THE BIOLOGY AND CONTROL OF LIRIOMYZA TRIFOLII (BURGESS) (DIPTERA: AGROMYZIDAE) ON TOMATOES

BY

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DECLARATION BY CANDIDATE

This Thesis is my original work and has not been presented for a degree in any other University.

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DECLARATION BY SUPERVISOR

This Thesis has been submitted for examination with my approval as University Supervisor.

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ABSTRACT

The study of the life history of the American serpentine leaf miner *Liriomyza trifolii* (Burgess) has been carried out both in the field and in the laboratory. The life cycle was found to be dependent on temperature and relative humidity. In the field the duration was 27 days as compared to 16.4 days in the laboratory at 79 $\pm$ 2% R.H. and 25 $\pm$ 1^{o}C.

Host range surveys were done at several locations in the country. A total of 43 plant species in 13 plant families were found to be hosts of *L. trifolii*. There was a definite host preference for Compositae, Solanaceae, Cucurbitaceae and the Leguminosae families in all the areas visited. Four indigenous agromyzid species were also found mining leaves of various host plants. Four species of parasites of *L. trifolii* were reared from the larvae and pupae of *L. trifolii*. Two species were dominant in all areas while the other two occurred in very small numbers.

Six inseticides were evaluated for their effects on *L. trifolii* and its parasites on tomatoes. The insecticides were in two groups:

Systemics and non-systemic sprays. Triazophos which was outstanding in the control of the leaf miner was found to have adverse effect on the parasites. The systemics: oxamyl and disyston were found to be ideal both for controlling *L. trifolii* and preserving the parasite complex.

Correlation between damage caused by *L. trifolii* and yield was not significant. Thus, it was noted that application of insecticide treatments should relate to the marketable yield and the extent of damage in any given situation.

CHAPTER 1

1. INTRODUCTION

1.1. Horticultural crops: A general survey

Kenya like many other developing countries developed its agriculture with the emphasis of only a few main cash crops, mainly coffee, tea and pyrethrum. This trend as would be expected has changed rapidly within the last decade. Horticultural crops occupy a prominent position in the economy of the country. As shown in Table 1, the outstanding potential resource for the industry coupled with expanding market opportunities for the produce, both within Kenya and Overseas, has produced remarkable growth within a short time (Anon, 1980a). Apart from the increase of total weight of exported produce there has been great diversification of the commodities produced. Due to the fact that a wide range of horticultural crops can be grown under different climatic conditions prevailing in the country, the Ministry of Agriculture in 1977 established priorities of carrying out a study towards development of horticultural crops

Table 1. Horticultural crop production: 1970 - 1980

Figures in metric tonnes*

Produce	Year 1970	Year 1980	Differences (Percentage)
Pineapple	849.3	1882	121.6
Mangoes	1079	1409	30.6
Avocadoes	- **	653	100
Miscellanous Fruits	-	327	100
Passion fruits	-	278	100
Melons	-	56	100
French beans	883	4963	162.1
Capsicums	285.6	111	-61.1
Okra	285.8	943	230
Brinjals	-	1792	100
Karelas	-	771	100
Mooli	-	269	100
Dudhi		311	100
Other asian vegetables	790.8	766	-3.1
Cutflowers	62.3	3844	6068.4
Courgettes	-	1134	100
Chillies	-	1636	100
Miscellanous vegetable and other produce	-	1479	100

*Economic Review of Agriculture 1970-1980

**Figures not available.

(Anon, 1980b).

Broadly, the objectives were to carry out research work on vegetables, fruits and common ornamentals, thus improving quality and production. The study included tomatoes, capsicums, onions, cucumbers, french beans, brinjals, chillies, carrots, cabbage, melons, okra, courgettes, Asian vegetables, fruits such as pineapples, passion fruit, citrus, mangoes, guavas, limes, grapes, bananas, pears and peaches. Others were common ornamentals for export, such as carnations, chrysanthemums, gerbera, and anthurium. During the development plan of 1979/1983, (Anon, 1979), it was envisaged that most of these crops would be grown mostly by small scale farmers. The success of such programmes was aimed at improving income growth through intensification of land use and creation of employment. The exportation of such horticultural produce would also earn and save a substantial amount of foreign exchange.

1.2. Entry of *L. trifolii* into Kenya

L. trifolii is a major pest of chrysanthemums in U.S.A. It is also present in South and Central America and the Carribean (Spencer, 1973). Since its introduction in Kenya it has been recorded on a wide range of crops. Most of the vegetable and ornamental flowers mentioned earlier are suitable hosts of the pest. Plants in more than 45 genera are known to be hosts, (Steigmaier, 1966). In Hola Irrigation Scheme it has been recorded on Sunflower. At Thika Horticultural Research Station the leaf miner has been recorded on tomatoes, melons, courgettes, okra, onions, grams and beans.

In early 1977, the leaf miner pest L. trifolii was introduced into Kenya through unquarantined chrysanthemum cuttings from Florida, U.S.A. (De Lima, 1979). These cuttings were commercially multiplied in Msongaleni estate near Kibwezi where serious outbreaks occurred in mid 1977. By the end of the same year, some measure of chemical control had been achieved. However through the later part of 1978 and in 1979 the pest became progressively more difficult to control and it spread to many parts of the country.

A recent visit by the author (September, 1984) at Msongaleni Estate near Kibwezi confirmed that the multimillion chrysanthemum project is no longer in operation, primarily due to the ravages of L. trifolii. Consequently, the licence to export chrysanthemum cuttings to the United Kingdom was withdrawn in 1980 for the fear that the produce might introduce the leaf miner into the importing country. The banning of the importation resulted in loss of much needed foreign exchange and also mass unemployment for the local people in the area.

It is against this background that the study of the American serpentine leaf miner *L. trifolii* was undertaken. The study of its biology was necessary to provide an appropriate prelude in determining possible control measures. A survey of host range of *L. trifolii* was also done in several areas in Kenya. Such a study is essential in determining suitable or preferred alternative host plants and possibly it may help in establishing and determining some cultural control methods. Insecticidal trials for the control and the effect of these on the leafminer parasites were also carried out.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Taxonomy and life-history of *Liriomyza trifolii* (Burgess)

The American serpentine leaf-miner (MAFF common name*) *L. trifolii* belongs to the 75% of 1800 species of Agromyzidae which are known to be leaf miners Spencer (1973). *L. trifolii* has been variously recorded as *Oscinis trifolii* Burgess (1880), *Liriomyza alliovora* Frick (1925). The latter name is recognised as a synonym of *L. trifolii*. This species of the leaf miner has frequently been mis-identified and (Spencer, 1973) points out that, it is not surprising that species feeding on a wide range of plants and having an extensive distribution should have been described by different authors with different names. This is particularly true of the American

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*Ministry of Agriculture Food and Fisheries (United Kingdom)

Liriomyza species. Owing to their general similarity, these species have frequently been mis-identified and it is unfortunate that inaccurate names have appeared in many important papers in American and other economic literature. Thus, before World War I, Webster and Parks (1913) recorded *Agromyza pusilla* Meigen on twenty-four species of plants. *Oscinis trifolii* (Burgess), is recorded as a synonymn of *Agromyza pusilla* Meig. Various aspects of the biology were studied and they noted that during oviposition, the female uses the exudate as food after puncturing the leaves. However, only a small percentage of punctures contained eggs. They found that generally, the incubation period of the egg lasted from 3-8 days depending on the climatic conditions. Similarly, the larval period ranged from 3-12 days during the summer months and decreased as the days got cooler. Pupal period was 8-28 days depending on the climatic conditions. McGregor (1914) discusses *Liriomyza* spp (mis-identified as *L. scutellata* Fall) damaging cotton in South Carolina. By McGregor's illustrations, Spencer (1973) reports that the pest could have been *L. trifolii*. Similarly life history studies of various mis-identified species of Liriomyza spp have been studied by Oatman and Michelbacher (1958, 1959). The species discussed in the above was L. pictella. Spencer, (1973) disputes this identity and asserts that the species was certainly not L. pictella. Smith et al., (1962), Webb and Smith (1969, 1970) also discussed the life history and damage caused by chrysanthemums in green-houses in Delaware, New Jersey, Ohio and Pennsylvania by a species originally identified as Liriomyza spp by Frick (1957). The same was later identified as Liriomyza munda Frick. Spencer (1973) after examining the specimens confirmed that the leaf miner was indeed L. trifolii. Harris and Tate (1933) have also studied the life history of L. trifolii as Agromyza pusilla Meig on onions. They found that the egg stage lasted for a period of 3-5 days and the larval stage from 5-7 days. Pupation occurred in the soil and took 8-12 days. The length of the period depended on the prevailing climatic conditions. Thus, they concluded that the development from egg to adult takes about three weeks on onions. The life cycle of the closely related species L. langei take 3-5 weeks according to Jefferson and Eads (1952).

The same duration holds true for L. trifolii in Tanzania (Katundu, 1980). Askew (1968) has made detailed studies on the life history of the leaf miners: Agromyza demeijerei Hendel, Phytomyza citisi Brischke and Leucoptera larbunella Stainton, on the host plant laburnum. Beri (1974) has made precise observations on the life history of Liriomyza brassicae Riley on the host plant Tropaesolum majus Linn. The duration of the first, second and final instars averaged 51, 42.5 and 64 hours respectively. The incubation period of the egg averaged 3.3 days whereas the whole larval period lasted 6.5 days. Pupal period averaged 9.17 days. These observations were recorded when the flies were reared at $28^{o} \pm 1^{o}C$ and 84% ± 2% relative humidity. In his review of Liriomyza spp and other American leaf miners, Miller (1978) noted that depending on climatic conditions eggs hatch in 2-5 days. Duration of larval development, he noted, varies in temperature and host plant. Larvae of L. trifolii may aestivate when mid-summer temperatures exceed $77^{o}F$ ($25^{o}C$) (McGregor, 1914).

Females are capable of laying 300-500 eggs in 4-11 days (Gilbert, 1976) and adults may live up to 20 days but more usually upto 14 days, (Miller, 1978).

2.2. Economic Importance

Leaf-miners were first recorded in the literature towards the end of the 17th century when Beckman in 1680 as quoted by Spencer (1973), discussed and illustrated the strange forms which had appeared in great numbers the previous year on cherry trees in Frankfurt/Older, Germany. The popular conception at that time was that those mines represented little serpents which had descended from the skies or emanated from the foul air of the local swamps, hence, the serpentine leaf mine. The leaf-mine of _L. trifolii_ varies in form with the host plant but when adequate space is available it is normally long, linear, and not greatly widening towards the end. The larvae **feed** on the parenchyma tissue of the leaves. The photosynthetic capability of the leaves and especially of young plants can be drastically reduced as the chlorophyll and mesophyll is destroyed. The mines, are unsightly especially in vegetables and ornamentals and cause reduction in crop value (Miller, 1978). Adult feeding and oviposition activities produce leaf stippling which further reduces the saleable value of the crop (Musgrave et al, 1975). Quantitative estimates of yield loss are scarce. However, Wolfenbarger and Getzin (1963) reported an increase in yield on peppers when dimethoate was sprayed at weekly intervals. Similarly, Wolfenbarger and Wolfenbarger (1966) found that there is a relationship between tomato yields and leaf miner infestations. They related mine counts and found a correlation with yield reduction by correlation coefficient techniques. Levins et al, (1975) failed to demonstrate any significant connection between leaf miner damage and tomato yields. Poe et al, (1978) had similar results. Johnson et al, (1980a) showed that in Southern California densities of *Liriomyza sativae* Blanchard mines did not significantly reduce fruit yields in full grown tomatoes. In another experiment, Johnson et al, (1980b) recorded significant tomato yields from methomyl treated plots as compared with plots treated with dipel and chlopyrifos and the untreated check. This was inspite of the fact that leaf miner densities were significantly higher in the methomyl treated plots.

2.3. Host Range

L. trifolii is one of the few species of Agromyzidae which is truly polyphagous, Spencer (1973). He further observes that the phenomena of polyphagy is primitive and is actually being reversed. Further speciation, therefore, can be expected, with the new species evolving, having a more typical monophagous or oligophagous feeding habit.

As early as 1913, Webster and Parks recorded the serpentine leaf miner *Agromyza pusilla* Meig. Synonym *Oscinis trifolii* (Burgess) on 24 host plants. The pest had been reared successfully on all the hosts which mostly were cultivated plants. Lange and Smith (1947) noted that it was economically 'hazardous' to grow peas and sugar beet due to the damage of *Liriomyza pusilla* Meig (*L. trifolii*). Beans, peppers, okra, cucumbers, English peas, spinach, lettuce, radish and many ornamentals are known to be hosts of *L. pusilla* and *Liriomyza* spp respectively (Mayeux and Wene 1950, Hills and Taylor 1951, Jefferson and Eads, 1952). *Liriomyza* spp was observed on cucumbers, melon, squash, tomatoes and weeds of amaranth family by Wilcox and

Howland (1952). These authors noted that damage to the various hosts from the leaf miner attack, resulted from a devatilizing effect due to the loss of leaf surface and leaves. Beans, cabbages, okra, peas, potatoes, squash, tomatoes and turnips were so severely attacked by *L. pusilla* in Florida, that the plants became brown as if burnt and individual plants frequently perished (Wolfenbarger, 1958). Oatman (1959a) has done host range studies of *Liriomyza pictella* (Thomson). He listed sixteen plant families as suitable hosts for the pest., Most of these were in the Leguminosae, Compositae, Curcubitaceae and Solanaceae families.

Adlerz (1961) observes that leaf miner damage on water melon is most severe when the plants are small with two or more true leaves. Al-Azawi (1966) documented 16 plant species being hosts to *Phytomyza atricornis* Meig a polyphagous agromyzid. Steigmaier (1966) recorded 47 genera on 10 plant families as hosts to *L. trifolii*. He noted that the leaf miner has a specific host preference for Compositae. He also observed that the weeds among the hosts act as host plant reservoirs throughout the year especially in South Florida. Here in Kenya, *L. trifolii* has been recorded on chrysanthemums, tomatoes, sweet melons, and green grams (De Lima, 1979). In Tanzania L. trifolii has also been recorded on beans (Katundu, 1980).

2.4. Parasites

Detailed studies of the parasites of the Liriomyza spp attacking commercial crops, mostly in the United States have been made. Unfortunately, Spencer, (1973) points out that, the exact identity of the leaf miners considered is uncertain in almost all of these valuable papers. As early as 1913, Webster and Parks noted that the serpentine leaf miner is severely parasitized. They reared 28 species of hymenopteran parasites from the mined foliage of alfalfa and other forage crops in the United States. At times, they noted that the minute enemies became too numerous as to render the study of the pest very difficult. The ability of the parasites to keep down the populations of the pest was also recognised by Harris and Tate (1933). They studied L. trifolii as Agromyza pusilla Meig. They mentioned that in Iowa the onion leaf miner is subject to heavy parisitism, the percentage rate of which increased 'progressively with the season such that the preponderance of insects emerging from infested leaves collected are hymenopterous parasites'. Hills and Taylor (1951) on parasitisation of dipterous leaf miners on cantaloupes and lettuce on Salt River Valley, Arizona, notes that there is a difference between the distribution of parasites as per the two crops. A total of 17 hymenopteran parasites was found infesting the serpentine leaf miner. The parasites reduced the miner population greatly or down to zero. Significantly, however, the two authors found that repeated applications of DDT were ineffective against leaf miner populations, but rather reduced the parasite numbers resulting in increasing leaf miner density. Similar studies by Michelbacher et al, (1951), Wilcox and Howland (1952), Wene (1955) resulted with the same conclusions. Oatman (1959b) observes that parasitism of _L. pictella_ increased as crops matured. Further, he established a correlation between parasitism and leaf miner population densities. Getzin (1960) on selective insecticides for vegetable leaf miner control and parasite survival showed that the chemicals delnav and dimethoate showed the greatest amount of selectivity for controlling L. munda and allowed survival of the hymenopteran parasite Derostenus variipes (Cwfd). He noted that delnav appeared to be a promising chemical available for use in an intergrated control programme. Harding (1965) identified and recorded four families of hymenopterans parastising L. munda.

Steigmaier (1966) reared many parasites of L. trifolii from its larvae and pupa. These were Opius spp (Braconidae), Chrysocaris spp, Closterocerous cintipennis Ashm, Derostenus spp, D. agromyzae (Cwfd), D. variipes (Cwfd), Diglyphus spp and Mirzagrammosoma lineaticeps Girault (Eulophidae). In the family Pteromalidae, he reared Halticoptera patellana (Dalman). However, he never indicated the relative importance of the hymenopterans in the control of the leaf miner. More recently the importance of the parasites in the control of leaf miner, or the use of the same to fit an integrated control programme have been investigated (Oatman and Kennedy, 1976, Poe et al, 1978, Schuster et al, 1979, and Johnson et al, 1980a, 1980b). Oatman and Kennedy, (1976) showed that due to at least in part methomyls' adverse effect on parasites attacking L. sativae and its inability to control the leaf miner, an outbreak of the pest can be induced by the application of the chemical. Poe et al, (1978) evaluated eight insecticides and found that there were more parasites from plots treated with leptophos and endosulfan than either from the check or any of the other insecticidal treatments he used on L. sativae. Johnson et al, (1980a) showed that chlorpyrifos gave excellent control of the vegetable leaf miner L. sativae but decimated its parasite populations whereas dipel did not affect either the host or its parasites. Parasites, therefore, are an important factor when deciding on the control measures.

2.5. Leaf miner Control

Insecticidal control of leaf mining Agromyzidae is complicated by their internal feeding habits and by differences in the life histories of individual species (Spencer, 1973, 1979). It is obvious that insecticides which may be highly effective on foliage or against free living larvae may not be effective on larvae or eggs protected within the tissue of the leaf. Spencer (1979) in his report on chrysanthemum project at Msongaleni, Kibwezi pointed out that ideally an effective systemic insecticide should be sought which will destroy both the females feeding from the leaves and the eggs and larvae present in the chrysanthemum leaves. However, a different control approach is required for any given case due to the differing behaviour and biology of the different species. A detailed knowledge, therefore, of the life history of the particular agromyzid pest and ideally also of their parasites is thus a pre-requisite for obtaining optimal results from any programme of chemical control.

Most methods of pest control, namely, mechanical, cultural, chemical and biological have been tried on Agromyzidae, especially more specifically against the polyphagous _Liriomyza_ spp and _Phytomyza_ spp. One of the earliest recommendations was by Curtis (1844), in England (Manchester area). Phlox and Pansies were being damaged by _Liriomyza strigata_ Meigen. The pansies were to be protected from the attacks of the flies by gauze frames to cover over the pots similar to those used for protecting meat against fresh flies'. Webster and Parks (1913) on damage to alfalfa by Liriomyza spp reports that 'doubtless cutting of the crop for hay at once as soon as the depredations were observed would prevent a recurrence'. Deep fall ploughing would bury the pupae so deep in the ground as to put them beyond the possibility of emerging as adults. Furthermore, keeping down volunteer growth along ditch banks and in wastelands would greatly diminish the number of pupae which yearly enter hibernation.

2:5.1. Botanical Insecticides

One of the earliest botanical substances used in the control of leaf miner was nicotine (Sanders, 1912). It was sprayed against Phytomyza syngensiae (Hardy). He used nicotine as the formulation 'Black leaf 40' a nicotine solution with or without whale oil soap. This proved to be a complete and satisfactory control. It was not only effective against the adults but also affected the larvae through the leaf epidermis by osmosis. In England, Miles and Cohen (1936) found that routine spraying of chrysanthemums with nicotine solution at intervals of not more than 30 days gave effective control of the leaf miner *Phytomyza syngensiae* (Hardy). Spencer (1979) reports that nicotine was successfully used against *P. syngensiae*, a chrysanthemum leaf miner at Boston and Milwaukee. He further suggested that the same should be tried against *L. trifolii* attacking chrysanthemums at Kibwezi (Kenya). More recently, Webb et al, (1983) evaluated,the aqueous solution of neem-seed extract against *L. sativae* and *L. trifolii*. The host plant was 'Henderson bush lima bean'. They found that neem-seed extract was highly efficacious as an insecticide against larvae of both *L. sativae* and *L. trifolii* but not very effective as an anti ovipositional repellant.

2.5.2. Chemical Control

Speyer (1936) used poison baits containing sugar solution and sodium silica fluoride. The spray of the same solution also proved effective for at least three days. Derris powder mixed with nicotine was found not to be effective against *Phytomyza solani* Macq.

Organo-chlorines have been extensively used in the control of *Liriomyza* spp. Speyer and Parr

(1948) tested DDT and BHC in England against *L. bryoniae* (as *L. solani*) Herring. BHC was found to be more effective but the really significant finding was the greater toxicity of DDT to hymenopteran parasites than to adult agromyzids. Earlier Lange and Smith (1947) in both laboratory and field trials found that chlordane was most effective as compared with DDT, BHC or Hexa-ethyl tetraphosphate against the pea leaf miner *Liriomyza orbona* Meig. Spencer (1973) notes that the identity of this species is not certain. Similarly Wolfenbarger (1947) found that chlordane was very effective against *L. sativae* on potatoes. Mayeux and Wene (1950) on the control of serpentine leaf miner *L. pusilla* on pepper observed that in the fields, miners became more numerous following the use of certain insecticides especially BHC and DDT. They also found that good control was possible with chlordane - DDT dust applied weekly. Mines were likely to become very heavy when dusting was discontinued or when irregular applications were made. Hills and Taylor (1951) reported that DDT sprayed on cantaloupes was ineffective against leaf miners *Liriomyza* spp but reduced the parasite populations. Similar findings were reported by several authors (Kelsheimer, 1948, Wilcox and Howland, 1952, Wene, 1958, 1955). In his review of a decade of control measures against Liriomyza spp in Florida (U.S.A.), Wolfenbarger (1958) showed that DDT was only partially effective against the leaf miner and definitely less effective than aldrin, dieldrin and endrin. Michelbacher et al, (1951) found that dieldrin proved to be more effective than aldrin against L. sativae attacking melons irrespective of formulation. Similarly, Michelbacher et al, (1953) found that dieldrin is more effective than aldrin and heptachlor in controlling L. sativae (as sub-pusilla Frost) on tomatoes in California. Toxaphene, BHC, Lindane and chlordane were more effective than DDT according to Wilcox and Howland (1952). The authors in a subsequent experiment showed that concentrated sprays of dieldrin and EPN gave good control but DDT, schradan, and toxaphene gave poor control.

Generally, organophosphates are less persistent than organo-chlorines, hence, the emphasis on the choice of the former group in the control of the leaf miner parathion, diazinon and dimethoate, have been the mostly used organophosphates in the control of *Liriomyza* spp. In Florida (U.S.A.) as early as 1948, parathion proved to be outstanding in preventing mines on tomatoes (Wolfenbarger, 1948). In California, Jefferson and Eads (1952) reported that parathion was most effective against *Liriomyza langei* Frick as compared to chlordane, toxaphene, BHC and EPN. Wene (1955) reported that high volume spraying of parathion on infested host plants gave good control of leaf miners. It also reduced the parasite populations. There was also an indication that lindane, endrin and dieldrin reduced the parasite population but not as acutely as parathion. In his review, Wolfenbarger (1958) notes that diazinon was then currently recommended against *L. pusilla*. He notes that some of the chlorinated hydrocarbons such as chlordane, lindane, endrin and dieldrin were effective in the initial experiments, but became ineffective after one to three seasons. EPN and diazinon then gave outstanding to excellent prevention of the leaf miner. He also noted that parathion was not so effective after 10 years as it was originally. A few years later, diazinon like parathion proved to be ineffective (Wolfenbarger, 1961).

He attributed the lack of efficacy to high populations and reduction of natural enemies. According to his observations, disyston and phorate proved promising since the systemics provided six to eight weeks of protection. However, dimethoate, he noted, was clearly superior to any other spray treatments. In 1960, Getzin reported that in Rio Grande Valley there was no evidence of parathion tolerant leaf miner. In his experiments, Adlerz (1961) found that the number of leaf miner larvae were significantly lowered after application of dibrom, parathion and diazinon as opposed to application of demeton, trithion or phosphamidon.

Granulated systemic insecticides have been used by Harding and Wolfenbarger (1963) against _Liriomyza sativae_ (as _munda_ Frick) attacking peas and cucumber. They reported that 55 days after treatment Bayer '25141' and phorate were superior to disyston, dimethoate and methyl demeton. However, it was noted that there was no significant difference in the number of surviving parasites. Similarly, Al Azawi (1967) compared systemics with conventional sprays against the chrysanthemums leaf miner in Iraq. The other group of insecticides namely carbamates have not been widely used against leaf miners. However, Wolfenbarger and Getzin (1963) tested four compounds in Texas. These were sevin, zineb, Bayer 39007, and zectron but considered that these insecticides were not effective. Selective insecticides have been used in the control of vegetable leaf-miner L. munda on cantaloupes and pepper, (Getzin, 1960). The insecticides delnav and dimethoate showed the greatest amount of selectivity for controlling leaf miner and allowing survival of hymenopteran parasites.

Poe (1974) and Poe et al (1978) have carried out similar work. All the eight insecticides used showed significantly higher number of active and total mines as compared with the check. They also noted that on tomato leaves there were significantly more leaf miner parasites from plots treated with leptophos and endolsulfan than either from the check or any other insecticidal treatments. Yield data taken as total number of tomato fruits indicated no significant differences among treatment (Poe et al 1978). With the discovery of newer insecticides evaluation of the same against L. trifolii has been reported. Allen (Person. Comm.) notes that this particular leaf miner has developed a wide spectrum of resistance to many insecticides and it requires relatively high dosages of the new synthetic pyrethroid, such as permethrin. More recently from an efficacy data received from Begley (1983 unpublished) the chemical Trigard and Avermectin gave excellent control of L. trifolii. Both of these chemicals have an emergency use permit on celery, lettuce and tomatoes in Florida (U.S.A.)

CHAPTER 3

3. THE BIOLOGY OF LIRIOMYZA TRIFOLII (BURGESS) ON TOMATOES

3.1. Introduction

Owing to the fact that *L. trifolii* was a newly introduced pest in Kenya (De Lima, 1979) and its effects so disastrously felt in the chrysanthemum industry, it aroused considerable concern to entomologists and the farmers. Its polyphagous feeding nature was particularly alarming. Beri (1974) noted that in his country India, entomologists had neglected the study of agriculturally important agromyzids. Since its entry into Kenya no previous work on the biology of the leaf miner has been carried out. It was then clearly desirable to investigate its biology which in turn would help to formulate reasonable control programmes.

3.2. Materials and Methods

Biological studies were carried out in the field and also in the laboratory. The site for field observations was at Thika Horticultural Research Station, 42 km North East of Nairobi. In all the experiments, tomato Lycopersicum esculentum Mill of 'money maker' variety was used as a host. The seeds which were certified were procured from Simpson and Whitelaw, Nairobi.

3.2.1. Field Observations

A seed bed was prepared on 22-2-1983 and the tomato seeds were sown on the same day. The bed was 2 m long and 1 m wide. The seeds were drilled in rows with an inter-row spacing of 20 cm. A few grains of diammonium phosphate was incorporated in the soil. No staking was done. The objective of the experiment was to make a preliminary study of the leaf miner's life history in the field. Similar studies were carried out by Katundu (1980) on L. trifolii on beans in Tanzania. The seed bed was watered daily. Germination was noticed after seven days and daily observations were then undertaken when the plants had acquired two true leaves. Nylon cloth strips were algned along the rows of the tomato seedlings to trap the falling larvae.

3.2.2. Laboratory experiments

3.2.2.1. Rearing

A stock culture was first established in the laboratory. The hosts used were tomato plants raised in pots in a greenhouse. Infested tomato leaves from a large tomato field were collected at Thika Research Station. These were placed in polythene bags and transported to the National Agricultural Laboratories, Nairobi where they were placed in emergence containers.

A large cage measuring 2m x 1m x 1m was placed in the experimental room. The cage had a wooden bottom and was constructed with transparent glass on all its sides. It had two sleeved openings which were used for introductions of the insects and water for the plants (Plate 1a). Two leafy potted tomato plants were placed in the cage. Ten newly emerged adults of L. trifolii of each sex were introduced through the sleeved opening. As the older plants approached defoliation they were replaced with fresh ones and the culture was maintained through out the experimental period.

3.2.2.2. Life-history studies

All laboratory observations were made at controlled environmental conditions. Temperature was maintained at 25 $\pm$ 1^{o}C and the relative

Plate 1a Rearing cage of *L. trifolii* x 0.1

humidity at 79 $\pm$ 2%. The temperature was regulated by a thermostatically controlled heater where as humidity was governed by a humidifier (X-pel air). The two parameters were continuously monitored by a thermohydrograph which was centrally situated in the room. In addition, a manual thermometer was used to take daily readings. A built in fan was used to circulate the air. The lighting system was timed to give the room twelve hours of light and twelve hours of darkness. Infested tomato leaves were introduced into the emergence container under the above conditions.

Materials for construction of the emergence cages (Plate 1b) included glass slabs measuring 16 cm x 16 cm blotting paper of the same size, standard lamp chimneys, rings of iron wire 0.3 mm thick and 10 cm diameter and fine netting material. Four rows of four glass slabs were arranged on a flat table and the blotting paper was placed on them. One lamp chimney was placed on each glass slab. Leaves were introduced from the top of the chimney and then covered with a lid. The lid was constructed by fixing the netting material of the appropriate size to the ring using a needle and a thread. All parasites

Plate 1b Emergence cages in the laboratory x 0.1

and adult flies emerged after two weeks.

Life history studies were carried out by introducing one male and female fly into a sleeve cage which had a tomato branch inside it. The sleeve cage (Plate 1c), was constructed with iron frames and nylon cloth. The cage frame had a base of 6 cm tapering to the opening which had a diameter of 3 cm. A nylon cloth 'pocket' was then fixed and then the adult flies were introduced through the opening. The flies were removed after twenty four hours by which time they had laid the eggs. The life history was then followed on the tomato leaves upto adult emergence. The incubation period of the egg was observed and recorded. The length, width and duration of larval instars of twenty larvae were taken and recorded (a method used by Beri, 1974). Measurements of length, width, and duration of twenty pupae was also recorded immediately after larval period. The width and length measurements of the larvae and pupae were taken using a stage micrometer and ocular piece calibrated and fitted into a binocular microscope at X20.

Plate 1c Sleeve cage on tomato branch x 0.1

3.2.3. Sex ratio

Batches of pupae were recovered from infested tomato leaves. These were placed in emergence cages. The emerged adult males and female flies were counted and recorded.

3.3. Results

3.3.1. Field observations

Leaf punctures were clearly discernible two days after the adult leaf miners were noticed on the young tomato plants. They were concentrated near the edges of the first primary leaves. Small serpentine mines were observed when the plants were two weeks old. Wriggling larvae were found on the nylon cloth strips eight days after the leaf miner adults were detected on the leaves. These larvae transformed into pupae the next day. Emergence of the adults was first observed twenty seven days after the parent adult miners were observed on the young tomato plants. Emergence was evident from the empty pupal cases on the nylon cloth.

Admittedly field experiments could not have a similar precision in the study of the life history as the laboratory experiments. However the daily observations from the time the seeds were sown gave an estimate of the flies life cycle. From the observations it was evident that _L. trifolii_ completed its life cycle within 27 days under Thika Research Station conditions (Table 2).

3.3.2. Laboratory experiments

3.3.2.1. Life history

3.3.2.1.1. Egg and incubation period

Oviposition by _L. trifolii_ occurred within the mesophyll of the leaf of the tomato plant, predominantly from the adaxial surface. At the site of the egg, the leaf surface is slightly raised. This characteristic of the oviposition site is difficult to see and takes a lot of time to detect. The modified technique of Simonet and Pienkowski (Parrella and Robb, 1982) was used to detect the egg. The mean length and width of 20 eggs was 0.23 mm and 0.13 mm respectively (Table 3).

The mean incubation period of *L. trifolii* eggs was found to be 4 days and 12 hours (Table 4) under constant environmental conditions of 25 ± 1°C and 79 ± 2% relative humidity.

3.3.2.2. The Larva

3.3.2.2.1. First Instar (Plate 2a)

The *L. trifolii* egg hatched into a tiny colourless and laterally compressed maggot. Its anterior end tapers and the posterior end is truncate. The mean larval length was 0.56 mm with a range of 0.51 and its duration was 54.4 hours when reared at 25 ± 1°C and 79 ± 2% relative humidity. The first instar larva commenced feeding immediately and became faintly green due to its feeding on the green leaf tissues.

Table 2. Thika Horticultural Research Station: Temperature and humidity readings during the field experiment 1982

Month	Mean monthly % relative humidity		Mean monthly air temperatures	Mean monthly total rainfall
	0.600Z	1200Z	°C	cm
January	79	50	19.6	0.7
February	80	43	20.9	0.0
March	80	42	15.8	118.8
April	84	55	20.4	153.9
May	81	57	20.0	37.1
June	84	57	19.1	7.5
July	76	47	19.7	24.9
August	83	51	17.8	7.7
September	75	43	19.7	7.1
October	-	-	19.9	248.9
November	-	-	20.0	198.6
December	-	-	21.6	67.0

Table 4. The Incubation period of _L. trifolii_ eggs

Egg-laying		Hatching		Incubation
Date	Time	Date	Time	Period
7-11-83	11.00 a.m	11-11-83	8.00 a.m	3 days 21 hours
20-12-83	12.00 Noon	25-12-83	8.00 a.m	4 days 19 hours
28-12-83	12.00 Noon	2-1-84	10.00 a.m	4 days 22 hours
7-1-84	12.00 Noon	12-1-84	11.00 a.m	3 days 23 hours
10-2-84	4.00 p.m	15-11.84	9.30 a.m	4 days 18 hours 30 min
15-2-84	10.00 a.m	19-2-84	6.00 a.m	4 days 18 hours
				Mean 4 days 12 hours

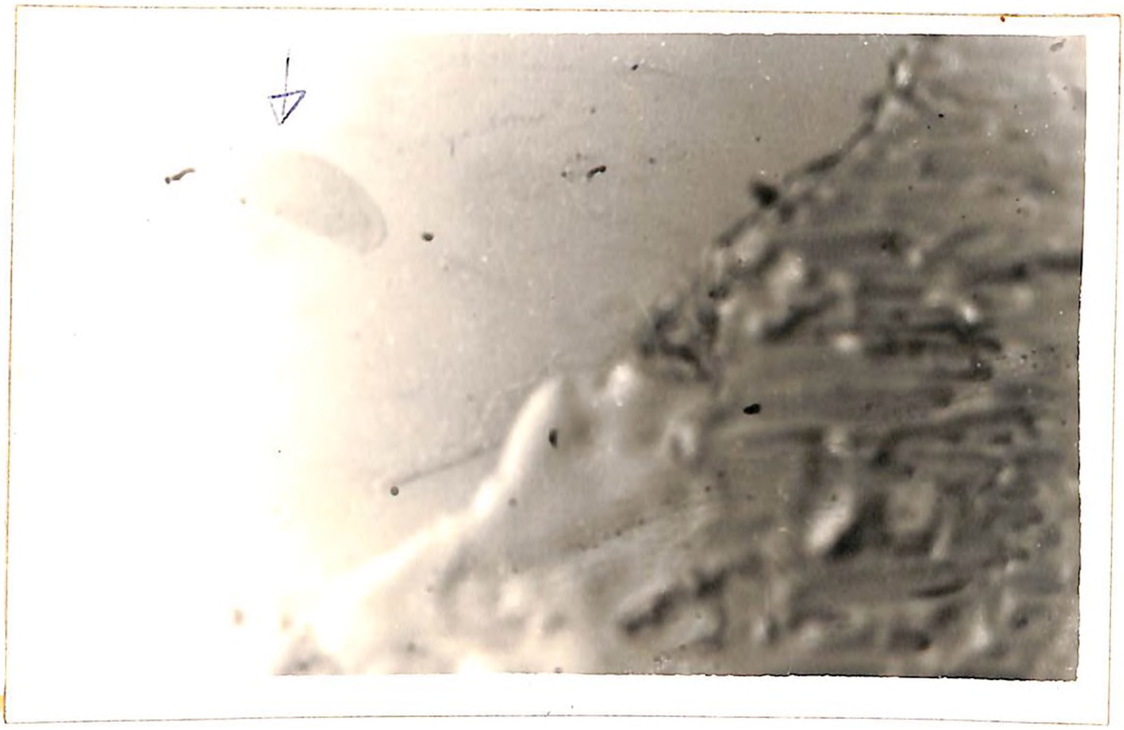

Plate 2a First instar larva of L. trifolii x 500

3.3.2.2.2. Second Instar (Plate 2b)

After 54.4 hours the 1st instar larva transformed into a second instar larva which is light yellow in colour with prominent black sclerotized mouth hooks. The dark green chlorophyll - like matter in the intestines is clearly visible in this instar. The duration lasted 66.2 hours. The larval mean length was 1.42 mm within a range of 0.82.

3.3.2.2.3. Third Instar (Plate 2c)

The third instar larva is distinctly yellow in colour. The size is more robust and the mouth hooks are larger and more prominent. The head region, three thoracic and the eighth abdominal segments are clearly disernible. The teeth of sclerotized mouth hooks extend into the oral opening. The larval length averaged 2.05 mm with a range of 0.4. The duration of this instar was 44.8 hours.

3.3.2.2.4. The Pupa (Plate 3)

When larvae were fully grown they cut small

Plate 2b Second instar larvae of L. trifolii x 500

Plate 2c Third instar larva of L. trifolii x 500

Plate 3 Pupae of L. trifolii x 500

semicircular holes on the underside of the tomato leaves and fell to the bottom of the cage. Larvae were found to wander restlessly for an average of 2-3 hours before pupation took place. The pupa became yellow brown in colour assuming a more deeper yellow brown as they matured. The pupal length and width averaged 1.6 mm and 0.8 mm respectively. The pupal period lasted for an average of 9.5 days. The duration of the three larval instars and pupae together with their measurements are summarised in Table 5.

3.3.2.2.5. The Adult (Plate 4a and 4b)

The adult *L. trifolii* leafminer is a small fly slightly smaller than the common bean fly *Ophiomyia phaseoli* (Tryon). It has a mat-greyish mesonotum. The antennal segments are bright-yellow in colour. It has a bright yellow patch on the thorax just behind the wings. The legs and underbody are yellowish brown in colour. The sexes are easily distinguished in that the female is more robust and has well developed ovipositor used in making ovipositing and feeding punctures. Apparently the male does not make

Table 5. Size measurements and duration of developmental stages of *L. trifolii*

STAGE	DURATION		LENGTH		WIDTH	
	Mean (hrs) ± SE	Range	Mean (mm) ± SE	Range	Mean (mm) ± SE	Range
First Instar	54.4 ± 0.5	4	0.56 ± 0.05	0.51	0.29 ± 0.04	0.42
Second Instar	66.2 ± 0.2	2	1.42 ± 0.07	0.82	0.42 ± 0.02	0.27
Third Instar	44.8 ± 0.2	2	2.05 ± 0.04	0.4	0.54 ± 0.02	0.21
Pupa	228 ± 1.5	14.4	1.6 ± 0.03	0.4	0.8 ± 0.01	0.15

Plate 4a Adult of L. trifolii (Male) x 500

Plate 4b Adult of *L. trifolii* (Female) x 500

punctures on the leaves, hence it has a poorly developed ovipositor.

3.3.3. Sex ratio

The seven batches of pupae (A - A) emerged into adults after two weeks. These were sexed and their ratios determined. The results which are shown in Table 6 revealed that there were 1.4 females to every 1 male (1.4:1). The percentage hatch was quite high in most batches having an average of 75.3%. Very few pupae failed to emerge with an exception of batch F. This could have been because of higher mortalities due to diseases etc.

3.4. Discussion

3.4.1. Field observations

Preliminary studies of the life history of *L. trifolii* at Thika Horticultural Research Station revealed that the leafminer has a life cycle of approximately four weeks under the Thika Station's environmental conditions. These results concur with observations made by Katundu (1980) at Lyamungu Research Station (Tanzania) on beans.

Table 6. Sex ratio of *L. trifolii* emerging from 8 batches of pupae

Batch Number	Date	Number of Pupae	Emergence	Males	Females
A	20-10-1983	30	86.7	10	16
B	27-10-1983	67	89.6	27	33
C	10-11-1983	60	88.3	17	36
D	16-11-1983	21	90.5	9	10
E	24-11-1983	22	95.5	10	11
F	30-11-1983	20	55.0	4	7
G	2-12-1983	33	97.0	10	22
H	15-12-1983	48	85.4	20	21
TOTAL		301	75.3	107	146
RATIO				1	1.4

The duration is by no means exact. However, the information obtained from this observation was useful in as much as it gave insight into the approximate time when chemical insecticides aimed at controlling both the larvae and adults could be applied in the field. Various authors have recorded the life cycle of *L. trifolii* as being between 3-4 weeks in outdoor experiments (Webster and Parks, 1913; McGregor, 1914; Smith et al, 1962 and Steigmaier, 1966). All the authors were in agreement that the life cycle, like in most insects is dependent on prevailing climatic conditions especially temperature and humidity.

3.4.2. Laboratory experiments

In the controlled environmental laboratory conditions the life cycle which took 16.4 days to complete was shorter than in the field experiment. It is, therefore, apparent that the two parameters are determinant in the duration of the life cycle.

The life cycle of *L. trifolii* was also found to be similar to other species of the same genus. As reported by Beri (1974), *L. brassicae*, under laboratory conditions of $28^{o} \pm 1^{o}C$ and 84% ± 2% R.H., has an incubation period of 3 days 7 hours 51 minutes, larval duration of 6.5 days and a pupal period of 9.17 days. Webb and Smith (1969) points out that duration of L. munda varies with temperature and host plant. They found that time for larval development on bean decreased as temperatures increased from $15.6^{o}C$ to $26^{o}C$. At comparable temperatures larval development was more rapid in bean than in tomato or chrysanthemum. It has been reported that larvae of L. trifolii may aestivate at temperatures above $26^{o}C$ (McGregor, 1914; Webb and Smith, 1969) and that larval development above this temperature rapidly decelerates. This could have accounted for the extremely low populations of the leafminer during the hot months of January and February 1984, at Thika Horticultural Research Station.

3.4.3. Damage by L. trifolii

The most destructive stage of L. trifolii like most other insects is its larvae. The larvae make unsightly serpentine mines in the palisade tissues of many vegetables and ornamentals causing reduction in crop value (Gilbert, 1976) (Plates 5a and 5b). On tomatoes, the larval mining reduces the photosynthetic capability of the plant as the chlorophyll and mesophyll are destroyed. Leaf fall is not uncommon in severe infestations, thus exposing plant stems to normal action and the fruit to scald due to lack of shading. The larvae cause additional damage when eating out exit holes in the leaves prior to pupation. Adult feeding and oviposition activities produce leaf stippling which further reduces the market value of the crop. The above activities also facilitate secondary invasion of pathogens (Genung et al, 1975).

There was no correlation between the length of the mine and the length of the larvae (corr. coeff. = 0.3) whereas there was very high correlation between the width of the mine and the width of the larvae (corr. coeff. 0.9). The study of larval duration in diverse environmental conditions on various horticulral crops is of paramount importance. As Genung and Harris (1961) observes, the amount of time that the maggots spend in the leaf may possibly indicate the necessary frequency of application especially

Plate 5a Damage of *L. trifolii* on young tomato plants x 0.02

Plate 5b *L. trifolii* damage on Cucurbits (Melon) x 0.02

with insecticides of little residual activity.

All in all it can be said that knowledge of weather parameters especially temperatures and relative humidity at the planting season could certainly help to predict necessary control measures of the pest.

CHAPTER 4

4. HOST RANGE OF LIRIOMYZA TRIFOLII (BURGESS)

4.1. Introduction

Burgess (1880) was the first person to describe *L. trifolii* from specimens reared from *Trifolium repens* L. in the District of Columbia, hence the name (Spencer, 1965). Although its name was derived from a host in the Leguminosae, Spencer (1973) reports that, the leaf miner infests a wide range of plant genera. By definition, polyphagy is the indiscriminate feeding on a number of different plant orders (Spencer, 1973). Going by this definition he observes that *L. trifolii* is one of the very few truly polyphagous species of Agromyzidae. Steigmaier (1966) has recorded the pest on forty seven genera in ten plant families. After its introduction into Kenya, in early 1977 (De Lima, 1979), it has spread into various parts of the country. This aspect of the study was undertaken to investigate hosts of both cultivated and wild plants in the specified areas.

4.2. Materials and Methods

4.2.1. Survey of *L. trifolii*

During the study period, it was not possible to carry out a country-wide distribution survey due to the constraints of the prevailing economic conditions which made means of transportation extremely difficult. It was, however, possible to collect samples of infested materials from several localities. The specific areas visited were: Kibwezi (the site of the original introduction), the Kibirigwi Irrigation Scheme (Central Province), Machakos and Kitui Districts (Eastern Province). This was done in the sub-stations of the Ministry of Agriculture and the adjacent small scale farms. Thika National Horticultural Research Station and the surrounding horticultural farms were also visited. A few farms around Nairobi area were checked for the presence of the miner.

4.2.2. Infestation of *L. trifolii* on host Plants

The severity of infestation for a particular host plant was arbitrarily recorded as being severely, moderately or lightly mined (Oatman, 1959a). If more than half the plants' leaves contained mines, the plant was recorded as severely mined (denoted by three asterisks). If the mined foliage was fifty per cent and not less than ten per cent, the plant was recorded as moderately mined and those with less than ten per cent as lightly mined. The last two were denoted with two and one asterisk(s) respectively. The date and place of collection were also included in the records as shown in Table 7.

4.2.3. Rearing and Identification

Infested foliage of the various host plants was placed in small polythene bags, which were ventilated by puncturing a few holes during transit. The plants were identified at the Botany department, University of Nairobi. The mined leaves were then transferred into ventilated emergence cages. The cages were constructed as previously described (Chapter 3). After four weeks from the date of introduction of the leaves, the pests and parasites emerged and were identified at the National Agricultural Laboratories, Nairobi, from previously recorded

Table 7. Host plants of *L. trifolii*

FAMILY AND BOTANICAL NAME	COMMON NAME	UTILISATION	DATE COLLECTED	PLACE COLLECTED
1. ACANTHACEAE				
Barleria• spp	-		10 December 1982	Kibirigwi
2. AMARANTHACEAE				
Amaranthus•	Amaranth	Vegetable	26 October 1982	Thika
3. CHENOPODIACEAE				
Beta vulgaris L.	Spinach beet	Vegetable	2 March 1982	Kibwezi
Spinacia oleraceae L.	Spinach	Vegetable	26 October 1982	Thika
4. COMPOSITAE				
Chrysanthemum spp•••	Chrysanthemums	Ornamental	2 March 1982	Kibwezi
Bidens pilosa L.••	Black-jack	Weed/herb	26 September 1982	Thika
Dhalia• spp	Dhalia	Ornamental	"	Kibwezi
Galinsoga parviflora•• Cav.	-	Weed	10 December 1982	Kibirigwi
Gerbera spp••	Gerbera	Herb/Ornamental	"	Kibwezi
Helianthus annuus••• L.	Sunflower	Oil seed	26 September 1983	Kibwezi
Lactuca sativa L.•	Lettuce	Vegetable	12 October 1982	Thika
Vernonia lasiopus O. Hoffm•		Weed/Herb	15 July 1982	Machakos
5. CUCURBITACEAE				
Cucumis aculeatus Cogn.••	-	-	2 March 1982	Kibwezi
Cucumis dipsaceaus Spach.•	-	-	30 March 1982	Kibwezi
Cucumis melo••	Melon	Fruit		Kibwezi
Cucumis melo reticulatus•	Cantaloupe	Fruit	5 September 1982	Thika
Cucumis sativus L.••	Cucumber	Vegetable		Kibwezi
Cucurbita maxima Duch.••	Pumpkin	Vegetable	5 September 1982	Thika
Lagenaria sphaerica Sond.		Weed/Herb	2 March 1982	Kibwezi
6. CRUCIFERAE				
Barbarea spp.•	-	Weed/Herb	10 October 1982	Kibwezi
Erucastrum arabicum• Fisch. and Mey	-	Weed/Herb	26 February 1982	Thika
7. EURPHOBIACEAE				
Croton megalocarpus Hutch.•	-	Tree	10 December 1982	Near Kibirigwi Irrigation Scheme

Table 7. Host plants of L. trifolii (cont'd)

FAMILY AND BOTANICAL NAME	COMMON NAME	UTILISATION	DATE COLLECTED	PLACE COLLECTED
8. LEGUMINOSAE				
Crotarlaria agatiflora•	-	Weed/Herb	5 October 1982	Thika
Indigofera arrecta A. Rich•	-	Shrub		Kibwezi
Lathyrus spp••	Grass pea	Herb/fodder	11 July 1982	Machakos
Phaseolus spp•••	Bean	Pulse	11 July 1982	Machakos
Pisum sativum L.••	Green pea	Vegetable	8 July 1982	Kitui
Vicia faba L.••	Broad bean	Vegetable	"	Thika
Vigna unguiculata (L) Walp••	Cowpea	Pulse/Vegetable	8 July 1982	Kitui
9. LILIACEAE				
Allium cepa L.••	Onion	Vegetable	21 April 1982	Kibirigwi
Allium porrum L.••	Leek	Vegetable	"	Irrigation Scheme
10. MALVACEAE				
Gossypium spp••	Cotton	Fibre	26 September 1983	Kibwezi
Hibiscus esculentus L.•••	Okra	Vegetable	17 February 1982	Thika
Hibiscus rosa-sinensis L.•	Hibiscus	Ornamental	10 November 1982	Nairobi
11. POLYGONACEAE				
Oxygonum sinuatum (Meisn.) Dammer•	-	Weed	17 February 1982	Thika
12. SOLANACEAE				
Capsicum annuum L.••	Green pepper	Vegetable/spice	10 February 1982	Thika
Capsicum frutescens• L.	Chillies	Spice/drug	10 February 1982	Thika
Lycopersicun esculentum Mill•••	Tomato	Fruit/Vegetable	5 October 1982	Thika
Solanum melongena L.•••	Eggplant	Vegetable	12 October 1982	Thika
Solanum nigrum L.••	-	Herb	12 October 1982	Thika
Solanum tuberosum L.••	Irish potato	Food	15 October 1982	Nairobi
13. UMBELLIFERAE				
Apium graveolens L.••	Celery	Vegetable	10 October 1982	Kibwezi
Daucas carrota L.••	Carrot	Vegetable	9 November 1982	Thika

specimens. Those in doubt were sent to the Commonwealth Institute of Entomology, London, for confirmation and identification. .

4.3. Results

4.3.1. Host Plants of L. trifolii

A total of 13 plant families were found to be hosts of L. trifolii in the different places visited. The pest displayed a broad host range as envisaged by the wide range of hosts it infested. The hosts were in both the monocotyledonous and dicotylendonous plant groups. The hosts recorded were mostly cultivated horticultural crops most of them of immense economic importance in the country both for domestic and export. Ornamentals and weeds were also found to be attacked by this pest. The preferred host plants were in the families: Compositae, Leguminosae, Solanaceae and Cucurbitaceae in all the areas visited. The severity of the damage as envisaged through the amount of the foliage mined showed host preference of certain species of plants (Table 7).

4.3.2. Other leaf miners

The serpentine leaf mines on plants is the typical observable presence of leaf miner damage. In this investigation L. trifolii was the predominant species. Other species which were observed had basically similar type of mines as L. trifolii. The results of the investigation are shown in Table 8.

4.3.3. Parasites of L. trifolii

Several parasites were reared from larvae and pupae of L. trifolii. The predominant species in all the areas surveyed were Hemiptarsenus semiabaclava Grlt. and H. semiabaclavus (Eulophidae). Chrysontomyia spp also a eulophid and Aphidencyrtus africanus Gahan (Encyrtidae) were very rare. All the above were pupal parasites.

4.4. Discussion

As the results have revealed, L. trifolii has spread in many parts of the country since its introduction to Msongaleni Estate, Kibwezi from Florida (USA). The pest has spread in all

Table 8. Other leaf miners found in surveyed areas

Species	Host Plant
	CAPPARACEAE
Liriomyza spp	*Gynadropsis gynadra* L. (Birg)
	COMPOSITAE
Phytomyza syngensiae Hardy	*Chrysanthemums* spp
	SOLANACEAE
Phytomyza horucola Goureau	*Solanum tuberosum* L.
	CRUCIFERAE
Liriomyza brassicae Riley	*Brassica oleraceae* L.

Date	Place Collected
5 November 1982	Nairobi
2 March 1982	Kibwezi
2 March 1982	Kibwezi
4 April 1983	Nairobi

directions, covering vast areas. It has also been reported in Tanzania (Lyamungu Research Station) (Katundu, 1980). Spencer (Person. comm.) points out that Agromyzidae are a very mobile group of insects since they have no problem in crossing vast expanses of water such as the barrier between New Zealand and Australia. Therefore, the dispersal of the pest in the country was relatively easy. The spread could probably have been aided by winds and it would be interesting to compare the wind patterns and leaf miner distribution in the country.

Spencer (1973) notes that L. trifolii is one of the few agromyzids which is truly polyphagous. He further notes that the phenomena of polyphagy is primitive and further speciation is to be expected tending towards an oligaphagous or monophagous feeding habit. Schoohoven (1968) reports that polyphagy is where many plant species from different families are eaten. In the foregoing study it was observed that there were 43 species of plants in thirteen plant families which were hosts of L. trifolii, The study was by no means exhaustive and given more time several other hosts may have been added to the list.

It is interesting to note that cotton was rarely infested in Kibwezi area in 1978 and 1979. During a visit by the author at the same area in 1983, there were numerous mines and larvae in a cotton plantation. More than 40 per cent of the total leaves of individual plants had mines. This could have been as a direct result of cessation of the vast chrysanthemum acreage which was uprooted in the year 1981. The absence of available host plants, as it were, could have accounted for the sudden heavy attack on cotton.

The availability of alternative hosts in form of numerous weeds and wild plants makes the control of the leaf miner very difficult. These hosts will maintain a continuous low population which may serve as a source of infestation in newly planted crops. Similar observations were made by Steigmaier (1966).

Thorsteinson (1960) observed that the food plant range of some insects is curiously correlated with the natural taxonomic plant groupings (genera or families), but there are also many insects whose food plants are distributed in an apparently random pattern among plants without special regard to botanical affinities. The later is true for *L. trifolii* as the host range study of the pest reveals.

The phenomena of host selection, and in fact, preference is a complex process involving different responses usually to different stimuli (Kennedy, 1965). Chemical, visual, tactile stimuli interact with the odd plant substances such as alkaloids, flavonoids and glycoside and the inherent plant constituents of sugars, salts, and amino acids to determine the final host preferred. In the foregoing study it has been noted that some species and indeed some families are more preferred than others by the leafminer, *L. trifolii*. The Compositae, Solanaceae and Leguminosae and Cucurbitaceae were clearly more preferred by *L. trifolii* in all the areas visited.

It can be reasonably argued that the preferred hosts had more superior qualities such as food content, succulence of the leaves during oviposition, hence the preference. Chemical stimuli play a key role in the final selection of a host (Kennedy, 1965). Thorsteinson (1960) has a detailed report regarding chemical stimuli as predominating regulators of food plant selection. He points out that a classification of food plant preferences in pure chemotactic terms, should be attempted and then correlated with the botanical affinities that might emerge. He observes that this approach requires that plants are thought of in terms of assemblage of chemicals which provide chemotactic signal patterns perceptually significant for phytophagous insects. The abstraction he notes, is no less real than the morphological pattern that provides plant taxonomists with their basis of identification.

During the host range survey, it was evident that there were numerous mines on the foliage of some host plants but upon rearing, very few of the adult species emerged. This could be attributed to heavy parasitism and the plant reactions to mining larvae. In the latter case this might have been due to the plants' hypersensitive reactions to the larvae. In this case leaf tissues dried up in the area containing the larvae and thus terminated their development. This particular behaviour was observed in <u>Erucastrum arabicum</u> Fisch and Mey. (Cruciferae) and *Helianthus annus* L. (Compositae).

In most cases *L. trifolii* preferred older leaves of host plants except on locations where the infestation was exceptionally heavy. This phenomena was also noted by Jefferson and Eads (1952) on *Liriomyza langei* Frick on asters. This factor could be useful in the control of the pest. For instance, chemicals could specifically be applied on the older leaves where the pest occurs in high numbers.

In this study it clearly has been demonstrated that *L. trifolii* is a truly polyphagous leaf miner. The study of its host range is by no means exhaustive. Further investigations covering a wide range of host plants will provide additional information on species and plant families that may act as hosts.

CHAPTER 5

5. INSECTICIDAL EVALUATION AGAINST LIRIOMYZA TRIFOLII (BURGESS) AND ITS PARASITES ON TOMATOES

5.1. Introduction

L. trifolii has established itself well in Kenya as one of the most important pests on cultivated crops. This in part is evidenced by the frequency of occurrence during surveys and the numerous complaints received at the advisory laboratory at the National Agricultural Laboratories, Nairobi. The collapse of the multi-million chrysanthemum industry at Kibwezi, with subsequent loss of many jobs, dramatically emphasized the impact the new pest had on the horticultural industry.

Currently, there is no insecticidal recommendation for the control of this leaf miner. It is against this background that the need to investigate the efficacy of several insecticides for possible control was conceived. The significance of various hymenopteran parasites of leaf miners has been suggested (Musgrave et al, 1975, Poe et al, 1978). The need to evaluate the effect of the insecticides on tomato yield and the parasites was examined.

5.2. Materials and Methods

Field trials were conducted at Thika Horticultural Research Station, 42 km, North East of Nairobi. All observations in this study were made on staked 'Money-maker' tomato variety.

5.2.1. First Experiment - 1982

The seedbed was prepared on 22-2-1982 and the seedlings were transplanted 30 days later on prepared experimental plots. Each plot was 3 m x 3 m containing 15 tomato plants. Interrow spacing was 50 cm and between rows was 150 cm. This gave a sampling population of five plants of which four randomly selected plants were sampled. The four plants adequately represented the sampling population. The outer rows were buffers or guard rows. A distance of one meter between each plot served as a path between the plots. The layout of the experiment was a complete randomised block design of seven treatments with four replicates for each treatment. The plots were thoroughly watered by overhead irrigation two days before transplanting. Double super-phosphate fertilizer at the rate of 200 kg/hectare was applied (one teaspoonful per planting hole). Subsequently, when the tomato plants averaged a height of 30 cm a top dressing of calcium ammonium nitrate was broadcasted at the rate of 100 kg/ha. Six insecticides were tested for their effects on the leaf miner and its parasites. There were two categories of insecticides. The first group which was comprised of non systemic sprays included: Permethrin, fenvalerate and triazophos. The second group was the systemics which included: Oxamyl, disyston and carbofuran. The sprays were applied by a calibrated standard, C.P.-3 sprayer; commonly used by the small scale farmers. The systemics were applied as soil inoculants into the planting hole. The rates of application are shown in Table 9.

Four plants were sampled in each plot. Two indices were adopted for the purpose of this investigation. Index I was based on leaf injury represented by the number of mines per sample of 30 leaflets positioned randomly on the tomato plant. All the mines were counted. (Jefferson and Eads, 1952; Michelbacher et al, 1953; Wolfenbarger 1961; Poe et al, 1978). Index II involved the number of mined leaves of the four sampled tomato plants,

Table 9. A detailed list of insecticide treatments evaluated for control of *L. trifolii* on tomatoes

Commercial formulation	Active Ingredient	Rate Kg a.i/ha	Rate applied $9m^2$ plot (g.a.i.)
Furadan 10G	carbofuran	2.30	2.10
Sumicidin 10 Ec	fenvalerate	2.78	0.25
Ambush 6 Ec	permethrin	0.18	0.02
Vydate 10G	oxamyl	2.30	2.10
Disyston 10G	disulfoton	2.30	2.10
Hostathion 40 Ec	triazophos	8.33	0.75
Untreated check	-	-	-

(Al Azawi, 1966; Levins et al, 1975). Sampling was started on 8/4/82, one week after foliar insecticide application and thereafter weekly for a total of six times. Unfortunately, no data on yield or parasites was recorded. The experiment was terminated abruptly due to rampaging wild animals which damaged most of the tomato plants.

5.2.2. Second experiment - 1983

Apart from confirming results of the first experiment, the second experiment was initiated with the aim of acquiring parasites and yield data. Transplanting of the tomato seedlings was done on 24/3/83. The experimental layout, sampling method, and application of treatments were similar to the first experiment of 1982.

5.2.2.1. Effects of insecticides on parasites of *L. trifolii*

Ten tomato leaflets from each of the four tomato plants per replicate were randomly selected and placed in polythene bags and taken to the laboratory where they were introduced into emergence cages. The insects that emerged were counted and recorded. Identification was done at the National Agricultural Laboratories and the Commonwealth Institute of Entomology (London).

5.2.2.2. Yield

After three months from the day of transplanting, tomato fruits began maturing. The harvest from each plot was weighed and recorded. Only four plants from each replicate were marked for harvesting.

5.3. Results

5.3.1. First experiment 1982

The results of the first experiment are summarised on Tables 10 and 11. As indicated in Table 10, disyston and oxamyl treatments showed significant differences during the first week after treatment. The two synthetic pyrethroids i.e. fenvalerate and permethrin were statistically equal, with the latter treatment showing significant differences with the check only during the final week. Triazophos was consistently effective throughout the experimental period and

Table 10. Mean number of mines made by *L. trifolii* on insecticide treated and untreated tomato leaves - 1982 Experiment

Treatments	Mean number of mines per 30 leaflets in weeks					
	1	2	3	4	5	6
1. Carbofuran	2.414 ab	2.763 b	2.408 b	2.718 b	2.846 b	2.657 c
2. Fenvalerate	2.281 ab	2.453 ab	2.383 ab	2.124 a	2.314 ab	1.349 a
3. Permethrin	2.495 ab	2.552 b	2.205 ab	2.011 a	2.377 ab	2.593 bc
4. Oxamyl	2.876 b	2.585 b	2.375 b	1.764 a	2.026 a	1.801 abc
5. Triazophos	2.400 ab	2.005 a	1.681 a	2.153 ab	1.938 a	1.354 ab
6. Disyston	2.156 a	2.486 ab	2.082 ab	2.241 ab	2.067 a	1.565 ab
7. Check	2.684 ab	2.399 ab	2.603 b	2.623 b	2.551 ab	2.448 bc

Mean separation in vertical column by Duncan's multiple range test on transformed data $\sqrt{x + \frac{1}{2}}$. Values of means bearing the same letter are not significantly different at P 0.05.

Table 11. Mean number of mined leaves by _L. trifolii_ on insecticide treated and untreated tomatoes - 1982 Experiment

Treatments	Mean number of mined leaves per tomato plant in weeks					
	1	2	3	4	5	6
1. Carbofuran	2.548 a	3.222 b	3.249 b	2.912 b	2.833 ab	3.127 d
2. Fenvalerate	2.593 a	2.752 b	2.467 a	2.979 b	2.644 ab	1.598 a
3. Permethrin	2.598 a	2.670 b	2.494 a	2.793 b	2.501 ab	2.415 bc
4. Oxamyl	2.522 a	3.008 b	1.898 a	2.790 b	2.337 a	1.895 a
5. Triazophos	2.396 a	2.011 a	2.536 a	2.049 a	2.493 ab	3.113 d
6. Disyston	2.792 a	2.335 b	2.492 a	2.828 b	2.513 ab	1.977 ab
7. Check	2.837 a	2.913 b	3.225 b	3.134 b	3.135 b	2.784 cd

Mean separation on vertical columns by Duncan's multiple range test on transformed data $\sqrt{x + ½}$. Values of means bearing the same letter are not significantly different at P 0.05.

it showed the lowest mean number of mines. Carbofuran did not effectively reduce the number of mines on leaves and during the fourth, fifth and sixth week showed more mean numbers of mines than even the check plots. However the differences were not significant. As shown in Table 11 there were no significant differences between all the treatments, the first week after treatment. However triazophos had the least number of mined leaves (mean 2.396) as compared with the check (mean 2.837). Triazophos continued to reduce the number of mined leaves and significant differences between the check were noted during the fourth and sixth week. Oxamyl showed remarkable reduction of mined leaves during the third week (mean 1.898) as compared with the check (2.782).

5.3.2. Second Experiment - 1983

Results of index I which was based on number of mines per sample of 30 leaflets five weeks after foliar insecticidal application are shown in Table 12. Triazophos (Means 2.131, 1.994, 1.870, 1.697, 1.245), Permethrin (Means 1.914, 1.918, 1.947, 1.585, 1.074) and Fenvalerate (Means 1.874,

Table 12. Mean number of mines made by L. *trifolii* on insecticide treated and untreated tomatoes - Experiment 1983

Treatments	Means of mines per 30 leaflets in weeks				
	1	2	3	4	5
Carbofuran	1.691 a	2.150 ab	2.087 a	2.206 bc	1.301 a
Fenvalerate	1.874 a	2.139 ab	1.849 a	1.349 a	1.183 a
Permethrin	1.914 a	1.918 a	1.947 a	1.585 ab	1.074 a
Oxamyl	2.046 a	2.028 ab	1.933 a	1.301 abc	1.233 a
Triazophos	2.131 a	1.994 a	1.870 a	1.697 ab	1.245 a
Disyston	1.801 a	2.250 ab	1.650 a	1.324 a	1.039 a
Check	1.637 a	2.634 b	2.552 b	2.455 c	1.640 b

Mean separation in vertical columns by Duncan's multiple range test on transformed data $\sqrt{x + \frac{1}{2}}$. Values of means bearing the same letter are not significantly different at P 0.05.

2.139, 1.849, 1.349 and 1.183) showed their efficacy in descending order over the whole experimental period. The soil inoculants oxamyl and disyston and carbofuran showed appreciable reduction of leaf miner as opposed to the results of the first experiment. All the treatments were statistically significant during the final week as compared to the check plots. As shown in table 13, there were no significant differences between total number of mined leaves between the check and the treatments one week after application of the treatments. However, triazophos showed significant differences compared with the check during the second week. All treatments were significantly effective, compared to the check plots during the third week. During the fourth and the fifth week, all treatments were not statistically significant.

5.3.3. Effect of insecticides on the parasites of *L. trifolii*

Three eulophid species of parasites of *L. trifolii* were identified: *H. semiabiclavus*, *H. semiabiclava* and *Chrysonotomyia* spp. An encyrtid hymenopteran parasite *Aphidencyrtus*

Table 13. Mean number of mined leaves by _L. trifolii_ on insecticide treated and untreated tomatoes - Experiment 1983

Treatments	Means of mined leaves per tomato plant in weeks				
	1	2	3	4	5
Carbofuran	2.568 a	3.657 c	2.757 a	3.435 a	4.011 ab
Fenvalerate	2.566 a	3.512 c	2.065 a	3.240 a	3.732 ab
Permethrin	2.579 a	3.243 bcd	2.458 a	3.279 a	3.279 ab
Oxamyl	2.476 a	3.019 abc	2.251 a	3.077 a	3.077 ab
Triazophos	2.585 a	2.540 ab	2.076 a	2.963 a	2.929 a
Disyston	2.330 a	2.365 a	2.409 a	3.358 a	3.809 ab
Check	2.732 a	3.879 d	4.026 b	3.785 a	4.021 b

Mean separation in vertical columns by Duncan's multiple range tests on transformed data $\sqrt{x + \frac{1}{2}}$. Values of means bearing the same letter are not significantly different at P 0.05.

africanus Gahan was also identified. The last two parasitic species occurred in very low numbers. Consequently, they were not subjected to statistical analysis. The data taken during the first week indicated that triazophos had significantly less numbers of both L. trifolii and hymenopteran parasites than the other treatments. It was observed that parasites from the soil inoculant treatments were not statistically different from each other. Similar results were also observed during the second week after treatment. However, more parasites emerged from carbofuran treated plots. During the third week, the check and the carbofuran treatments had significantly higher number of parasites than triazophos or oxamyl treatments. The same trend was also found in the fifth week (Table 14).

5.3.4. Yield of tomatoes

The weight of harvested tomato fruits showed no significant differences between treatments and the

Table 14. Mean number of adult L. trifolii and its parasites reared from leaf samples of insecticide treated and untreated tomatoes - 1983 Experiment

Treatments	Mean numbers of L. trifolii and its parasites in weeks							
	1		1	2	3		4	
	L. trifolii	Parasites	L. trifolii	Parasites	L. trifolii	Parasites	L. trifolii	Parasites
1. Carbofuran	2.658 ab	2.449 b	2.922 b	2.096 a	2.646 ab	1.979 b	2.781 b	2.241 b
2. Fenvalerate	3.335 bc	2.799 b	2.001 b	1.352 a	2.439 a	1.565 ab	2.332 ab	1.554 b
3. Permethrin	2.714 ab	1.835 b	3.358 b	1.966 a	2.546 ab	1.274 ab	3.037 b	1.610 b
4. Oxamyl	3.204 bc	2.714 b	3.051 b	1.679 a	1.626 a	1.570 ab	2.727 ab	1.312 b
5. Triazophos	2.171 a	1.418 a	1.570 a	1.055 a	2.144 a	1.055 a	1.346 a	1.055 a
6. Disyston	3.251 bc	2.530 b	2.815 b	1.570 a	2.144 a	1.346 ab	2.736 ab	1.626 b
7. Check	3.878 c	2.611 b	3.203 b	2.177 a	3.562 b	1.979 b	4.160 c	2.628 b

Means separation in vertical columns by Duncan's multiple range tests on transformed data $\overline{x + ½}$ P 0.05.

Values of means bearing the same letter are not significantly different at P 0.05.

check (Table 15). However oxamyl had the highest mean weight of 10.03 kilograms while the control and disyston had the lowest mean weights of 8.06 and 7.91 kilograms respectively. There was no correlation between yield and the damage over all the weeks in the second experiment.

5.4. Discussion

5.4.1. Control of *L. trifolii*

Liriomyza leaf miner species have long been recognised as pests of vegetables in, United States of America (Hills and Taylor, 1951). During the fall of 1948, leaf miner outbreaks on lettuce and cantaloupes in the Salt River Valley (Arizona - USA) was so serious that some fields were abandoned and disked. No insecticides that could control this pest were known during this time. A review of control measures against leaf miners especially *Liriomyza* spp shows that most of the conventional insecticides have been tried against these versatile pests. One striking feature, however, is the phenomenon of development of resistance towards various organo-chlorines, organophosphates and carbamate insecticides (Genung, 1957;

Table 15. Yield of tomato trials - 1983

TREATMENTS	MEAN WT (KG)
Carbofuran	8.32 a
Fenvalerate	9.90 a
Permethrin	9.45 a
Oxamyl	10.03 a
Triazophos	9.01 a
Disyston	7.91 a
Control	8.06 a

Means separation in vertical columns by Duncan's multiple range test on untransformed data. Values of means bearing the same letter are not significantly different at P 0.05.

Wolfenbarger, 1958, 1961).

After its introduction into Kenya in 1977 (De Lima, 1979) there were serious outbreaks on the chrysanthemums at Kibwezi in 1978 and 1979. A wide range of chemicals were used against the pest and apparently they were not effective. As Spencer (1979) notes in his report, after appraising the pest in the field, there was a major infestation which was marginally controlled by the massive use of 28 different insecticides (Table 16). The author is in agreement with Spencer (1979) that lack of effective control methods may partly be as a result of incorrect application of insecticides or by the leaf miners' resistance.

Genung (1957) noted that a few important species affecting vegetable crops in Florida including the leafminer L. pusilla had become increasingly difficult to kill with insecticides. However, Kelsheimer (1957) points out that before a conclusion is made regarding certain materials being resisted by insects, it is necessary to evaluate certain factors that have an effect upon good insect control; these may include insecticide formulation, timeliness of application, compatibilities and thoroughness of application.

Table 16. List of chemicals tried against *L. trifolii* on Chrysanthemum at Mwonzaleni, Kibwezi 1977-1980

	Chemical Name	Trade Name
1.	Aldrin	Aldrin*
2.	Aldicarb	Temik
3.	Azinphos-methyl	Gusathion
4.	Carbaryl	Carbaryl*
5.	Carbofuran	Furadan
6.	DDT	DDT*
7.	DDT + Carbaryl	Dimecron*
8.	Demeton-s-methyl	Metasystox
9.	Diazinon	Diazinon
10.	Dimethoate	Roxion*
11.	Dimethyl thiophosphate	Lebaycid
12.	Disulfoton	Disyston*
13.	Endosulfan	Thiodan
14.	Ethyl paraphos	Ethyl paraphos.
15.	Fenitrothion	Sumithion*
16.	Formothion	Anthio
17.	HCH	Lindane*
18.	Parathion	Kalitox*
19.	Permethrin	Ambush**
20.	Pirimiphos-methyl	Actellic*
21.	Phorate	Phorate
22.	Omethoate	Folimat
23.	Oxamyl	Vydate granules*
24.	Oxamyl	Vydate liquid*
25.	Triazophos	Hostathion**
26.	Trichlorfon	Dipterex
27.	Permethrin	Decis*
28.	+	

+ The identity of this chemical was missing.

* Gives control in varying degrees.

The choice of triazophos, fenvalerate, and permethrin sprays had no particular significance. However, triazophos has been used in United Kingdom in eradication of L. *trifolii* (Bartlett and Powell, 1981). Permethrin and fenvalerate are both recent synthetic pyrethroids and have almost similar properties.

Granulated systemic insecticides for pest control have been tried by several workers. (Andre et al, 1961; Harding, 1962; Harding and Wolfenbarger, 1963; Al Azawi, 1966). Spencer (1979) in his report on chrysanthemums at Kibwezi notes that an effective systemic insecticide should be sought which will destroy both the females feeding on the leaves, the eggs and larvae present in the leaves. Three systemic insecticides which are easily available were included in the trials viz. carbofuran, oxamyl and disyston. Harding (1962) observes that beneficial insects are often not severely harmed and are therefore, able to reduce further insect infestations. This observation is also confirmed in the present study.

In this investigation, the performance of various treatments varied either in the reduction of leaf mines or the number of mined leaves on the tomato plants. Triazophos proved to be more effective in mine reduction of the tomato plants as well as the number of mined leaves per individual plant. This could have been due to its ability to penetrate the plant tissues. Presumably it killed the larvae inside the leaves. Fenvalerate which has a rapid knockdown and repellant activity was the second best insecticide. Surprisingly, carbofuran which is a systemic insecticide widely used for controlling many pests in the country had poor results in mine reduction on leaves and mined leaves. Generally, Index I which was the number of mines per sample of leaves showed more sensitivity in determination of miner damage than Index II, the number of mined leaves. Results of the latter index were more varied and sometimes were not consistent. This would indicate that the female of L. trifolii would probably probe into the leaves and possibly lay only a few eggs. On the other hand it would concentrate its oviposition on particular leaves resulting in more density of mines per given sample.

More mines were found on the older leaves of tomato plant rather than on the younger leaves. Jefferson and Eads (1952) similarly found that

L. langei preferred the older leaves on asters.

The estimation of damage on tomatoes by leaf miner has varied with several workers. Mines per leaflet have been used by Mayeux and Wene (1950), Lange and Smith (1947) and Michelbacher et al (1953). Number of surviving larvae after treatment was used to indicate insecticidal efficacy by Adlerz (1961) whereas Wolfenbarger (1964) counted the number of pupae per 100 leaves. The number of mines per one-man hour search was used by Oatman and Kennedy (1976). Levins et al (1975) and Al Azawi (1967) counted the number of infested leaves. Poe et al (1978) investigated insecticidal effects on *L. sativae* and their parasites on tomatoes. The number of total mines per thirty leaflets was used to gauge the infestation levels regarding the treatments. This method was used in the present study. Among the insecticides used in the present investigation, only disyston and oxamyl had been tried earlier by other workers on leaf miners.

Harding and Wolfenbarger (1963) found that disyston and phorate were the best materials relative to reduction of leaf mines in the upper leaves of Southern peas. Al Azawi (1966) found that the chemicals gave good protection against

Phytomyza atricornis Meigen for more than two months. The lowest active mine counts were recorded in the methamidophos, methomyl + oxamyl, oxamyl and acephate treatments in the work carried out by Poe et al, (1978). Schuster et al, (1979) carried out similar work with oxamyl spray against L. sativae on tomatoes. He found that two applications of oxamyl were effective in reduction of leaf miner damage where one active mine per three terminal leaflets was the damage threshold.

5.4.2. Parasites

A review of control practices of the leaf miner shows that the pest has a great capacity for resistance to a broad range of insecticides. More recently, the significance of various hymenopteran parasites to leaf miner control has been suggested (Musgrave et al, 1975). These beneficial insects apparently control leaf miners in vegetables that are not heavily treated with insecticides. Incidentally, there were only two species of parasites which were recovered in appreciable numbers in this study. These were eulophids, H. semiabiclava and H. semiabclavus. The other identified species A. africanus

(Encyrtidae) and Chrysonotomyia spp were rare or absent and were not subjected to statistical analysis. Other workers in U.S.A. have reported several species of hymenopteran parasites but invariably one or two species were dominant (Wene 1955; Oatman 1959b; Getzin 1960; Harding 1965; Jensen and Koehler 1953; Poe et al 1978). Getzin (1960) noted that delhav and dimethoate insecticides showed greatest amount of selectivity for controlling *L. munda* and allowing survival of *Diglyphus variipes* Cwfd, a hymenopteran wasp. Oatman (1959b) who reared 19 species of parasites noted that there was a strong correlation between parasite and leaf miner numbers. In the present study triazophos spray was the most effective chemical against *L. trifolii* and also most toxic to the parasites. Permethrin, a synthetic pyrethroid was least toxic to the parasites while maintaining a good control of the leaf miner. Bearing in mind the importance of parasites in the control of leaf miner populations permethrin would be a good choice in an intergrated control programme. The soil inoculants: oxamyl, carbofuran and disyston were better at preservation of parasites than the foliar sprays. Similarly, these insecticides could also be recommended for the control of the leafminer. However, carbofuran was not very effective on leaf miner populations during the first experiment. This could have been due to poor efficacy or erronous application.

In some instances sprays of various chemicals have been shown to accentuate the populations of leaf miners due to elimination of parasites. (Oatman and Kennedy, 1976). They found that application of methomyl, induced outbreak of L. sativae on tomatoes because it is more toxic to the parasites. No similar results were observed in the foregoing investigations.

5.4.3. Yield

Losses on account of leaf miner damage range from total to practically none (Wolfenbarger, 1961). Under heavy infestation the author found that young tomato seedlings at Thika Research Station withered and died. On the other hand, the treatments showed no significant differences in yields as compared to the check. Oxamyl showed a slight increase of yield which was probably due to its nematicidal, acaricidal and insecticidal properties. It is, however, admitted that data for one season cannot give conclusive results.

Correlation of yield and damage between both Index I and Index II was very low and of no statistical significance. Several workers have endevoured to correlate damage and yield with differing opinions. Wolfenbarger (1961) who conducted his pesticide experimental trials for seven years was unable to demonstrate a reduction in potato yields due to increased populations of leafminers. On the other hand Wolfenbarger and Wolfenbarger (1966) indicated that yield might be affected by leaf miner damage. Levins et al, (1975) using a regression model analysis failed to show that leaf miners directly affect yield of tomatoes. He concluded that in seasons when leaf miner damage is less than complete foliage loss, application of chemicals may be unnecessary. The same conclusions were drawn by Poe et al, (1978) and Johnson et al, (1980a, 1980b). In fact, Johnson et al, (1980a) found that signigicantly higher yields were recorded from methomyl treated plots as compared to dipel and chlorpyrifos treatments although leaf miner densities were significantly higher in the methomyl treatments.

CHAPTER 6

6. GENERAL DISCUSSION AND CONCLUSIONS

1. As in most cases of new pest introductions claims are often made by the offending parties, that the pest was probably present but undetected in the country. However, according to De Lima's (1979) independent documented report, *L. trifolii* was not present in the country before chrysanthemum imports from Florida were made. It is now evident that *L. trifolii* has established itself in the country as one of the most important pests on diverse horticultural crops.

2. In view of the massive insecticides that have unsuccessifully been used for the control of *L. trifolii* in Msongaleni Estate, Kibwezi, it is desirable that insecticidal resistance of this pest should be sought. This would be in conjunction with setting up several trials using different insecticides with varying rates of applications. Emphasis should be directed to proper and correct application and timeliness of the treatments.

3. Bartlett and Powell (1981) and Powell (1981) have given accounts of how *L. trifolii* was eradicated in England and Wales and at Efford Experimental Horticulture Station (Hampshire) respectively. Introductions of the pest were from Kenya and Malta from imported chrysanthemum cuttings. However, the authors conviction is that eradication of this pest cannot be possible in Kenya. Apart from the massive resources involved, our tropical conditions and crop husbandry is very different from the temperate conditions such as that of United Kingdom.

4. The present study reveals that triazophos was better at controlling *L. trifolii* than the others. Permethrin, fenvalerate, oxamyl all showed a measure of control of the pest. In the U.S.A., the chemicals Avermectin and Trigard are proving to be excellent in controlling vegetable leaf miners (Begley, 1983). It is notable that a review of literature regarding chemical control shows that *L. trifolii* has progressively become resistant to various insecticides (Wolfenbarger, 1958). The apprehension here is that given time, the

above insecticides will become ineffective against leaf miners. Consequently an integrated control approach would be desirable especially where parasites would be preserved and encouraged to keep down leaf miner populations.

5. In the foregoing studies it has been shown though not conclusively that the damage caused on leaves by L. *trifolii* does not affect tomato yield. Levins et al, (1975) points out that there is a strong evidence that in many seasons expenditures for leaf miner control on Florida grown tomatoes may be wasted - little is gained by using resources to control essentially harmless pests. He observed that it is the fruits not leaves that were marketed and there was no correlation between fruit yields and leaf miner damage.

The author would like to note that the conclusions of Levins et al (1975) are very relevant to the Kenyan situation. Similarly, emphasis of leaf miner damage should be placed on the end product or the marketable yield.

The collapse of the multimillion chrysanthemum project at Msongaleni (Kibwezi) was due to the fact that chrysanthemum cuttings which involved the damaged leaves was the marketable yield. As such the buyers rejected the produce due to the visible mines. On the contrary the damage on tomato leaves does not affect the fruits and it would be injudicious to apply chemical insecticides due to the presence of mines only. Wolfenbarger and Wolfenbarger (1966) in a study on tomato yields and the effect due to Liriomyza spp damage for 9 years drew a sequential sampling plan for determining need for control measures. They drew linear regression equations to show the expected yield reductions from leaf miner populations. Decision lines to spray or not to spray were proposed when 40% and 10% of the leaves averaged 1 or more mines per leaflet. This type of study is wanting in a lot of crops being affected by leafminer pests in Kenya.

It would be pertinent to conclude by quoting Wolfenbarger (1961), that "there is no quick, simple nor easy solution to the leaf miner problem".

REFERENCES

1. Adlerz, W.C. 1961. Control of leaf miners on water melon in Central and South Florida. Fla. Agric. Expt. Sta. Jour. Series 1331: 134-137.

2. Al-Azawi, A.F. 1966. Seed treatment with phorate, disulfoton and other insecticides to control pea insect pests in Iraq. Bull. Ent. Res. 59(4): 859-863.

3. Al-Azawi, A.F. 1967. Agromyzid leaf miners and their parasites in Iraq. Bull. Ent. Res. 57: 285-287.

4. Andres, L.A., H.T. Reynolds, and T.R. Fukuku. 1959. The use of the systemic insecticides for control of the cabbage and cauliflower. Jour. Econ. Ent. 52(6): 1045-1059.

5. Anon. 1979. The Kenya development plan 1979 - 1983. Government Printers, 523pp. Kenya.

6. Anon. 1980a. Economic Review of Agriculture 1970 - 1980. Economic Planning Division Min. of Agric. Government Printers. Kenya.

7. Anon. 1980b. The Kenya Farmer, English press. 50pp.

8. Askew, R.R. 1968. A survey of leaf miners and their parasites in laburnum. Trans. R. Ent. Soc. Lond. 120: 1-37.

9. Bartlett, P.W., and D.F. Powell. 1981. Introduction of American serpentine leaf miner *Liriomyza trifolii* into England and Wales and eradication from commercial nurseries, 1977 - 1981. Plant Pathology 30: 185-193.

10. Begley, J.W. 1983. Efficacy data on the materials Trigard and Avermectin on control of *Liriomyza trifolii* Burgess (Diptera: Agromyzidae) (Unpublished).

11. Beri, S.K. 1974. Biology of the leaf miner *Liriomyza brassicae* Riley (Diptera: Agromyzidae). Jour. Nat. Hist. 8: 143-151.

12. Burgess, E. 1880. The Cover Oscinis (*Oscinis trifolii* Burgess n.s.p.) Rep. U.S. Dept. Agric. 1879: 200-201.

13. Curtis, J. 1844. *Agromyza violae* (the pansy-fly). Gardener's Chronicle April, 20: 244-245.

14. De Lima, C.P.F. 1979. *Liriomyza trifolii* (Diptera: Agromyzidae). An important new leaf miner in Kenya. Kenya Ent.

Newsletter 10: 8.

15. Frick, K.E. 1957. Nearctic species in the *Liriomyza pusilla* Complex, No. 2. *L. munda* and two other species attacking crops in California. Pan Pacific Entomologist 33: 59-70.

16. Genung, G.W. 1957. Some possible cases of insect resistance to insecticides in Florida. Fla. Agric. Expt. Sta. Jour. Series 667: 148-152.

17. Genung, G.G., and E.D. Harris 1961. Notes on the biology and control of serpentine leaf miner(s) in the Everglades. Fla. Agric. Expt. Sta. 1330-137.

18. Genung, W.G., and M.J. Janes, 1975. Host range, wild host significance and in-field spread of *Liriomyza trifolii* and population build up and effects of its parasites in relation to fall and winter celery, (Diptera: Agromyzidae). Research Report. Fla. Agric. Expt. Sta. 1975.

19. Getzin, L.W. 1960. Selective insecticides for vegetable leaf miner control and parasite survival. Jour. Econ. Ent. 53: 872-875.

20. Gilbert, M.N. 1976. Chrysanthemum leaf miner. Connecticut Greenhouse Newsletter 73: 13-16.

21. Harding, J.A. 1962. Tests with systemic insecticides for control of insects and certain diseases on tomatoes. Jour. Econ. Ent. 55(1): 62-65.

22. Harding, J.A., and D.A. Wolfenbarger. 1963. Granulated systemic insecticides for vegetable insect control in South Texas. Jour. Econ. Ento. 56(5):687-689.

23. Harding, J.A. 1965. Parasitism of the leaf miner Liriomyza munda in the winter garden area of Texas, Jour. Econ. Ent. 58(3): 442-443.

24. Harris, H.M., and H.D. Tate. 1933. A leaf miner attacking cultivated onion. Jour. Econ. Ent. 26: 515-516.

25. Hills, O.A., and A.E. Taylor. 1951. Parasitization of dipterous leaf miners in canataloupes and lettuce in the Salt River Valley, Arizona. Jour. Econ. Ent.

44(5): 759-762.

26. Jefferson, R.N., and O.C. Eads. 1952. Control of leaf miners and other insect pests of asters. Jour. Econ. 45(3): 476-481.

27. Jensen, G.L., and S.C. Koehler. 1953. Seasonal distributional abundance and parasites of leaf miners of alfalfa in California. Jour. Econ. Ent. 63(5): 1623-1628.

28. Johnson, M.W., R.E. Oatman, and A.J. Wayman. 1980a. Effect of insecticides on the populations of the vegetable leaf miner and associated parasites on summer pole tomatoes. Jour. Econ. Ent. 73(1): 61-66.

29. Johnson, M.W., R.E. Oatman, and A.J. Wayman. 1980b. Effect of insecticides on populations of the leaf miner and associated parasites on fall pole tomatoes. Jour. Econ. Ent. 73(1):67-71.

30. Katundu, J.M. 1980. Agromyzid leaf miner, a new insect pest in Tanzania. Tropic. Gra. Leg. Bull. 20: 8-16.

31. Kelsheimer, E.G. 1948. Insecticidal value of DDT and related synthetic compounds on vegetable crop insects in Florida.

Fla. Agr. Expt. Sta. A report. 1947: 46-47.

32. Kelsheimer, E.G. 1957. Other causes of poor control sometimes attributed to resistance. Fla. Sta. Hort. Soci. 667: 152-153.

33. Kennedy, J.S. 1965. Proceedings of the association of applied biologists: Mechanism of host plant selection. Ann. App. Biol. 56: 317-322.

34. Lange, H.W., and M.L. Smith. 1947. Control of a leaf miner on peas. Jour. Econ. Ent. 40(4): 496-499.

35. Levins, R.A., S.L. Poe., C.R. Litter, and P.J. Jones. 1975. Effectiveness of a leaf miner control program for Florida tomato production. Jour. Econ. Ent. 68(6): 772-774.

36. Mayeux, H.S., and P.G. Wene. 1950. Control of serpentine leaf miner on pepper. Jour. Econ. Ent. 43(5): 732-733.

37. McGregor, E.A. 1914. The serpentine leaf miner on cotton. Jour. Econ. Ent. 7: 447-454.

38. Michelbacher, A.E., W.W. Middlekauff, and L.G. Glover. 1951. Studies with aldrin

and dieldrin against melon insects. Jour. Econ. Ent. 15 (3) 470-5.

39. Michelbacher, A.E., O.G. Bacon, W.W. Middlekauff, and E. Erwin. 1953. Tomato insect investigations in Northern California in 1951. Jour. Econ. Ent. 46(1): 73-76.

40. Miles, H.W., and M. Cohen. 1936. The Chrysanthemum leaf miner and its control. Jour. Min. Agric. 43: 256-261.

41. Miller, G.M. 1978. A review of <u>Liriomyza</u> spp and other American leaf miner pests associated with Chrysanthemums, (Diptera: Agromyzidae). Sixteenth Report of the Working Party on Phytosanitary regulations. Athens, 7th - 8th June, 1978. E.M.P.O. Publications: Series C No. 57.

42. Musgrave, C.A., S.L. Poe, and H.V. Weems Jr. 1975. The vegetable leaf miner <u>Liriomyza</u> <u>sativae</u> Blanchard (Diptera: Agromyzidae) in Florida. Fla. Dep. Agric. Consumer Serv. Div. Plant Industry. Ent. Circ. 162: 4pp.

43. Oatman, E.R., and A.E. Michelbacher. 1958. The melon leaf miner, <u>Liriomyza</u> <u>pictella</u> (Thomson)(Diptera: Agromyzidae).

Ann. Ent. Soc. Amer. 51: 557-566.

44. Oatman, E.R. 1959a. Host range studies of the melon leaf miner Liriomyza pictella (Thomson) Diptera: Agromyzidae. Ann. Ent. Soc. Amer. 52: 739-741.

45. Oatman, E.R. 1959b. Natural control studies of the melon leaf miner Liriomyza pictella (Thomson). Jour. Econ. Ent. 52(2): 895-898.

46. Oatman, E.R., and A.E. Michelbacher. 1959. The melon leaf miner Liriomyza pictella (Thomson) (Diptera: Agromyzidae) II. Ecological Studies Ann. Ent. Soc. Amer. 52(1): 83-89.

47. Oatman, E.R., and G.G. Kennedy. 1976. Methomyl induced outbreak of Liriomyza sativae on tomato. Jour. Econ. Ent. 69(5): 667-668.

48. Parrella, M.P., and L.K. Robb. 1982. Technique for staining eggs of Liriomyza trifolii within chrysanthemum, celery, and tomato leaves. Jour. Econ. Ent. 75: 383-384.

49. Poe, S.L. 1974. Selective application of insecticides for sustained fruit yield of tomato. Fla. Agric. Expt. Sta. Jour.

Series 4703: 165-169.

50. Poe, S.L., P.H. Everett, J.D. Schuster, and C.A. Musgrave. 1978. Insecticidal effects of *Liriomyza sativae* Blanchard larvae and their parasites on tomato. Jour. Georg. Ent. Soc. 13(4): 322-327.

51. Powell, D.F. 1981. The eradication campaign against American serpentine leaf miner *Liriomyza trifolii* at Efford Experimental Station. Plant Pathology 30: 195-204.

52. Sanders, J.G. 1912. A remedy of chrysanthemum leaf miner. Jour. Econ. Ent. 5(6): 472.

53. Schoonhoven, L.M. 1968. Chemosensory bases of host plant selection. Rev. App. Ent. 13: 115-136.

54. Schuster, D.J., C.A. Musgrave, and J.P. Jones. 1979. Vegetable leaf miner and parasite emergence from tomato foliage sprayed with oxamyl. Jour. Econ. Ent. 72(2): 208-210.

55. Smith, F.F., A.L. Boswell, and H.E. Wave. 1962. New chrysanthemum leaf miner species Florists Review, June 1966 2pp.

56. Spencer, K.A. 1965. A clarification of the status of *Liriomyza trifolii* (Burgess)

and some related species. Proc. Ent. Soc. Wash. 67(1): 32-40.

57. Spencer, K.A. 1973. Agromyzidae (Diptera) of economic importance. Series: Entomologica. Vol. 9 B.V., Publishers The Hague.

58. Spencer, K.A. 1979. Report on a visit to Kenya to assess the infestation of Chrysanthemum at Msongaleni with Liriomyza trifolii. Brooke Bond Liebig. 5pp.

59. Speyer, E.R. 1936. Leaf miner on tomato plant Rep. Expt. Res. Sta. Cheshunt (1936) 28: 70.

60. Speyer, E.R., and W.J. Parr. 1948. Tomato leaf miner Liriomyza solani Herring. Rep. Expt. Res. Sta. Cheshunt (1948) 34: 43-51.

61. Steigmaier, C.E. Jr. 1966. Host plants and parasites of Liriomyza trifolii in Florida. (Diptera: Agromyzidae) Fla. Ent. 49(2): 75-80.

62. Thorsteinson, A.J. 1960. Host selection in phytophagous insects. Ann. Rev. Ent. 5: 193-218.

63. Webb, R.E., and F.F. Smith. 1969. Effect of temperature on resistance in Lima bean, tomato, and chrysanthemum to Liriomyza munda Frick. Jour. Econ. Ent. 62: 458-462.

64. Webb, R.E., and F.F. Smith. 1970. Survival of eggs of Liriomyza munda in chrysanthemum during cold storage. Jour. Econ. Ent. 63(4); 1359-1361.

65. Webb, R.E., A.M. Hinebaugh, R.K. Lindquist, and M. Jacobson. 1983. Evaluation of aqueous solution of Neem seed extract against Liriomyza sativae and Liriomyza trifolii (Diptera: Agromyzidae). Jour. Econ. Ent. 76(2): 357-362.

66. Webster, F.M., and T.H. Parks. 1913. The serpentine leaf miner. Jour. Agric. Res. 1(1): 59-87.

67. Wene, G.P. 1955. Effects of some organic insecticides in the population of the serpentine leaf miner and its parasites. Jour. Econ. Ent. 48(5): 596-597.

68. Wene, G.P. 1958. Control of serpentine leaf miner on peppers. Jour. Econ. Ent. 46(5): 789-793.

69. Wilcox, J., and F.A. Howland. 1952. Control of dipterous leaf miner on tomatoes in California. Jour. Econ. Ent. 45(4): 634-639.

70. Wolfenbarger, D.O. 1947. The serpentine leaf miner and its control. Fla. Agric. Expt. Sta. Press. Bull. 639: 1-6.

71. Wolfenbarger, D.O. 1948. Control studies on the serpentine leaf miner on potato and tomato. Proc. Fla. Hort. Soc. 61: 181-186.

72. Wolfenbarger, D.O. 1958. Serpentine leaf miner. Brief history of a decade of control measures in South Florida. Jour. Econ. Ent. 51(8): 357-359.

73. Wolfenbarger, D.O. 1961. Leaf mining insects especially the serpentine miners on vegetable crop plants and their control. Fla. Agric Expt. Sta. Jour. Series: 1325: 131-133.

74. Wolfenbarger, D.A., and L.W. Getzin. 1963. Selective toxicants and toxicant surfactant combinations for leaf miner <u>Liriomyza munda</u> Frick; Control and parasite survival. Fla. Ent. 46(3); 251-265.

75. Wolfenbarger, D.A. 1964. The effect of insecticides, rates, intervals between and number of applications and insecticide-oil and surfactant combinations for insect control on Southern peas. Jour. Econ. Ent. 57(6): 966-969.

76. Wolfenbarger, D.A., and Wolfenbarger, D.O. 1966. Tomato yields and leaf miner infestations and a sequential sampling plan for determining need for control treatments. Jour. Econ. Ent. 59(2): 279-283.