109-111. 1915.

(16) Larrimer, W. H. and W. B. Noble. Determination of the Percentage of Parasitism of the Hessian Fly. Journal of Agricultural Research, Volume 32, number 11, pp. 1049-1051. 1926.

(17) Lloyd, L. The Control of the Greenhouse White Fly (Asterochiton vaporariorum) With Notes on Its Biology. Annals of Applied Biology, Volume 9, pp. 1-32. 1922.

(18) McDaniel, E. I. Greenhouse Insects. Michigan Agricultural Experiment Station, Special Bulletin 134. 1924.

(19) Morrill, A. W. The Greenhouse White Fly (Aleyrodes vaporariorum Westw.). U. S. Department of Agriculture, Bureau of Entomology, Circular 57. 1905.

(20) Muggeridge, J. (Note on the Economic Importance of Encarsia formosa). Annual Report, Department of Agriculture, New Zealand. 1935-36.

(21) Payne, N. M. The Differential Effect of Environmental Factors upon Microbracon hebetor (Say) (Hymenoptera-Braconidae) and Its Host Ephestia kuhniella Zeller (Lepidoptera-Pyralididae). Ecological Monographs, Volume 4, pp. 1-46. 1933.

(22) Peterson, Alvah. A Manual of Entomological Equipment and Methods. Part One. 1934.

(23) Quaintance, A. L. and A. C. Baker. Classification of Aleyrodidae. U. S. Department of Agriculture, Bulletin 27 (Tech. Series, two parts) pp. 1-114. 1913.

(24) Richardson, C. H. The Oviposition Responses of Insects. U. S. Department of Agriculture, Bulletin 1324, pp. 1-18. 1925.

(25) Rolfs, J. B. and H. S. Fawcett. Fungus Diseases of Scale Insects and White Fly. Florida Agricultural Experiment Station, Bulletin 119, pp. 71-82. 1913.

(26) Ruzicka, J. Einige Bemerkungen uber die Nonenbekampfung und biologischen Wege. Forstwiss. Zentralbl., Volume 47, pp. 537-538. 1925.

(27) Shelford, V. E. The Relation of Abundance of Parasites to Weather Conditions. Journal of Economic Entomology, Volume 19, pp. 283-289. 1926.

(28) Smith, R. C. A Study of Temperature and Humidity Conditions in Common Types of Insect Rearing Cages. Journal of Agricultural Research, Volume 43, pp. 547-557. 1931.

(29) Speyer, E. R. An Important Parasite of the Greenhouse White Fly. Bulletin of Entomological Research, Volume 17, pp. 301-308. 1927.

(30) _____. Entomological Report. 13th Annual Report Experimental and Research Station. Nursery and Mkt. Gdn. Ind. Devpmt. Soc. 1927, pp. 60-80 Chestnut-Herts. 1928.

(31) _____. The Greenhouse White Fly, Journal Royal Horticultural Society, Volume 54, part 1, pp. 181-192. 1929.

(32) _____. A White-fly Parasite. 14th Annual Report Experimental and Research Station. Nursery and Mkt. Gdn. Ind. Devpmt. Soc. 1928, pp. 96-100, Chestnut-Herts. 1929.

(33) _____. Practical Methods for Glasshouse Insect Control. 15th Annual Report Experimental and Research Station. Nursery Mkt. Gdn. Ind. Devpmt. Soc. 1929, pp. 54-60. Chestnut-Herts. 1930.

(34) Speyer, E. R. Biological Control of the Greenhouse Whitefly. Nature, Volume 74, pp. 1009-1110. 1930.

(35) Stuardo, O. C. Algunas Observationes Sobre Tres Afelininos Parasitos de Trialeurodes vaporariorum (West.) Quaint. Rev. Chil. Hist. Nat., Vol. 31, pp. 129-131, 144-149, 1927. (In Review of Applied Entomology--Series A -- Agricultural, Volume 17, p. 23. 1929).

(36) Sweetman, H. L. Study of Chemical Control of Relative Humidity in Closed Spaces. Ecology, Volume 14, pp. 40-45. 1933.

(37) _____. The Biological Control of Insects. The Comstock Publishing Company, Ithaca, N. Y. 1936.

(38) Thompson, W. R. Theorie de l'action des Parasites Entomophages. Accroissment de la Proportion d Hotes Parasites Dans le Parasitisms Cyclique. Inst. de France, Acad. des Sci. (Paris), Compt. Rend., Volume 175, pp. 65-68. 1922.

(39) Tonnoir, A. L. The Biological Control of the Greenhouse White Fly in Australia. Journal of the Council for Scientific and Industrial Research, Australia, Volume 10, number 2, pp. 89-95. 1937.

(40) Watson, J. R. White-fly Control, 1914. Florida Agricultural Experiment Station, Bulletin 123, pp. 7-14. 1914.

(41) Weber, H. Lebensweise und umweltbeziehungen von Trialeurodes vaporariorum (Westwood) (Homoptera-Aleurodinae).

Erster Beitrag zu einer Monographie dieser Art. Zeitschrift fur. Morphologie und Okologie der Tiere, Volume 23, pp. 575-753. 1931.

(42) Webster, F. M. and W. J. Phillips. The Spring Grain-Aphis or "Green-Bug". U. S. Department of Agriculture, Bureau of Entomology, Bulletin 110. 1912.

(43) Wilson, G. F. Biological Control of the Greenhouse White Fly. Gardener's Chronicle, Volume 89, pp. 15-17. 1931.

(44) Note Without Author. White Fly Parasite. Proceedings Royal Horticultural Society, Volume 60, part 4, p. 52. 1936.

(45) Note Without Author. Journal of the Council for Scientific and Industrial Research, Australia, Volume 6, pp. 127-128. 1933.