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FINAL REPORT

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Integrated Control of Tomato Pests in Greenhouses

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FINAL SCIENTIFIC REPORT: INTEGRATED CONTROL OF TOMATO PESTS IN GREENHOUSES

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ABSTRACT

Insect and mite pests are often limiting factors in greenhouse tomato production, either by causing direct losses through feeding, or indirectly by transmitting viruses that cause plant diseases. This cooperative project aimed to assess and reduce the impact of several major insect and mite pests by using pesticides, biological controls and physical controls.

Major research objectives of the project were met, and included the following general results: 1. The leafminer, *Liriomyza trifolii*, can reduce yields of greenhouse tomatoes, but only if infestations are severe over long periods of time. One of the main aspects of yield effects may be delays in production. This information makes the use of natural enemies very possible. 2. Several greenhouse environmental factors can be manipulated to increase *L. trifolii* mortality, including humidity, substrate and plastic mulches combined with water. These factors are generally compatible with natural enemies. 3. Physical barriers and positive air pressure were at least as effective as insecticides in preventing *Bemisia tabaci* infestations and subsequent Tomato Yellow Leaf Curl Virus (TYLCV) transmission. 4. Tomato planting date (in Israel) was correlated with *B. tabaci* activity within greenhouses and also with the incidence of TYLCV. 5. Classical biological control methods were not useful for *B. tabaci*, because TYLCV transmission and spread was not reduced. 6. The use of insecticides, physical barriers or host-plant resistance appear to be the only practical ways to deal with *B. tabaci* on greenhouse tomatoes.

<u>TABLE OF CONTENTS</u>	<u>PAGE</u>
ABSTRACT	1
OBJECTIVES OF ORIGINAL PROPOSAL	2
CHEMICAL CONTROL	3
PHENOLOGY AND DAMAGE	7
BIOLOGICAL CONTROL	9
HOST-PLANT RESISTANCE	12
PHYSICAL CONTROL	14
SAMPLING METHODS	22
YIELD REDUCTION	23
RESEARCH PROGRESS	29
LITERATURE CITED	29

OBJECTIVES OF THE ORIGINAL PROPOSAL

1. SHORT-TERM RESEARCH

1.1 Evaluate pesticides for pest suppression, including non-conventional pesticides such as *Cephalosporium lecanii* and extracts of the tree *Azadirachta indica* (neem).

1.2 Evaluate effects of pesticides and application methods on natural enemies. This was not dealt with in this project because there is a large working group under the direction of Dr. Hassan in Darmstadt, W. Germany that conducts studies for this purpose on a coordinated basis.

1.3 Screen outdoor plants as potential hosts for greenhouse crop pests and viruses that cause plant diseases.

1.4 Correlate field infestations of the whitefly *Bemisia tabaci* with infestations on greenhouse tomatoes in the same year. Also, to seek a correlation between the number of *B. tabaci* caught on yellow sticky traps and number of TYLCV-infected plants, in order to determine a threshold for pesticide applications.

1.5 Evaluate the whitefly parasite *Encarsia formosa* under the low and high temperatures found in greenhouses in the US and Israel, to determine if there are any limits to using these parasites. This objective was not addressed because several recent studies by Prof. Joop van Lenteren and co-workers have shown that within the temperature limits for growth of the tomato, *E. formosa* will successfully control *Trialeurodes vaporariorum*, if introduction rates are adjusted accordingly.

1.6 Evaluate any tomato cultivars developed under other breeding programs for resistance to *B. tabaci*, *L. trifolii* and TYLCV.

2. MID-LONG-TERM RESEARCH

2.1 Trials with physical procedures, such as traps, air pressure, plastic tunnels, etc. These factors were researched under this and other objectives.

2.2 Evaluate *T. urticae* control on tomato by *P. persimilis*.

2.3 Evaluate parasites for *L. trifolii* control. Several parasitic hymenopteran species have been found associated with *L. trifolii* on tomatoes. Research on this objective will be reported here and in association with other objectives.

2.4 Study distribution of pests on and among plants at different growth stages, to help determine a sampling procedure.

2.5 Develop information on the economic injury level of *L. trifolii* on greenhouse tomato.

2.6 Study the flight behavior of *B. tabaci*, as well as means of *T. urticae* dispersal.

2.7 Monitor the occurrence of pests that become more important as pesticide use is diminished.

FINAL REPORT

OBJECTIVE 1.1

ISRAEL: Some of the pests attack greenhouse tomatoes each year: whiteflies, tomato russet mites, carmine spidermites and recently also the serpentine leafminer. Others appear occasionally: aphids transmitting PVY, or very rarely: caterpillars and thrips. In order to pick from January to April, tomatoes must be planted in the beginning of October. Thus, the required planting season overlaps in time with the highest risk of whitefly/TYLCV infestation. Being the key problem, all pest control activities were aimed primarily to prevent TYLCV transmission by all means. Obviously, these extremely intense control measures also prevented the damage of other pests. Any change in the cultivation methods, e.g. the use of TYLCV-resistant cultivars, or the extension of the growth season, e.g. planting in August and picking from November to June, will immediately affect the pest control strategy.

1.1. TYLCV bearing whiteflies

The whitefly/TYLCV complex is by far the most important pest problem. The virus can not be controlled directly, nor can virus infected plants be cured. The only way to control virus damage is by preventing its transmission by the whiteflies. This problem is so severe that growers used to spray every other day, or every day, during the first 2-3 months of the growth season. This heavy spraying schedule prevented injury by most pests but, some growers have encountered health problems. Also, the whitefly may develop resistance to pesticides, a well known phenomenon (Prabhacker et al., 1985) which had probably started (Berlinger et al., 1987, Seligman, 1987). Being the key pest, all control experiments were directed against the tobacco whitefly to prevent TYLCV transmission. At the same time the effects of whitefly-control measures were examined on other tomato pests.

Methods: The fact that TYLCV-bearing whiteflies may infect, at a high rate of probability, a healthy tomato plant within 4h of feeding was the guideline of the development of a quick and reliable method to mass screen insecticides. The method consists of a laboratory and a complimentary field test. The laboratory tests: Young potted tomato plants, with 4-6 leaves, were treated by dipping them for 10 seconds into the different insecticide solutions. During the test period the plants were kept in a climatically uncontrolled greenhouse. Six leaflets per tested-insecticides were sampled separately, at random. Onto each leaflet, 10-20 slightly co2-anesthetised laboratory-reared *B. tabaci* adults were confined by means of a Munger-cell. The bioassays were performed with laboratory reared whiteflies. After 4h of forced contact, at 28+°, the rate (%) of mortality/knock-down effect was determined. This test was carried out stepwise in the way described in Table 1. One day after the treatment the plants were observed first for phytotoxicity. If positive, the insecticide could be either eliminated, and no further observations were done anymore, or the concentration of the insecticide could be reduced and the laboratory-test restarted. The same procedure was repeated on days 3 and 6.

If the result (% mortality) was worse than that of the standard insecticide (SI), the bioassay set-up was left for a second observation on the next day. If after those total 24h the result was still worse than that of the SI, the insecticide was eliminated. But, if the whitefly mortality increased with

time, and reached similar values to that of the SI, the concentration of the insecticide could be increased, and the test restarted. On the other hand, if the result was better or at least equal to that of the SI, again two possibilities could be followed: either trying to decrease the concentration and restarting the test, or going on to the second step and performing a new bioassay, with a new group of whiteflies, 3 days after the treatment. When this bioassay was positive, the third bioassay, 6 days after treatment was performed, after which the decision was made whether to go on to the much more expensive field test. The stepwise bioassay (on day 1, 3 and 6) of the laboratory test was aimed at checking the residual effect of the tested insecticides; preventing possible artifacts due to high volatility of the insecticide and their escape to the final field test.

The field test: The field tests were performed during August-October when the naturally occurring whitefly population reached its peak (Fig.1). The trials were performed in microplots (5x2m), each consisting of 30 tomato plants, planted in 3 single rows of 10 plants of the determined cultivar VF M-82-1-8 (Produced by Hazera Company). Every treatment was performed in 6 microplots (replicates) and arranged in a randomized blocks. In order to ensure, as much as possible, an equal probability of virus infection rate of all plants, each microplot was bordered by a row of tomato plants which had been previously inoculated in the laboratory with TYLCV. The insecticides were applied twice a week, with a high volume and high pressure motorized back-sprayer (DM-9, made in Japan). The results were evaluated weekly by counting the plants that showed virus symptoms.

The experiments were terminated when the unsprayed control plots reached 100% infection. The insecticides were compared also with a standard insecticide (Fenpropathrin) as in the laboratory test. A high correlation was found between adult mortality (%), after 4h of forced contact in the laboratory tests, and the incidence of virus transmission in field tests. The highest correlation was found between the laboratory test, 6 days after treatment, and the field test. According to the above described method, insecticides belonging to different chemical groups were tested (Table 2). Insecticides of the organo-phosphorous, carbamate, organochloride and the pyridine groups, did not meet the requirements of the method. Only some of the pyrethroids were efficient enough (signed +). The insecticides which were selected by this method were found efficient in preventing the TYLCV transmission in open field crop tomatoes, as well as in greenhouse tomatoes.

In 1986 the approved insecticides were not efficient enough in controlling the spread of the virus. This was in contrast to the previous years, and 1987 (Figure 5). In our field test in 1986, tomato plants were treated with Cymbush, Karate and Talstar; and compared with Smash (SI) and an untreated control. In all treatments the rate of virus infected plants, 9 weeks after planting, was similar to the control and significantly higher than in other years. Contrary to previous years the laboratory test performed in 1986 with our laboratory whitefly strain, was not correlated with the field experiment as regards TYLCV infection.

To explain these unusual results the following was noticed: 1) In laboratory experiments using Smash at 0.3% and Cymbush at 0.3%, a lower rate of mortality was noticed among field collected whiteflies compared with our laboratory strain (Table 3).

Table 3. Mortality of whiteflies; field collected (1986) Vs laboratory strain (Laboratory test).

Duration of test		% Mortality			Laboratory strain		
		Field collected					
Days	Hours	Smash	Cymbush	Control	Smash	Cymbush	Control
1	4	41.1b	42.2b	0.0a	90.2c	91.8c	1.1a
1	24	83.9b	85.8b	0.0a	98.4c	100.0c	3.9
3	4	56.2b	54.8b	0.0a	98.2c	94.2c	0.0a
3	24	86.7b	81.0b	10.7a	87.8b	88.3b	3.7a

Note: The significance was analyzed for each experiment separately. The statistical analysis was applied horizontally.

When the two strains were grown separately, under laboratory conditions (28° C) for 3-4 generations, no differences in % mortality were observed any more. Therefore it was concluded that the obtained results (Table 3) were due to physiological rather than genetic resistance; i.e., were caused by differences in environmental conditions under which the two populations had developed before. In autumn of 1986, especially from 21 August- 31 September, daily mean temperatures were much higher than in previous years. When smash pre-treated plants were exposed for 6h to constant high temperatures (41° or 44°), a significant decrease in whitefly mortality was found: 64.4 and 43.4% respectively in comparison with an average of 87.6% found in pretreated control plants kept throughout at 28°. As to other recommended insecticides, Cymbush, Karate and Talstar pre-treated plants, such a phenomenon was not noticed. A chemical-residue test confirmed this result. Thus, this negative temperature dependence can be only a partial explanation for the control failure. The whitefly population in 1986 was significantly higher than in previous years, or in 1987. According to the better control of the TYLCV transmission in 1987 than in 1986, with the same insecticides, it seemed that the population size was the dominant factor in the failure of the chemical control in 1986. To check this hypothesis the expected whitefly population density was calculated, by the 'rule of three', for the other years, based on the whitefly/virus ratio found in 1986. Accordingly, the expected number of whiteflies should have been 300, real whereas the trapped number was 455, and 700 compared with 860 found in 1987. It was concluded that there also was a high correlation between whitefly density and TYLCV infection.

The above mentioned pyrethroids (Table 3) were recommended by the Extension Service, Ministry of Agriculture, and are used by the growers. Still their efficiency is limited by the whitefly population density

The tomato russet mite: The following is based on observations conducted on russet mites in commercially cultivated greenhouses. When sulphur was used, to control plant diseases, only 5% of the plants were found to be infested by the russet mite in April, compared with 96% in greenhouses which were not treated with sulphur or any other acaricide during the same period (Fig.6). In field observations it was found that plants, which were sprayed continuously with pyrethroids against whiteflies transmitting TYLCV (see chemical control- whiteflies), were not infested by the tomato russet mite whereas control plots were severely damaged.

The carmine spider mite: In field observations, performed within a control experiment against whiteflies transmitting TYLCV, it was found that plants which were sprayed continuously with pyrethroids were not infested by the carmine spider mite, whereas unsprayed control plots were severely attacked.

Leaf miners: No chemical control trials were performed against leaf miners. When chemical control was applied against whiteflies, the leaf miners were controlled as well (Figure 8).

PVY bearing aphids: Being a non-persistent virus, PVY transmission can't be restricted by controlling the aphids chemically within the greenhouse.

USA: Greenhouse Whitefly, *Trialeurodes vaporariorum*: Several experiments were conducted to evaluate various pesticides for their effect on greenhouse whiteflies. This insect is not the threat to transmit virus diseases that *B. tabaci* is, so control within a few hours is not critical. Results reported here were based on experiments using honeydew deposition from whitefly nymphs that had been exposed to different pesticides. This method has been described by Melamed-Madjar et al., (1983). Tomato plants were exposed to adult whiteflies for approximately 24 hr to obtain eggs. Adults were then shaken off and plants placed in cages until most nymphs were in the second instar (approx. 14 days). Treatments were applied by dipping leaves in the different pesticide dilutions. Most of the pesticides used were pyrethroids, but organophosphates, carbamates and microbial materials were also included. Leaves were removed and placed in munger cells beginning 24hr after treatment. Honeydew deposition and number of nymphs were recorded after 30 minutes. Results are shown in Tables 4 & 5.

In general, pyrethroids provided excellent control of whitefly nymphs, based on honeydew deposition. However, one pyrethroid, fluvalinate, was not very effective when evaluated in this manner (Table 4). The carbamate insecticides bendiocarb and oxamyl, plus the Beta-exotoxin material thuringiensin also were quite ineffective.

Table 4. Efficacy of pesticides vs. *Trialeurodes vaporariorum* nymphs on tomato based on honeydew deposition.

Pesticide*	Rate	Drops/nymph: 24h**		96h**
PP321 1EC	0.0005%	.09	a	.74 bc
PP321 1EC	0.001%	.2	a	.17 a
Fenpropathrin 2.4EC	0.005%	0	a	.13 a
Fenpropathrin 2.4EC	0.01%	.28	a	.94 c
Fenpropathrin 2.4EC	0.02%	.11	a	.42 ab
Bifenthrin 2EC	0.004%	.11	a	.13 a
Bifenthrin 10WP	0.004%	.9	b	.41 ab
Cypermethrin 2.5EC	0.005%	.35	a	.4 ab
Permethrin 25WP	0.01%	.01	a	.12 a
Cyfluthrin 2EC	0.01%	.27	a	0 a
Untreated		.93	b	.93 c

* Applied by dipping leaves into dilutions.

** Means of 4 replications; 24 and 96h indicated time after treatment when samples taken; data recorded after 30min; means in each column followed by a letter in common are not significantly different (P=0.05), according to Duncan's NMRT.

Table 5. Efficacy of pesticides vs. *Trialeurodes vaporariorum* nymphs on tomato based on honeydew deposition.

Pesticide*	Rate	Drops/nymph**
Permethrin 2EC	0.01%	0 a
Permethrin 25WP	0.01%	.03 a
Fluvalinate 2F	0.009%	.53 b
Bendiocarb 76WP	0.09%	.73 c
Oxamyl 2L	0.03%	.76 c
Thuringiensin	10 ml/liter	.73 c
Untreated		.5 b

* Applied by dipping leaves into pesticide dilutions.

** Means of 4 replications; Samples taken 24h after treatment and data recorded after 30 min; 'means followed by a letter in common are not significantly different (P=0.05), according to Duncan's NMRT.

EVALUATION OF NEEM EXTRACT FOR *LIRIOMYZA TRIFOLII* CONTROL ON TOMATO SEEDLINGS

One greenhouse experiment was conducted to evaluate the potential of crude neem seed extracts, obtained from Dr. Martin Jacobson, USDA Natural Products Laboratory, for leafminer prevention and control on tomato seedlings. Previous experiments had evaluated the possibility of placing rooted chrysanthemum cuttings in neem extract solutions for different periods of time prior to planting out the crop (Lindquist, 1986). Results of these experiments indicated that from 2-4 weeks of leafminer control/prevention could be expected using this method, although there was some phytotoxicity and plant growth regulator effects at higher rates and longer exposure times. In the tomato experiments, bare-rooted seedlings were placed in 0.1, 0.3, 1 and 3% neem extract solutions (w:v) for 2, 4 and 24 hours. Tomatoes were then planted in 10-cm diam pots and placed in cages for exposure to adult *L. trifolii*.

All treatment concentrations and times were severely phytotoxic, and most plants were dead after a few days. Therefore, no efficacy data were recorded and this treatment method was abandoned. A commercial formulation, Margosan-O, containing 3000 ppm of azadirachtin, is registered by the U.S. Environmental Protection agency. This formulation was not evaluated, and may be less phytotoxic.

OBJECTIVES 1.3 & 1.4: PHENOLOGY AND DAMAGE

ISRAEL: During 1984-6 all observations and experiments were conducted in the Northern Negev region: Gilat Regional Experiment Station, Besor Experimental Farm and at Sede Nitzan where the greenhouses were treated by the growers and each year 7-9 tomato-greenhouses were observed. The commonly grown tomato cultivars were cv.111 and cv.121, planted at a density of about 2800 plants/1000m². The usual growth season lasted from planting at the beginning of October, and harvesting from January to April-May.

The tobacco whitefly: The indoor population densities were determined by yellow sticky traps (Berlinger, 1980); 10-20 traps were distributed evenly in

every greenhouse (1000 m²) at a height of 25cm. The traps were operated usually during the whole growth season. The traps were collected weekly, counted and replaced by new traps. Likewise, the TYLCV infected plants were counted and the per cent infected plants was calculated. The outdoor whitefly population was also monitored, using 10 of the same traps, installed in pairs, at a height of 25cm and with a distance of 2m between each. In order to find a correlation between the incidents of virus infection and whiteflies, the cumulative weekly percentage of TYLCV-infected plants was plotted against the cumulative number of whiteflies/trap. This calculation was done for each observed greenhouse, every year. The summary of all 8 sets of observations was plotted together in one diagram (Fig. 3).

Tomato russet mite: Infested plants were counted weekly and per cent infested plants was calculated. Carmine spider mite: The tomato plants were observed weekly for the appearance of mites. In addition, usually in February, 10-20 bean plants (Contender cv. and/or Hilda cv.) were planted evenly among the tomato plants, as indicator plants (IP). Once in two weeks the adult spider mites were counted on the IPs and on the neighbouring tomato plants. Adult mites were counted on a sample of three fully expanded bean leaves; i.e., about 300 cm². On tomato plants, the mites were counted on an identical leaf area as on the IPs, at a height of 0-2.0m.

The serpentine leaf miner: Adults were counted weekly on the same sticky traps used for the whiteflies. Larvae were counted weekly on 100 leaflets which were sampled at random from all plants in the greenhouse, at a height of 0-2.0m. To determine parasitism rate, leafminer larvae were collected by sampling infested leaves and examined in the laboratory (x10 magnification). The percentage of active parasitism was calculated.

Results

During winter and spring (January- May) very few whiteflies were trapped outdoors. The numbers of trapped whiteflies increased somewhat in June and more in July, reaching a peak in September after which they decreased again, rather quickly, to low numbers, during end of November or in December, depending on the particular year (Fig.1).

Whiteflies Indoors

In the beginning of the growth season (October - November) the indoor population is completely determined by the presence of the outdoor population, as can be seen from the high correlation which was found when comparing the density of the outdoor and the indoor populations (Fig.2). This correlation is explained by the continuous immigration of outdoor whiteflies into the greenhouses. From November on, the immigration of outdoor whiteflies ceases almost completely. During winter, January, February and part of March, the indoor population remained at a very low density. It starts to increase again in April with the increasing temperatures.

The tomato yellow leaf curl virus (TYLVC)

In many indoors and outdoors observations a very high correlation ($R=0.92-0.97$) was found between the number of trapped whiteflies and the incidents of virus infected plants (e.g. Fig.3). Hence, traps are considered as a good, reliable and useful tool for monitoring purposes. The TYLCV appearance follows that of the whiteflies, with lag of the incubation time

(Fig.4). In unsprayed control plots 80-100% of plants became infected (Fig.4), and in frequently sprayed greenhouses 10-50% (Fig.5). Infection level followed primarily the whitefly population density during the three most important months, September-October-November, of each year. The numbers of whiteflies, trapped during that critical period was: in 1984 - 339.3, in 1985 - 165.4 and in 1986 - 1260.8 whiteflies/ trap.

The tomato russet mite

The russet mite, being a pest of mature plants, was never found on young plants; from planting to January no russet mite infestation was found (Fig.6). In February the first injured plants were detected in greenhouses which were not treated with acaricides during the picking period. Their numbers increased in spring, together with the increase of the prevailing temperatures. In April 96% of all the plants were already infested.

The carmine spider mite

The mites started to appear in winter, during February-March, when their population consisted of adults, at a very low density; 3-10/sample (Fig.7). In April, they started to reproduce, and in some greenhouses they reached a density of 170/sample at the beginning of May.

The serpentine leaf miner

Larvae were found from planting time to the end of December, as demonstrated in Fig. 8-A. Adult flies were trapped, by yellow sticky traps, through the whole growth season (Fig.8-B) probably as a result of a continuous immigration into the greenhouses. In spite of the presence of adults, no leafminer reproduction was found indoors during winter, probably due to the low prevailing temperatures and the presence of efficient parasitoids.

Aphid borne PVY PVY (potato virus Y) is transmitted by aphids. It was not found every year. The most severe attack, during the years of this research program, was in 1983. PVY-infected plants were found in commercially sprayed greenhouses during the beginning of the growth season, October-November, 1983, at a rate of 1.5-5.3%

To summarize, the most severe damage to greenhouse tomatoes in Israel is caused by TYLCV, transmitted by the tobacco whitefly, in the first three months of the growth season. The younger the plant is infected, the greater the damage. There is no effect of virus-infection on fruit quality, and their fruit is not distinguishable from that developed on healthy plants. Thus, the TYLCV damage is quantitative, and inversely related to the age of the attacked plant. During winter (January-February) the activity of the whitefly population is markedly reduced and no further spread of the virus disease occurred. This situation may change somewhat if the winter is mild. The renewed TYLCV infections in March-April are not commercially important any more, since by that time all fruit which will be picked had already set. Because of the delay in their population buildup (March), the tomato russet mite, like the carmine spider mite, usually did not reach the threshold of economic damage, at least as long as winter temperatures were not unusually high and the picking season was not extended beyond the common date (May).

OBJECTIVE 1.5 BIOLOGICAL CONTROL

ISRAEL

Whiteflies: In the case of primary virus transmission by immigrating adults, classical biocontrol, using parasites (e.g. *Eretmocerus mundus*, *Encarsia lutea*) or pathogens e.g. *Cephalosporium* (*Verticillium*) *lecanii* (VERTALEC, MICOTAL) applied within the greenhouse, were useless.

Russet mite: No effective biocontrol agents are known.

The carmine spider mite: The predatory mites, *Phytoseiulus persimilis*, used in the experiments, were supplied by Mr. A. Falk, Biological Control Insectaries (Kibbutz Sde Eliyahu, D. N. Bet-Shean 10 810, Israel). The evaluation of the results, i.e. counting both the carmine spider mites and the predatory mites is described above in the section on pest phenology. The success of biocontrol by the introduction of predators is highly dependent on the correct timing of the predator's release and on the correct predator/prey ratio applied. Both problems are based on a good, quick and reliable, method to monitor spider mite populations. The late population buildup in March, when the tomato plants are already high and rather old, the detection of the initial spider mite population is extremely difficult. To overcome this obstacle it was suggested to plant small, 2-3 true leaves old bean plants, evenly distributed among the crop plants, at a rate of 20/1000m². The bean plants are highly attractive to the carmine spider mite (Fig.11-A) as had also been shown in laboratory experiments (Beke van Dijk, 1987; Gerson and Aronovits, 1980), and thus could served as Indicator plants (IPs). With the progress of the research it was suggested that these IP's can serve also as release points for the predators since they hosted a more dense population of the prey then on the tomato plants (Fig.11-B and 11-C). An experiment was performed in 6 greenhouses, with three treatments in each of them: 1. control- without predators, 2. predatory mites released evenly on the tomato plants, 3. predatory mites released in patches on the IPs only. The results (Fig.12) indicated that a better control of the spidermites was achieved by releasing the predatory mites on the IPs, as release points. The bean plant (IP) was a familiar-milieu to the predators since the predators had been cultured, by the producer, also on beans. Finally, the IPs helped also to check the quality of the obtained predator shipment, since it was easier to observe the biocontrol process on the IPs than on the tomato plants. Biocontrol using predatory mites, was found to be effective, provided the application was timed precisely. Indicator plants helped in the improvement of the exact timing of the biocontrol application, in determining the required predator/prey ratio, checking the initial acclimatization of the predators, and determining the predators' quality by following their initial colonization on the IPs.

Leaf miners: In untreated plots, parasitization-rates increased with time; from 18.5% in November to 78.5% at the end of December (Fig.10). Hence the leafminers seem to be controlled efficiently by naturally occurring parasitoids.

USA

In U.S. greenhouses, the leafminer *Liriomyza trifolii* can develop very high populations. As part of the original objectives of this project, experiments were planned to evaluate the effectiveness of different Hymenopteran parasitoids in controlling leafminers. When the project was actually approved, it was felt that there was enough evidence, based on work such as Lindquist and Casey, 1983, to indicate very strong possibilities for biological control. This was contingent upon reduced pesticide useage and

lack of significant yield effects. The effects of *L. trifolii* on yields of greenhouse tomatoes are presented later in this report.

OBJECTIVE 1.6 EVALUATION OF TOMATO LINES FOR RESISTANCE TO DIFFERENT INSECT AND MITE PESTS BY CHOICE AND NON-CHOICE TESTS

ISRAEL

Breeding for resistance to pests:

Resistance to the tobacco whitefly, as the vector of TYLCV. The purpose of this work was to study the potentials of the wild accessions *Lycopersicon hirsutum* var. *glabratum*, *L. hirsutum* and *L. pennellii*, as sources of resistance for breeding a tomato cultivar resistant to the tobacco whitefly, *Bemisia tabaci*, the vector of Tomato Yellow Leaf Curl Virus (TYLCV).

Methods:

The experiments had been made with adult whiteflies in choice- and no-choice experiments. In choice experiments - the resistance was studied under laboratory and field conditions by evaluating the number of the eggs and larvae per whitefly female, found on a given area (one leaf) or by assessing the number of adults found on the plants. In non-choice experiments resistance was identified in terms of adult mortality rate. Four or ten adult females of unknown age were confined by means of a clip-on cage onto the under side of the examined leaf. After 24h the dead whiteflies were counted. The mortality rate (%) was calculated and corrected in relation to the control (0% mortality). Each experiment was conducted in 2-6 replicates.

Results

Out of ten *L. hirsutum* f. *glabratum* accessions that were evaluated, only 3 were relatively resistant in all the experiments: PI- 134418, PI-129157 and LA-407; in *L. pennellii*, 7 accessions were examined. Two were completely resistant: LA-716 and PI-78956. Out of 8 *L. hirsutum* accessions the two most resistant accessions in all experiments, were LA-1777, and IVT-771498.

All the accessions that were artificially infected by TYLCV, were found to be susceptible. Even *L. pennellii* plants became infested by whiteflies and infected by TYLCV, when the sticky exudate was removed artificially from their leaves. When the most resistant accessions, mentioned above, were tested in a field experiment during August-September 1986, LA-716 and PI-78956 of the *L. pennellii* group were found to be completely resistant to the virus transmission; LA-1777 and IVT-771498 of the *L. hirsutum* group were relatively resistant; and those belonging to the *L. hirsutum* f. *glabratum* group became infected by the virus like the susceptible tomato controls.

The success of a breeding program for resistance to insects is highly dependent on the availability of quick and reliable test methods. Adult mortality (%) after 24h of forced contact in a non-choice experiment using leaf-cages, gave the best correlation with resistance. Another investigated measure was 'leaf stickiness', used at least for preliminary screening purposes. Leaf stickiness was determined as % sucrose in an aqueous solution (Plage, 1975). Granulated sucrose was scattered upon a known area of the leaf and the surplus was carefully shaken off. The sucrose which remained sticking on the leaf was washed off with a measured quantity of water. The sucrose content of the water was then measured by means of a refractometer. In *L. hirsutum* f. *glabratum*, an increase in leaf stickiness from 0.6% to 5.6%, caused an increase in resistance as expressed by an increase in whitefly mortality from 14 to 85%. However, even the stickiest plants were not completely resistant. It was concluded that when plant stickiness is 2.0% or

less, they will be eliminated from the breeding program. But, plants possessing a stickiness of 2.1% or more must be tested again in a bioassay. In *L. pennellii*, plants possessing a stickiness of 0.8-1.0% are susceptible. Relative resistance (50%-90% whitefly mortality), was due to a stickiness of 2.0%. Absolute resistance, 100% mortality, was found whenever the stickiness was 2.2% or more. This method was applicable also to the progenies. When F₂ hybrid plants (*L. pennellii* X tomato) were classified arbitrarily into 3 categories, according to their stickiness: 1.0% or less- susceptible; 1.2-1.8%- relatively resistant; and 2.0% or more- completely resistant, the bioassay confirmed the suggestion. Thus it was concluded that stickiness is a useful tool in screening for resistance.

When plants were grown in winter in a greenhouse under naturally reduced light intensity, only two accessions of *L. pennellii*, LA-716 and PI-78956, and one of *L. hirsutum* f. *glabratum*, PI-365907, were found to be relatively resistant. Whereas, when grown under high light intensity, all examined accessions were resistant. Kennedy et al. (1981) found that light intensity and day-length (photoperiod) affected the resistance of *L. hirsutum* var. *glabratum* to *Manduca sexta*. Based on these results and on our own experience, an experiment was performed in which plants were grown under four light regimes in which photoperiod (long vs. short days) and light intensities (high and low intensities) were combined. One of the *L. hirsutum* var. *glabratum* accessions was remarkably more susceptible to the tobacco whitefly when grown under the lower light intensity, independent to day-length, compared with the control plants. Regarding *L. pennellii* accessions, only plants grown under a combination of low light intensity and short-day photoperiod, were susceptible; all other light regimes yielded resistant plants.

The main mechanism of resistance that was observed, was a physical interference caused by the sticky exudate which is produced by glandular trichomes on the leaf surface. The whiteflies became entangled in this exudate and physically immobilized. This mechanism seemed to be the dominant one in *L. pennellii*. In *L. hirsutum* and *L. hirsutum* f. *glabratum*, it is not yet clear whether resistance is due only to the stickiness or if a toxic factor is involved.

Volatile substances, collected from intact leaves of a resistant *L. hirsutum* f. *glabratum* plant (LA-407), did not show any toxic effects on the whitefly adults. One of these compounds was the ketone, 2-Tridecanone, which exists in a rather high quantity in the leaves, and was found to be responsible for the resistance to some moth larvae. This substance was also toxic to whiteflies, but in doses which were much higher than those which existed in the leaves. The concentration of 2-Tridecanone in the leaves was not always in correlation with their resistance. 2-Tridecanone was also affected by day length although this had no effect on the level of resistance. Another volatile ketone, 2-Undecanone, is also known to exist in high concentrations in the leaves of the plants, but there were no indications that it has any connection with the mechanism of resistance to the whiteflies. Extracts of whole leaves of one of the relatively resistant accessions (IVT-66088) were not toxic to the whiteflies by contact. As yet, we have not ascertained the presence of gastrototoxic substances in the plants. *L. hirsutum* leaves contain essential oils. Three of them, which were tested for resistance activity in their synthetic and natural form, affected whiteflies differently. Differences in the of ketones' content were found in leaves of various accessions. However, no correlation between their quantity or quality and previous laboratory experimental results could be found. Extract of the sticky exudate

of *L. pennellii* trichomes, applied onto cotton leaves, protected them from whitefly adults for about a month. A toxic contact effect, browning and killing of the whitefly, was observed even after the sticky effect was neutralized by applying it on a filter paper.

The property of stickiness was found to be of a dominant feature, combined with a low penetrance in the young stage of the plants, when F1 and F2 hybrids (*L. pennellii* LA-716 X tomato) were investigated. Among F2 hybrids, a few plants showed the level of resistance necessary to prevent the virus transmission, due to a sufficient level of stickiness (2.2% sucrose, or more) which was present on the first true leaves. These plants were considered to be good sources for further breeding.

Resistance to the Egyptian cotton leafworm *Spodoptera littoralis* in *L. pennellii*: The possibility to use *L. pennellii* accessions (LA-1277, LA-716 and L.A-751) as a source for breeding resistance to the larvae of *S. littoralis*, was studied. The sticky exudate of the glandular trichomes which cover the leaf surface was the mechanism responsible for resistance to the small, 1st instar larvae (L1), of *S. littoralis*, as was found for other small insects, like the above mentioned whiteflies, and for spider mites. Once the exudate was removed the small larvae were able to feed and develop normally on those leaves. Larger, 2nd and 3rd instar larvae (L2&L3), overcame the physical barrier of stickiness but, became confronted with another mechanism of resistance; i.e., the influence of a leaf substance which acted upon them like a juvenile hormone. This effect resulted in a high larval mortality, and, in adults, morphological deformation and sterility. In contrast, bigger L4 larvae were not affected by this mechanism and developed into normal and fertile adults. The same symptoms were found in all studied accessions but, especially in the ecotype LA 751 (*L. pennellii* Sisicaya). Hexanic and acetic leaf extracts of this ecotype, mixed into an artificial diet, affected the larvae.

USA: Tomatoes were evaluated and selected for their resistance to *L. trifolii* over several seasons. The original breeding line was obtained by crossing a *Lycopersicon hirsutum* selection (KR-9, from the Netherlands) as the male parent with an Ohio greenhouse breeding line. After several generations (to F4) of selections, two lines were backcrossed to 'Ohio CR-6', a standard greenhouse tomato, and two were self-pollinated. Selections were then further evaluated after exposure to leafminers, and additional crosses were made.

In general, the closer plants came to appearing like cultivated tomatoes, the less leafminer resistance was present. *L. hirsutum* supported very few leafminer larvae, probably based on physical leaf characteristics and/or glandular exudates. There were numerical differences in leafminer infestation levels between commercial cultivars and some selections, especially in the "choice" evaluations, but they were not significant ($p=.05$). In "non-choice" experiments, even numerical differences were less apparent. Due to the lack of technical help, experiments have been discontinued. 2.3.3. Mechanical control

OBJECTIVE 2.1 EVALUATION OF PHYSICAL METHODS

ISRAEL: Whiteflies: Mechanical control is aimed at minimizing the penetration of pests into the greenhouse, e.g. by: 1) inducing a positive air pressure within the structure, or 2) using a coverage.

Methods and materials

Positive air pressure in the greenhouse was performed by vents which sucked the outdoor air through a filter, a wet pad ('Desert-cooler').

The coverage consisted of a porous unwoven polypropylene sheet (17 g/m²) Agryl, produced by Sodoca, France. The plants in the experimental greenhouses were covered with Agryl, inside the greenhouse, 1-3 days before planting. The control houses were sprayed daily, for about two months from planting. The insecticides used were, as commercially recommended, pyrethroids: cypermethrin and fenpropathrin (see chemical control). The tomato plants were irrigated by a drip system and grown in the common commercial-agrotechnical way. The naturally occurring adult whiteflies were scored weekly by means of 5-10 yellow sticky traps per replicate. At the same dates the virus infested plants were counted and recorded. Experiment A was carried out in small plastic houses (10m²), experiments B, C and D were carried out in a glasshouse (700 m²) at the Besor Experimental Farm, and experiments E-H were carried out in commercial glasshouses (1000m²) at Sede Nitzan. Experiment D was aimed at answering the question "when could the grower stop to apply the whitefly control measures without endangering his yield?" To study the necessary duration of the control treatments, tomatoes were planted on 1st October, and grown in the commercially common agrotechnical way. One half of the greenhouse was sprayed with chemicals and in the second half the plants were protected by Agryl coverage. Each control-method was applied for various periods lasting from 0 days, the untreated control, to 56 days (2nd December) when the outdoor whitefly immigration practically ceased (e.g. Fig. 2). The number of whitefly/trap was calculated weekly for the first period of 85 days (until 31st December). TYLCV infected plants were counted 140 days after planting on 24th February. The results of experiments A, B, C and F were analyzed by the Students Newman and Keuls test for completely randomized blocks at a level of $p < 5\%$.

Experiments D, E, G, and H were not analyzed statistically because they were performed in 3-4 individually experiments, rather than in replicates, since for each experiment a whole, commercial, greenhouse was needed. The experimental details are summarized in Table 7.

Results: Induced air overpressure During a period of three months (2nd October - 4th January), 371 and 433 whiteflies/trap were caught in two regular greenhouses, compared with only 132 and 198 whiteflies/trap that were caught at the same time in two greenhouse in which overpressure was induced. These results indicated a considerable reduction (about 60%) of immigrating whiteflies, due to overpressure. This reduction in whitefly immigration resulted also in a reduction in the rate of TYLCV-infected plants: 26.4-29.8% in the regular greenhouses compared with 2.8-7.2% in the greenhouses possessing the air overpressure installation.

2) Agryl coverage

The effect of coverage vs . spraying on the number of whiteflies trapped and on TYLCV spread, was studied in three sets of experiments: In the first set, experiments A-C, significantly less whiteflies, and less TYLCV-infested plants, were found in the covered (unsprayed) plots, compared with the sprayed (uncovered) plots (Fig. 13). The second set of experiments (E-H) was conducted to verify if the results, obtained experimentally under low tunnels, are also reproduceable in commercially grown, normal sized greenhouses, each of 1000m². The results (Fig.14) indicated that the Agryl coverage prevented

the whitefly penetration as well as TYLCV infection in a better way than the commercially sprayed insecticides. In the third set (Experiment D), concerning the duration of control measures, plants which were not treated at all (i.e. 0 days) became almost totally, 98%-100.0%, infected by the virus (Fig. 15). The longer the duration of the treatment lasted, 14 - 56 days, less and less plants became infested. In the first period, i.e. after 24 days of treatment, there was no remarkable difference between the two treatments, covering and spraying. The longer the treatment lasted the more the coverage reduced the infestation rate (7.0-0.0%), compared with the sprayed plots (24.0-27.0% of virus infected plants). In conclusion: 1) Planting greenhouse tomatoes under a tightly closed Agryl coverage, reduced TYLCV infection rates considerably and can substitute for chemical control. 2) The plants can be uncovered, or spraying can be ceased, when the outdoor-whitefly's immigration decreased to almost zero, usually during November, but latest in December.

Leaf miners: In organically cultivated greenhouses, covered by Agryl from planting to end of November the appearance of adult leafminer, in yellow sticky traps, was delayed by about three weeks, in comparison with the commercially sprayed greenhouses (Fig.8-B), and mining larvae were difficult to find. At the same time a low infestation, less than 0.5 larvae/leaflet were found in commercially sprayed houses, compared with 1-3.5 larvae/leaflet in untreated plots.

PVY bearing aphids: In 6 organically-cultivated, with Agryl covered greenhouses, the rate of PVY-infected plants reached, as counted finally in February, 0.2-0.4% compared with 1.5-3.0% in 6 conventionally sprayed greenhouses. In a second observation in untreated plots, the infection rate reached 10.5%, in chemically treated plots 5.3% and in Agryl covered plots 0.0%.

USA: (Note: The following section is a manuscript sent to Environmental Entomology for review and possible publication.) LEAF MINERS IN the genus Liriomyza, and especially L. trifolii (Burgess), have become important pests of ornamental and agricultural crops in the past decade (Lindquist 1983). With the development of resistance to many insecticides by L. trifolii (Parrella et al. 1984) the implementation of control methods with less emphasis on insecticides has increased in importance. These methods include parasitoids (Johnson & Hara 1987, Minkenberg & van Lenteren 1986, Parrella et al. 1982), predators (Keularts 1980, Parrella & Bethke 1982) and nematodes (Parrella et al. 1982). Other practices shown to have potential in reducing leaf miner populations include the use of trap crops and yellow sticky traps (Herbert et al. 1984).

Manipulating the leaf miners' environment in order to increase mortality, particularly in the prepupal and pupal stages, may also be possible in greenhouses. Factors that could influence mortality are temperature, relative humidity, irrigation and substrate. Using temperatures to control leaf miner populations would not be successful, because temperatures unfavorable for leaf miners are also unfavorable for the host plant. Changing relative humidity may be more feasible as this condition is unlikely to harm host plants significantly. Reducing relative humidity will increase water loss by the prepupae and pupae, particularly if leaf miner prepupae are prevented from entering the soil. Increasing humidity may enhance the possibility of infection by pathogens.

Most leaf miner prepupae drop to the surface of the substrate under the

infested canopy. Very coarse substrates have been shown to increase leaf miner mortality (Oetting 1983), although the reason for this increased mortality was not determined. If the adverse effect of the substrate would be consistent for a relatively thin layer, then applying such materials underneath susceptible plants could be a further feasible contribution to the control of the insect.

The use of aluminum, paper, or plastic coverings can affect the severity of infestation of vegetable crops by various insects, including Liriomyza spp. (Chalfant et al. 1977, Price & Poe 1976, Webb & Smith 1973). Placing a barrier between the plant canopy and the soil surface will make removing prepupae and pupae possible. Physical destruction via drowning or trapping are other possibilities when water or sticky material, respectively, would be applied to its surface.

In this study experiments were carried out to investigate effects of several environmental factors on leaf miner prepupae and pupae, including: (a) relative humidity, (b) different types and depths of sand, and (c) wet and dry polyethylene soil coverings.

Materials and Methods

Relative humidity. Relative humidity-related mortality was determined for leaf miner prepupae and pupae by incubating them at $22 \pm 2^\circ\text{C}$ in large petri dishes (15 x 90 mm) with relative humidities of 20, 40, 50, 60, 70, 80, or 100%. Relative humidities of 20 to 80% were achieved by using different concentrations of aqueous sulfuric acid solutions (Weast 1985). A relative humidity of 100% was maintained by using a saturated aqueous copper (II) sulfate solution. All solutions were added to dishes 2 d before insects were introduced.

Leaf miner larvae were collected in a commercial greenhouse from heavily infested tomato plants. Leaflets containing nearly mature larvae were removed and brought to the laboratory. There the leaflets were placed on coarse wire mesh screen which was suspended over a sloping smooth plastic surface. Emerged prepupae were collected at the bottom of the plastic in petri dishes. Prepupae were collected within 5 min after emergence and a minimum of 100 was placed in each of 56 small petri dishes (5 x 40 mm). Half of these dishes were immediately placed in the larger dishes serving as humidity chambers, one small dish per humidity chamber. The remaining dishes with prepupae were placed in a growth chamber at $60 \pm 10\%$ R.H., and within 24 h after all had pupated were also placed in the humidity chambers, one small dish per humidity chamber. The chambers were randomly arranged in the growth chamber with four replications of each treatment. Two wk after the start of the experiment, the number of emerged adults was counted. The remaining pupae were either desiccated or had not developed at all after another 3 wk. Regression analysis was used to describe the relationship between relative humidity and leaf miner mortality.

Pupation depth and survival. Two experiments were conducted. The pupation substrate was washed sand, sieved into five fractions of the following particle size ranges: 0.3-0.5, 0.5-1.1, 1.2-1.7, 1.7-2.4 and 2.4-3.5 mm. In the first experiment, each sand fraction was placed in 20 x 20 cm cylindrical cardboard containers. The sand was air-dried and placed in a growth chamber at $22 \pm 2^\circ\text{C}$, $60 \pm 10\%$ R.H., and a 16:8 (L:D) photoperiod for 2 d before allowing leaf miner prepupae to enter. Illumination was provided with white fluorescent lamps. In all but the coarsest fraction, the substrate layer was 5 cm thicker than the maximum depth at which pupation occurred as determined in preliminary tests. In the coarsest sand some prepupae reached the bottom of the container irrespective of the depth. Leaf miner prepupae were obtained in the manner described above. Prepupae were collected within 5 min after emergence and a minimum of 100 were placed in the center of each container. The containers were randomly arranged in the growth chamber in a completely randomized design with three replications for each of the five treatments. Seven days after the prepupae were placed on the substrate, the location of the leaf miners in the substrate was determined by removing the sand in 5 mm thick layers by inserting a thin galvanized metal sheet through existing slits in the sides of the containers. The sand over the metal sheet was removed and all insects present removed by washing in water. Pupae, empty pupal cases and adult flies were counted in each sand layer until the number of insects recovered corresponded to the number of prepupae placed in the container. The same procedure was followed for all but the coarsest type of sand, where 10 mm thick layers were removed. All pupae removed from the sand were placed in plastic petri dishes (10 x 40 mm) and kept in the growth chamber for 10 d to determine pupal mortality. Regression analysis was used to describe the relationship between particle size and pupation depth.

In the second experiment cylindrical cardboard containers (12 containers 9 x 20 cm, and 4 containers 9 x 40 cm) were filled with air-dried coarse sand (particle size 2.8-3.5 mm) to four different depths: 5, 10, 18, and 30 cm. The containers were arranged in a growth chamber as described above, with 4 cylinders for each depth treatment. A minimum of 35 prepupae were placed on the surface of the sand in each container and allowed to complete development. After 3 wk the number of emerged adults was recorded and the sand examined for dead pupae and adults. Regression analysis was used to describe the relationship between substrate depth and adult emergence.

Polyethylene soil coverings. In the first experiment, compartments of 0.002 mm clear polyethylene, 1.6 x 1.2 x 2 m, were constructed inside a greenhouse. Cheesecloth covered the tops of the compartments for ventilation. Three different substrates were compared: (1) uncovered soil, (2) soil covered with 0.004 mm white polyethylene, and (3) soil covered with polyethylene as above, with water applied to the polyethylene surface. Additional illumination was provided by white fluorescent lamps. Minimum and maximum temperatures within the compartments ranged from 14.8 to 30.1 °C. Compartments were arranged in a randomized complete block design with 4 replications per treatment. Six 3 1/2-wk old 'Allround' tomato plants were transplanted in each compartment in two rows, 0.5 m apart on 0.5 m centers. One wk after transplanting, 5 adult males and 5 females were released in each compartment. The number of completed mines in all plants was counted 19, 41 and 61 d later to determine the increase/decrease of first, second and third generations, respectively. At these times no live larvae or adults were detected in any of the treatments.

The second experiment contained the same treatments as above, with the addition of soil covered with a layer of coarse sand (particles 3.5-5.5 mm) at least 50 mm thick. The soil in each compartment was drenched with carbaryl (40% AI, 10 l/ha) 1 wk prior to planting, in an attempt to prevent predators from reaching pupae. The same experimental design was used as in the previous experiment. Sixty four tomatoes cv. 'Caruso', 77 d old, were exposed to large numbers of leaf miner adults for 72 h in cheesecloth cages. Four plants infested with larvae were then planted in each compartment at a spacing of ca. 0.5 m. Two wk later, after all leaf miner larvae had emerged, the empty mines in all plants were counted. Heavily infested leaflets were removed after recording the number of mines they contained. Thirty days later, following the emergence of all larvae of the second generation, all completed mines were again counted. The number of pupae present on leaves was also determined. In both substrate experiments data were analyzed using analysis of variance and means were separated by Duncan's (1955) multiple range test.

Results and Discussion

Relative Humidity. Pupal mortality for relative humidities of 20 to 80% is presented in Figure 16. At 100% R.H. (data not shown), water droplets had started forming on the inside of the petri dish lids 4 d after the start of the experiment. Although most pupae seemed to develop normally, no adults emerged after the pupal cases became covered with mycelia of various fungi. At other humidities, mortality decreased as humidities increased. Humidity seemed to have a greater influence on prepupal rather than pupal survival. Maximum pupal mortality was ca. 50% at 20% R.H., whereas mortality was 90% when prepupae were incubated at 20% R. H. Prepupal mortality remained quite high

(>50%) at humidities less than 60%. It is not unusual to have relative humidities in the 30-50% range in northern greenhouses during winter months. However, if tomatoes or other plants are grown in soil without any covering, most leaf miners will pupate in this protective medium and it would be unlikely that high mortality because of desiccation would occur. Only those individuals pupating on the leaf surface would be exposed to conditions which could reduce their survival.

Pupation depth and survival. In all but the coarsest sand (particle size >1.5 mm) leaf miners pupated fairly close to the surface (Figure 17). The range of pupation depths in the sand fractions were: <0.5 mm: 5-20 mm, 0.5-1.2 mm: 5-25 mm, 1.2-1.7 mm: 5-40 mm, 1.7-2.4 mm: 5-60 mm, and 2.4-3.5 mm: 5-300 mm. There were no significant differences in pupal mortality among the treatments. No dead prepupae were found in any of the containers. In the second experiment, there generally was less emergence in the containers with more than 200 mm of sand (Figure 18). Most of the adults which died before emerging from the sand did not have their wings fully expanded. Thus, leaf miners were able to pupate and complete metamorphosis. Pupation at extreme depths in coarse substrates probably will reduce leaf miner populations because emerged adults will not be able to make their way to the surface. This method may not be practical in all crop production programs, but could be useful, for example, when potted plants are produced on expanded metal benches, allowing some larvae to drop beneath the benches.

Polyethylene soil coverings. The number of completed leaf mines on different sampling dates in the two experiments is presented in Table 8. In general, there were fewer leaf mines when plants were irrigated from above and water remained on the polyethylene. Prepupae dropping to its surface inevitably ended up in the water where they drowned within 10 minutes. Predation by the pavement ant, Tetramorium caespitum (L.), was evident within 3 h after second-generation prepupae dropped on the plastic in three of the four dry-polyethylene compartments in the first experiment. The ants apparently were attracted to the polyethylene by drops of honeydew produced by the greenhouse whitefly, Trialeurodes vaporariorum (Westwood). In one compartment without polyethylene soil covering, parasitism by Opius dimidiatus Muesebeck was observed.

Despite the application of carbaryl, the second experiment was terminated prematurely because of heavy predation of pupae by ants in two dry-polyethylene replications. After the second sampling date, only leaf miners which pupated on the leaf surface survived and completed their development. At the second sampling date, the fewest leaf mines were recorded in compartments where irrigation water remained on the polyethylene. Covering the soil with a 5 cm layer of coarse sand, as expected, did not significantly reduce leaf miner populations. Based on results in earlier experiments, the sand layer would need to be more than 20 cm thick to affect adult emergence.

The use of polyethylene coverings underneath leaf miner-infested plants could be useful in several ways, including exposure to low humidity (described above), predators and drowning. Polyethylene soil coverings combined with water applied to the surface can be a very effective method of reducing an infestation of L. trifolii in tomatoes, as well as other crops. This is especially true before the plant foliage canopy becomes thick enough to provide enough leaf surface for pupation. Prepupae will drown there within 5-10 min so that even receding water, because of high temperatures in the greenhouse, would not lower the water level fast enough for the prepupae to

come in contact with air again. Adding water to the plastic surface when needed will provide additional assurance that no prepupae will survive. The use of polyethylene in conjunction with water may reduce or eliminate the need for insecticide applications for leaf miner control when immigration of leaf miner adults can be prevented or significantly reduced.

These procedures would be generally compatible with a biological control program for leaf miners, although the presence of plastic soil covering could have a positive influence on other insect and mite pests. However, pupal parasites of leaf miners, such as Opius spp., will be removed from the system in the same way as the leaf miners themselves.

OBJECTIVE 2.4: EXPERIMENTS TO DEVELOP SAMPLING METHODS FOR *LIRIOMYZA*

TRIFOLII ON GREENHOUSE TOMATO

USA: A method to quickly assess the population dynamics of a leafminer infestation on greenhouse tomatoes is necessary in a pest management program. This is useful for both leafminers and their natural enemies.

Two 7 x 7 m greenhouse compartments were planted with tomatoes (cv. 'Ohio CR-6'). There were six rows of 10 plants each. Prior to transplanting, the seedlings were grown in organdy cages to prevent premature leafminer infestation. The two outside rows, plus the first and last two plants in other rows were considered border plants, and were not used in the sampling experiment. Every second plant of those remaining was assigned a number. After several weeks the plants that were not used for sampling were removed to facilitate pupal collecting. One week after transplanting 60 adult *L. trifolii* were released in each greenhouse compartment. Leaf sampling began 2 days later.

For sampling, leaves were counted from the base of the plant upward. This was done on the first sampling date, and the top leaf was tagged to serve as a reference point in the event that lower leaves fell off as plants aged or became heavily infested. The leaflets on each leaf were numbered from the terminal leaflet toward the stem. Sampling consisted of recording the number of completed leaf mines and active/dead/parasitized larvae at 7-14 day intervals for 8 weeks. The tomato plants had 21 leaves when the experiment was terminated. At that time all the sampling data for each plant was totaled (per plant, per leaf and per leaflet), and the data were subjected to correlation and regression analysis.

Results (Table 6) indicated that sampling the terminal three leaflets on less than half of the total leaves/plant will give good estimates of the total number of completed leaf mines on that plant. The best leaves for sampling depended on the number of leaves on the plant when sampled. At the last sampling date, when plants had 21 leaves, sampling the terminal three leaflets on one leaf (11th from the base) gave a highly significant correlation ($r = .90$) with the total number of completed leaf mines, and estimated 10.8% (range: 5-15%) of the total.

Table.6 Relationship between the number of completed leaf mines on three terminal leaflets of selected leaves and the entire plant.

No. leaves*	Leaves sampled**	Linear regression equation	R
8	2,3,4	$Y = .57(X) - .43$	.96
11	3,4,5,6	$Y = .23(X) + 1.21$	.84
14	4,5,6,7,8	$Y = .18(X) + 5.72$	.71
19	7,8,9,10,11,12,13,14	$Y = .17(X) - 17.08$	.88

* No. of leaves present on each of four sampling dates.

** No. completed leaf mines recorded on terminal three leaflets on each

OBJECTIVE 2.5 Yield Reduction of Greenhouse Tomatoes Resulting from Damage by Leaf Miners (Diptera: Agromyzidae) or Artificial Defoliation. (Note: this section is based on a manuscript being prepared for publication.)

MANY AGROMYZID LEAF miners are known to cause yield loss in vegetable crops if the infestation is severe (Spencer 1973). Several Liriomyza species may infest tomato plants and treatment of infested plants is recommended in a number of states. However, the exact relationship between the severity of a leaf miner infestation and the yield of the infested tomato crop has not been found yet. Nearly all studies of this relationship have been carried out with field tomatoes. Johnson et al. (1980a,b) found no statistically significant differences in field tomatoes by controlling leaf miners with insecticides even though the infestation level in the control plot reached 22 leaf mines/leaflet as compared with 3 leaf mines/leaflet in the least damaged plots. Levins et al. (1975) also found no statistically significant effect of leaf miner damage on yield of field tomatoes. In a preliminary investigation of greenhouse tomatoes, Lindquist (1974) found no significant yield reduction as a result of leaf miner infestation. On the other hand, Ledieu and Helyer (1985) concluded that there is no damage threshold below which no loss occurs, although the extent of the yield loss is not only determined by the severity of the damage but also by the location of the damaged leaves in relation to developing fruits. Wolfenbarger et al. (1966) concluded from yield and infestation data obtained over several years that when applying a sequential sampling plan finding mines in 40 % or more of the sampled leaves, an insecticide application was warranted to slow down a further leaf miner population increase.

All investigations of the effect of leaf miners on yield reported thus far, compared only total yields. However, one of the most important factors for greenhouse growers to compete successfully with producers from other areas is earliness in the supply of marketable tomatoes. Fruits marketed early in the season usually demand the highest price. Thus, even though total yields are not reduced, a delay in production could still mean a significant reduction in income to the grower.

The true response of a plant species to injury by leaf miners can only be determined by infesting plants with the insect, the infestation starting at different times, lasting for different periods, and for both these factors using different sizes of the insects' population.

Investigations of leaf miner damage and yield relationships are difficult as the number of damaging larvae can not be controlled easily because this depends on the oviposition activity of the female flies. The complexity of the tomato canopy and the crop's vascular system makes the effect of leaf damage on the development of flowers and fruits even more difficult to evaluate.

Simulation of insect pest damage to plants has many advantages over the use and management of the insect itself in order to establish this relationship and has been tried on numerous occasions. The amount of damage can be controlled to a large extent; the period in which the damage occurs and the duration, i.e. the number of generations allowed to develop, can be exactly determined. Artificial damage to tomato leaves has been shown to affect the rate of development of the inflorescences. Both inhibitory effects on flower initiation (Kinet 1977) and enhancing of the rate of fruit ripening (Slack 1986) have been reported.

Comparing the results of these experiments with those of experiments involving natural leaf damage is not easy, however. Although the apparent damage of the simulation may be correct, i.e. the area of photosynthetically active tissue destroyed is the same, the actual effect on the plant may not be exactly comparable.

In this study, several experiments were carried out in which the effects of heavy leaf miner infestation, occurring at different times in the tomato plants' development, on the early and total yield were investigated. In all these experiments only one generation of leaf miners was allowed to develop to limit the number of experiments to a manageable level. In addition, two predetermined infestation levels, each lasting one, two or three generations, were simulated by removing leaf tissue manually. The actual consumption of leaf tissue by the leaf miner larvae takes place over a 4- to 10-day period, depending on the temperature (Parrella 1987), during which the feeding rate increases. In this experiment this gradual removal of leaf tissue was simulated by spreading the leaf-cutting procedure out over a period of three days and only removing tissue from fully expanded leaves because only these would normally be infested.

In addition, one experiment was carried out to compare the effect of a leaf miner infestation of tomato plants on yield with that of manual removal of approximately the same leaf area.

Materials and Methods

Leaf miner-damaged plants. Experiments were carried out to compare yields of infested and uninfested tomato plants by exposing a number of plants to large leaf miner populations in order to achieve an infestation level as high as possible. A minimum of three adult flies per leaflet were observed in all experiments. Nevertheless, the oviposition rate varied considerably from experiment to experiment. After a period of ca. 3 days in the presence of leaf miner flies the plants were placed in greenhouses and cared for in a manner similar to that carried out in commercial greenhouses. As some infestation of control plants was inevitable, the level of infestation was reduced as much as possible by killing leaf miner larvae in the early instars with mounted needles. Infestation by a second generation of the insect was prevented by removing as many pupae as possible soon after emergence. To achieve this, pupation in the soil was prevented by using either cardboard or plastic sheets underneath the infested foliage. In addition, the insect growth regulator cyromazine was applied ca. 1 week after the emergence of the last larvae. Complete development of leaf miner larvae was not observed any more following this application.

In four experiments 'CR6' tomato seedlings were transplanted to 10 l plastic pots containing Promix BX^R (Premier Brands Inc.) which were placed in a 6.3 x 7.6 m greenhouse in rows on 85 cm centers and spaced 43 cm within rows. A total of 64 plants were used for each experiment arranged in a randomized complete block design with 8 plants per treatment replicated 4 times. Each experiment consisted of only two treatments, infested and control plants. In two experiments plants were infested by leaf miners in specially constructed cheesecloth cages in which only mature leaves below the second inflorescence were exposed to large insect populations. Although not all plants could be exposed simultaneously, the stage of development of the plant at which the exposure occurred was approximately the same for all plants. Care was taken to ensure that all treatments consisted of plants of comparable morphological development. In one experiment the plants were exposed to leaf miners at the pre-bloom stage of the first inflorescence, and in the second at first-bloom. In the third experiment all potted tomato plants which were to be infested, were placed simultaneously in a small greenhouse chamber in which a large leaf miner population was present. In the fourth experiment plants were placed in the cheesecloth cages at the vegetative stage when 4 leaves were fully expanded. As the plants were relatively small, they could all be placed in these cages at the same time. After infestation was achieved, all plants were transplanted into soil in the greenhouse. In the remaining three experiments 'Allround' seedlings were used and those plants to be exposed placed in a small greenhouse in the presence of large leaf miner populations at the appropriate time. In two experiments the layout of the experiment was as described above and exposure was at the vegetative stage when 5 leaves were fully expanded, exposed plants again being transplanted into the soil. The third experiment was carried out in a 16 x 4.8 m greenhouse area and consisted of four treatments: control plants, and plants exposed at the vegetative stage when 4, 5, and 7 leaves were fully expanded, respectively. Each treatment consisted of 11 plants in single rows 90 cm apart, spaced at 45 cm within rows.

Manual Defoliation. Seedlings of 'Caruso' tomatoes, seeded on 7 November 1986 were transplanted into a 21 x 4.8 m bed in a greenhouse on 9 January 1987. All cultural practices carried out in commercial greenhouses were applied. Leaf

miner damage was simulated by removing parts of the plants' foliage with scissors beginning 17 January. Ca. 10% of the leaf area to be removed was cut off on day 1 of the simulated infestation cycle, ca. 20 % on day 2, and the remainder on day 3. The levels of defoliation were 50% and 100% with only fully expanded leaves considered for tissue removal. Each level of defoliation was carried out one, two or three times, thereby attempting to simulate infestations by one, two or three successive generations of leaf miners. Subsequent defoliations were carried out at fifteen-day intervals. Control plants were not defoliated at all. There was one plant per treatment per replication with all treatments replicated 30 times except the thrice 100% defoliation which was replicated 20 times. The experiment was arranged in a completely randomized design. Data collected were plant height at two-week intervals beginning on 11 February date of first flowering and number of flower buds for each of the first 7 inflorescences, as well as weight and number of fruits harvested per cluster for the first 4 inflorescences. Statistical analysis was carried out by using analysis of variance.

Comparison of effects of leaf miner damage and manual defoliation. The tomato plants used were of the same source as those used for the manual defoliation experiment. Sixty plants were divided into three equal groups. One group of plants was exposed to a large leaf miner population for ca. 3 days in cheesecloth cages on 5 February 1987. All other plants were placed in similar cages but without insects under similar conditions during this period. Fifteen infested tomato plants and thirty uninfested ones were planted in a 5.4 x 4.8 m area of a greenhouse on 9 February at random locations. Plants of the second group were partially defoliated by means of scissors beginning on the day that first instar larvae were detected in large numbers in the infested plants. Attempts were made to remove only as much of the leaves as was occupied by the mines in the leaf miner-infested plants. As the leaf miner larvae developed in this first group of plants the area to be removed in these manually defoliated plants could be estimated. Ultimately about 50% of the leaf area in the infested plants was occupied by mines and, therefore, removed from the plants in the second group. Plants of the third group were the control. Continued infestation was prevented by catching emerging leaf miner larvae on plastic sheets placed on the soil underneath the plants. Predation by pavement ants (Tetramorium caespitum (L.)) made manual removal of the pupae unnecessary. All cultural practices carried out in commercial greenhouses were applied. Data collected were number and weight of the fruits of the first 4 clusters. They were analyzed using analysis of variance.

Results and Discussion

Leaf miner-damaged plants. An infestation by leaf miners for one generation at relatively high levels apparently only delays the development of tomato fruits for a short period when it occurs at anthesis of the first inflorescence. Figures 19 and 20 show examples of data obtained in two experiments. When tomatoes were infested during full bloom of cluster 1, (Fig. 19) there were significant yield differences in yields on clusters 1-3 on specific dates, but overall cumulative yields were not significantly different. Plants infested during first bloom did not show these differences (Fig. 20).

Although damage by leaf miner larvae reduces the photosynthetic activity of the affected leaves, this decrease in available assimilate may not affect fruit development and growth at all. Partial removal of leaves is known to increase the net assimilation rate (Tanaka & Fujita 1974, Wolk et al. 1983) because under normal conditions leaves perform photosynthesis below their potential. Although the tomato plant is considered to consist of a number of source-sink units (Tanaka & Fujita 1974) each composed of 3 leaves, truss and bud, these units are not absolute. No or little compensation for leaf loss is expected if an entire unit is defoliated (Watson & Casper 1984). Compensation occurs when leaves from various units are partially removed as would normally happen as a result of leaf miner infestation.

Leaf miners usually attack lower and middle leaves of tomato plants first. Because more than 2/3 of the canopy net photosynthesis is the result of the photosynthetic activity of the uppermost 1/3 (Acock et al 1978), even a large reduction in the active leaf area by leaf miners would have only a small effect on the overall assimilate production.

A decrease in the rate of photosynthesis need not necessarily be detrimental to the plant in the long run: compensation to damage by leaf miner larvae has been shown in bean. As the tissue removal by this insect is very gradual the plant may be able to produce extra tissue while this damage is being done. It also is possible for nutrients to be translocated from other leaves or organs to the inflorescences normally served by the damaged leaves. The photosynthetic potential of old and young leaves is not significantly different, therefore, loss of foliage due to early senescence may increase the light intensity on lower leaves. This in turn would result in an increase in the photosynthetic activity of the lower leaves resulting in a compensation for the loss of production in the infested leaves.

Manual defoliation. Repeated defoliation, especially at the 100% level, caused a significant delay in the development of the entire plant and, therefore, in the time of anthesis and fruit development (Fig. 21). The first inflorescence of the plants receiving the most severe treatment did not develop at all resulting, in a 10-day delay in fruit production. All treatments resulted in a significant delay in fruit production. Tolerance to mechanical damage by tomatoes has been demonstrated on numerous occasions. As this type of defoliation usually exerts greater pressure on the plant than any type of gradual defoliation by herbivorous insects, without associated injection of toxins, it seems likely that tomato plants would be able to tolerate defoliation by insects better.

Although the same amount of tissue may be removed by leaf miner larvae and by the manual defoliation the resulting effects on other tissues and organs of

the plant may be different. Leaf miner damage is frequently associated with chlorosis, possibly the result of toxins secreted by the insect or invading pathogens. The reduction in photosynthetic activity has been shown to be greater than could be accounted for by the removal of tissue alone (Parrella et al 198).

There will be continued shading of lower leaves to some extent.

Instantaneous decrease in shading on organs below removed plant parts. It is clear that repeated defoliation, especially at the highest level, delays the development of tomato plants considerably.

Response of tomato plants to wounding: transportation of hormone throughout the plant possibly eliciting a response to the wounding (Broadway et al. 1986) in the form of compensation etc. The wounding of the palisade tissue by the leaf miner larvae does have an effect on the tissue in its vicinity: reaction of the plant to the wounding and possibly in addition a response, negative or otherwise to possible production/secretion of toxic substance(s) by the larvae. However, a possible negative response within the affected leaf does not lead to an overall negative response in term of yield of the entire plant for a number of reasons. The leaf tissue removed produces excess assimilate and is, therefore, expendable. The plant can also compensate for the lost photosynthetically active area by making the remaining tissues more efficient and increasing their productivity or by increasing the total leaf area on the plant.

The relationship between leaf miner infestation and yield or for that matter defoliation and yield does not seem to be consistent. Interaction between the damage and other factors, such as climatic conditions may play an important role in the response of plants to tissue loss. Of particular interest is the difference in conditions between field and greenhouse grown tomatoes. Because of the many differences in these environments the effects of leaf miner infestation on the same plant species and cultivar may be entirely different. Air movement has been shown to have an effect on the structure of tomato plants while temperatures which usually reach may higher maxima inside greenhouses do certainly have inhibitory effects on flower and fruit production. Again the interaction between the leaf miners and the environmental conditions here can easily account for the differences in response of the plants in the two environments.

Comparison between manual defoliation and leaf tissue removal by leaf-mining insects:

1. M. complete leaf parts removed with as result less photosynthesis as well as reduced respiration than only palisade tissue (or spongy tissue) removed with continued shading and continued respiration by a larger amount of tissue.
2. Response of the plant to the different kinds of damage may not be identical even when only physical damage is done in both instances.
3. Possibility of production of a phytotoxic substance by the larvae with an effect beyond actual feeding injury.

Progress made in this research

1. The tomato greenhouse pests in Israel were identified and their phenology and damage was studied.
2. Yellow sticky traps were approved to be in high correlation with TYLCV incidence plants and thus a very good and reliable tool to study the whitefly appearance.
3. A quick and reliable laboratory method for mass screening of insecticides aimed at the prevention of virus transmission, was developed and used to evaluate pesticides against both *B. tabaci* and *T. vaporariorum*.
4. An IPM program, which allows Bio-organic tomato cultivation was developed in Israel. Progress toward this goal was made in the USA.
5. A breeding program for tomato resistance to the whitefly vector of TYLCV was started. In making selections for *L. trifolii* resistance in greenhouse tomatoes, most of the resistance was lost as plants became more like cultivated types, indicating physical factors were of primary importance.
6. A number of environmental and physical factors that affect pest development, survival and subsequent virus transmission were identified. These include physical barriers (to *B. tabaci* and *L. trifolii*), positive air pressure (*B. tabaci*), and water (*L. trifolii*, *F. occidentalis*).
7. Yield reduction potential of leaf miners on greenhouse tomatoes was studied, and results indicated that most of the potential reduction occurs when infestations begin early in the crop growth. Biological controls are therefore possible and practical.

In Conclusion- The application of an efficient IPM program is possible in both the USA and Israel, based on these results. This cooperative project evaluated several common and similar pest problems and found practical solutions to many of them. In some cases, the above pest management strategy also allows organic farming.

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Webb, R. E. & F. F. Smith. 1973. Influence of reflective mulches on infestations of Liriomyza munda in snap bean foliage. J. Econ. Entomol. 66: 539-540. sampled leaf compared with total completed leaf mines on plant.

Table 1. The testing method concept (SI = Standard Insecticide)

Tab. 2 . The tested insecticides
(+ recomendable, - unrecomendable)

<u>Common name</u>	<u>Generic name</u>	<u>Producer</u>	<u>Final tested Concentration %</u>	<u>Conclusion</u>
<u>Pyrethroids</u>				
Besis	decmethrin 25% E.C.	Roussel Uclaf	0.3	-
Cybolt	flucyhnate 10% E.C.	Cyanamid, Italy SPA	0.5	-
Cymbush	cypermethrin 10% E.C.	ICI	0.3	+
Karate	cyhalothrin 5% E.C.	ICI	0.3	+
Phenopracide	cypermethrin } + methidation } 50% E.C.	Cyba-Geigy Ltd.	0.3	-
Smash	fenopathrin 10% E.C.	Sumitomo Chemicals Co Ltd	0.3	+
Smash	fenopathrin 10% E.C.	Sumitomo Chemicals Co Ltd	0.3	+
+Virol }	mineral oil 80% E.C.	Pazchim, Israel	+1.0	+
Syprin	cypermethrin 20% E.C.	Dow Chemical USA	0.15	+
Telstar	biphenate 10% E.C.	FMC Chemicals	0.15	+
Titan	cypermethrin 20% E.C.	Shell International Chemical Co	0.15	+
<u>OP-compounds</u>				
Cotnion	azinophos ethyl 20% E.C.	Makhteshim Chemical Works	1.0	-
Divipan	dichlorovos 100% E.C.	Makhteshim Chemical Works	0.3	-
Dizictol	diazinon 25% E.C.	Makhteshim Chemical Works	0.3	-
Dorsan	chlorypyrphos 48% E.C.	Dow Chemical USA	0.9	-
Hostathion	triazophos 30% E.C.	Hoechst AG Verkauf Landwirtschaft	0.5	-
Orthene	acephate 75% W.P.	Chevron Chemical Company	0.3	-
Nuvathion	fenitrothion 10% E.C.	Cheminova A/S	0.3	-
Parathion	parathion 50%	Sandoz SpA	0.5	-
Reldan	chlorypirophos methyl 24% E.C.	Dow Chemical USA	0.45	-
Rugor	dimethoate 40%	Montedison		
+ Dorsan }	chlorypyrphos 48% E.C.	Dow Chemical USA	0.2	-
<u>Carbamates</u>				
Deltanet	Thiocarbamate 40% E.C.	Ciba-Geigy Ltd	0.3	-
Murphotox	mecarbam 50% E.C.	Dow Chemical USA	0.7	-
<u>Mineral Oils</u>				
Virol	mineral oil 80% E.C.	Pazchem	1.0	-
<u>Organochlorides</u>				
Benzilan	chlrbenside 25% E.C.	Makhteshim Chemical Works	0.2	-
<u>Pyridins</u>				
K-840	thiazopir 480 g/w	Rhone Poulenc Phytosanitaire	0.3	-
<u>Others</u>				
Amitraz	Amitraz 20% E.C.	FBC Ltd	1.5	-

Table 7: Agrotechnical and experimental details of the methods used in the experiments with covered and chemical control

<u>Exp.</u>	<u>Date of Planting</u>	<u>Duration of treatment (days)</u>	<u>Number of replicates</u>	<u>No. of plants/replicate</u>	<u>Method of coverage application</u>	<u>Type of Greenhouse</u>
A.*	10 .IX. 80	42	5	18	Stretched**	experimental
B.*	16 .IX. 81	40	5	60	Low-tunnel	experimental
C.	10 .X. 83	72	5	144	High-tunnel	experimental
D.	01 .X. 84	***	1	144	High-tunnel	experimental
E.	01 .X. 84	70	1	~3000	High-tunnel	commercial
F.	01 .X. 85	70	4	~3000	High-tunnel	commercial
G.	01 .X. 86	70	2	~3000	High-tunnel	commercial
H.	01 .XI. 86	40	1	~3000	High-tunnel	commercial

* after uncovering the plants, they were sprayed until mid December.

** directly on the plants.

*** 0, 14, 24, 35, 45, or 56 days after planting, according to experimental requirement.

Table 8. Mean number of completed mines in each of three (Experiment 1) or two (Experiment 2) Liriomyza trifolii generations on tomato plants grown in soil without covering, with dry or wet polyethylene soil coverings, and (Exp. 2), with a 5 cm thick layer of coarse sand covering the soil.

Pupation Substrate	Experiment 1			Experiment 2	
	Generation			Generation	
	1	2	3	1	2
sand over soil				39.1 ± 7.2 a	384.7 ± 13.8 a
soil	6.9 ± 1.1 a	58.0 ± 7.7 a	126.0 ± 54.8 a	29.7 ± 6.0 a	400.3 ± 57.7 a
dry poly	6.1 ± 1.1 a	39.9 ± 7.4 a	40.0 ± 18.3 b	38.1 ± 8.1 a	337.1 ± 43.8 a
poly +					
water	5.9 ± 1.7 a	15.6 ± 3.2 b	21.9 ± 7.2 b	29.4 ± 2.7 a	1.9 ± 1.0 b

Values are the means ± SEM of four replicates. Means in a column followed by the same letter are not significantly different ($p > 0.05$; Duncan's [1955] multiple range test).

Fig. 1. Whitefly phenology, Gilat Outdoors 1978-87

**Fig. 2 . Whitefly phenology out- and indoors
(Besor Exp. Farm, 1984/5)**

**Fig. 3 . Correlation between trapped-whiteflies (X)
and TYLCV-infected plants (Y), Sede-Nitzan
(Sprayed greenhouses, 1984-1986.)**

Fig. 4 . Whitefly and TYLCV appearance indoors
 (Untreated greenhouse, Besor Exp. Farm, 1984/5)

**Fig. 5. TYLCV appearance, Besor Exp. Farm
(Sprayed Greenhouses)**

Fig. 6. Russet mite appearance in Greenhouses
(Sede Nitzan, 1986/87)

**Fig. 7. Spider Mite Phenology on greenhouse tomatoes
(Seda Nitzan 1985/86)**

**Fig. 8 . Phenology of leafminer larvae and adults
in tomato greenhouses**

Fig. 9. TYLCV infection in field tests

Fig. 10. Phenology of leafminer larvae and % parasitism (#) in greenhouse tomatoes (Besor Exp. Farm, 1984/5)

Fig. 11. Spider mite Phenology and Biocontrol in Organic Greenhouses (Sede Nitzan, 1985/6)

Fig. 12. Biocontrol of the carmine spider mite

Fig. 13. Appearance of whiteflies and TYLCV

Fig. 14. Appearance of the whiteflies and TYLCV

Fig. 15. The effect of treatment duration on Whitefly appearance and TYLCV infection

FIGURE 16. Liriomyza trifolii mortality after exposure of prepupae and pupae, or pupae only, to different relative humidities at $22 \pm 2^{\circ}\text{C}$.

FIGURE 17. Liriomyza trifolii pupation depth in relation to substrate particle size.

FIGURE 13. Liriomyza trifolii adult emergence after pupation in different depths of coarse sand (particle size 2.8-3.5 mm).

FIGURE 19. Effects of one *Liriomyza trifolii* generation on greenhouse tomato yields when plants were infested at full bloom of cluster 1.

YIELD vs INFESTATION

FIGURE 20. Effects of one *Liriomyze trifolii* generation on greenhouse tomato yields when plants were infested at first bloom of cluster 1.

YIELD vs INFESTATION

FIGURE 21. Effects of manual defoliation on subsequent yields of greenhouse tomatoes (% = amount of foliage removed, 1X, 2X, etc. = repetitions of foliage removal).

FIGURE 22. Comparison of greenhouse tomato yields after Liriomyza trifolii infestation and manual defoliation.