VG003

Population dynamics and control of the tomato russet mite

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VG003

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HORTICULTURAL RESEARCH AND DEVELOPMENT CORPORATION

FINAL REPORT **PROJECT V/0003**

POPULATION DYNAMICS AND CONTROL OF THE TOMATO RUSSET MITE, *ACULOPS LYCOPERSICI* (MASSEE)

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SUMMARY

Investigations were carried out at the Biological and Chemical Research Institute, Rydalmere and at Somersby Horticultural Research Station to study the effect of climatic and biological factors that influence the population fluctuations of tomato russet mite (TRM), *Aculops lycopersici* (Massee), to check for the presence of resistance to insecticides among populations of TRM, to identify insecticides which are efficient in controlling TRM, to determine the presence of plant resistance in processing tomato varieties to TRM and to examine the possibility of reducing the number of insecticide sprays for TRM by the appropriate choice of insecticides for *Helicoverpa* spp. control.

Low humidity, high temperature and low rainfall favour TRM populations to build up and the opposite conditions were found to be unfavourable for population build-up. TRM can continue to reproduce throughout the winter if plants are available in the field. A cecidomyiid fly larva, nymphs of the "plague thrips", a tydeid mite, six different species of phytoseiid mites and a stigmaeid mite were found to be predatory on TRM life stages. An outbreak of a fungal infection by the entomogenous fungus *Hirsutella thompsonii* almost completely wiped out a field population of TRM. This fungus was found to be selective in causing mortality to TRM and not to the tydeid predatory mites. Endosulfan, demeton-S-methyl, chlorpyrifos, cypermethrin and trichlorfon were found to be effective in reducing TRM populations. Populations of TRM increased after the application of the fungicide copper oxychloride, possibly due to the selective mortality of copper oxychloride to the tydeid predatory mites. A laboratory bioassay technique for evaluating toxicity of insecticides to TRM was developed and used to test field collected populations of TRM for resistance to commonly used insecticides. Field populations tested were not resistant to insecticides tested. None of the five processing tomato varieties tested in the glasshouse showed any varietal resistance to TRM.

Introduction

The tomato russet mite (TRM), *Aculops lycopersici* (Massee) is an important pest on solanaceous crops throughout many parts of the world. Tomato russet mite was first described in Australia as a pest of tomatoes in Queensland in 1916 (Tyron 1917).

Adult mites are yellow-orange in colour, wedge-shaped, tapering posteriorly. Males are 150-200 μm long and females about 200 μm long and 50 μm thick. The eggs are spherical, about 55 μm in diameter. When first laid it is opalescent-white, later more cloudy and yellowish. There are two nymphal instars and the whole life cycle is completed within 5-7 days (Bailey and Keifer 1943).

The tomato plant is the main host for *A. lycopersici*, but infestations on both potato and egg-plant have been recorded, and it is likely that it has a number of other solanaceous hosts (Taylor 1978). This mite lives on popolo, *Solanum nodifolium*, in the Hawaiian Islands and in California TRM is known to reproduce on tomato, petunia, potato, nightshades, *S. nigrum* and *S. vilosum*, the tomatillo, *Physalis ixoparpa*, *Datura stramonium* and *D. feron* (Bailey and Keifer 1943). Tomato russet mite develops most profusely in hairy or glandular plants, which condition produces a more favourable habitat for the mite. Excessively sticky varieties of petunias seem immune. The nightshades and daturas are in the main less favoured hosts, perhaps largely due to the glabrous surfaces characteristic of most of these (Bailey and Keifer 1943). In Queensland TRM occurs on several weeds botanically allied to the tomato, such as the green and Cape gooseberries and two varieties of wild black currant. At times it may be abundant on English potatoes (Sloan 1945).

Mites affect tomato plants of all ages and may be responsible for serious foliage losses, the cause of which is frequently rather puzzling to the grower. The first symptom of injury is a slight curling of the lower leaves which then show a silvery sheen on the under-surface; later these leaves become bronze coloured, droop, and finally die. The lower part of the stem loses its surface hairs, becomes smooth, rusty brown or smoky-coloured and may later develop small, superficial cracks. As infestation increases, the mites gradually spread, discolouring the stems and destroying the foliage, until only the young terminal growth remains. Thus, the fruit is exposed to sunburn, plant growth is retarded, and blossom setting curtailed. In severe attacks, where infestation extends to the terminal growth, the young leaves may be distorted. Fruit may also be attacked and, when this is the case, the skin is discoloured and numerous small cracks appear, mainly at the stem end, but sometimes all over the surface.

Chemical control has been the answer to TRM outbreaks. Several insecticides and acaricides have given satisfactory control in the past, both under experimental and field conditions. Dicofol, wettable sulphur, cyhexatin, flubenzimine, profenofos, bromopropylate, chlorohexylate, endosulfan, propargite and abamectin have been found to be effective in controlling populations of TRM overseas (Cermeli *et al.*, Haji *et al.* 1988, Oliveira *et al.* 1983, Royalty and Perring 1987, Undurraga and Dybas 1988). In Australia sulphur was the first chemical to be used against TRM. Up until 1979 sulphur and malathion were recommended in NSW for TRM (Anonymous 1973, Anonymous 1979). From 1979 demeton-S-methyl, dicofol and dimethoate were added to the list of chemicals recommended for TRM control in Australia (Anonymous 1979). Monocrotophos and dimethoate were added to the list in 1988 at least in NSW (Hamilton and Macdonald 1988).

It is a general practice in Australia for the growers to depend on the insecticides sprayed for *Helicoverpa* control to keep TRM under check. This worked for a long time until the growers started complaining that some of the insecticides were not protecting the crop from TRM infestations (personal communication J.T. Hamilton). Complaints from growers on the Central Coast of NSW after 1988 and subsequent trials carried out in NSW by NSW Agriculture had shown that TRM may not be controlled by materials such as demeton-S-methyl, dimethoate, endosulfan or sulphur. Build up of resistance in TRM to some of these insecticides is implicated as a possible reason for the control failure (Hamilton and Macdonald 1988).

The objectives of this project were to investigate:

(a) The climatic and biological factors that influence the population fluctuations of TRM in crops.

(b) The prevalence of resistance to any insecticides among populations of TRM and to identify those insecticides which are efficient in controlling TRM.

(c) The presence of plant resistance in processing tomato varieties to TRM.

(d) The possibility of reducing/eliminating the number of insecticide sprays for TRM by the appropriate choice of insecticides for *Helicoverpa* control.

Methods and materials

A. Population dynamics

Three tomato crops were grown at the Somersby Horticultural Research Station in each of the 1989-1990 and 1990-91 seasons. Each crop consisted of two rows of 20 plants planted in an east-west direction. Three plants from each side of each row were selected and leaves at 30 cm height intervals were collected and examined in the laboratory for TRM. Until plants reached 30 cm high, whole plants were examined in the field. In the laboratory each leaf was examined under the microscope and both young and adult mites found in the field of view of the microscope at a fixed magnification were counted and recorded. The following factors were established to describe the mite densities: F1 = 0, F2 = 1-5; F3 = 6-25; F4 = 26-125; F5 = > 125.

B. **Collection of weather data**
Rainfall, temperature humidity and leaf wetness were automatically recorded from the crop area using a "Micropower" data logger. Temperature was recorded using a "PTAT" integrated circuit sensor, relative humidity was recorded by a variable capacitor type sensor and leaf wetness was recorded using a copper grid sensor. The data logger was programmed to receive measurements from these sensors every 12 minutes. Rainfall was measured using a tipping bucket rain gauge and 24 h rainfall was logged into the data logger. Data were retrieved every fortnight from the data logger and saved on diskettes.

C. **Search for natural enemies**
Random samples of leaves were taken from the study area and crops grown at and around Rydalmere for this purpose. Leaves were examined in the laboratory for any predators. Whenever a suspected organism is found in the TRM colony observations were made to confirm whether they actually fed on TRM. Their predation was recorded on a video or by taking photographs.

D. **Testing efficacy of pesticides**
A series of pot trials was conducted in the glasshouse to determine the effectiveness of different pesticides, registered to be used on tomatoes, on TRM using the Rydalmere strain. This strain has been in glasshouse culture for several years without any exposure to insecticides.

Potted tomato plants were infested with a known number of TRM by attaching a leaf disc carrying a known number of TRM adults. For each treatment TRM infested plants were thoroughly sprayed with a hand sprayer twice, the second spray being applied seven days after the first. Five replications (potted plants) were used per treatment. Control plants were sprayed with water. Fourteen days after the second spraying the number of TRM on five apical leaflets per plant was recorded. Endosulfan, demeton-S-methyl, chlorpyrifos, cypermethrin, trichlorfon, dicofol, pirimicarb, deltamethrin, permethrin, malathion, dimethoate, acephate, carbaryl, copper oxychloride, Mancozeb^R, Sumisclex^R, Kocide^R, Bravo^R, Benlate^R and thiometon were the pesticides tested. Treated plants were held in the glasshouse where the temperature was maintained around 27°C with natural daylight.

Because the number of mites increased in the copper oxychloride treated plants another experiment was set up under a more controlled manner to verify this.
Young tomato seedlings (3 leaf stage) were used to rear mites for the experiment. Seedlings were pulled out from the nursery bed and eight female and five male TRM were transferred onto each seedling under a stereomicroscope with a No. 0 camel hair brush. The root system of the seedlings was wrapped in wet cellucotton which in turn was wrapped with aluminium foil. This aluminium foil prevented the copper oxychloride from entering the root system. After the mite transfer these seedlings were sprayed with copper oxychloride using a Potter tower. Copper oxychloride was sprayed at two different rates: 3.75 micrograms/cm^2 and 7.5 microgrrams/cm^2.

Seedlings with the same number of mites were sprayed with tap water to be used as controls. After spraying seedlings were planted in styrofoam coffee cups filled with soil and kept in the glasshouse. Watering of the cups was done according to the simple wick method described by Toth *et al.* (1988). After 14 days plants were pulled out, examined under the microscope individually and all the mites on the plants recorded.

E. Testing for resistance to insecticides

A susceptible strain of TRM (Rydalmere) was maintained in the glasshouse for a number of years on potted tomato plants. Two other strains were collected, one from Whitten (Whitten 1) and another from Berenembah (Whitten 2) in NSW, from fields where insecticides were reported to have failed to control TRM. These two were established in the glasshouse as two different suspect resistant strains.

Several bioassay techniques were tried without success until the petri dish technique was developed. In this technique 36 mm petri dishes were half filled with agar, allowed to settle and stored in the refrigerator to be used when needed. Fresh tomato leaves were plucked from insect-free glasshouse grown tomato plants and 2 cm diameter leaf discs were cut with the help of a cork borer. These leaf discs were affixed to the agar surface in the petri dish with the lower surface of the leaf facing upwards by pressing the leaf discs with the fingers. The hairs on the surface of the leaf discs gave an anchoring effect as if the discs were glued to the agar surface. Ten adult female TRM were transferred to each of the discs with the help of a No. 0 camel hair brush under a stereomicroscope.

Before and after transferring mites the petri dishes with leaf discs were kept inverted on a tray with a wire mesh base and kept in an ice box to keep the mites inactivated. This restricts the mites to the middle area of the disc until they are treated with insecticide. Serial dilutions of insecticides were sprayed onto the discs with mites with the help of a Potter tower. Three such discs were used for each dilution and each test was replicated three times. Treated petri dishes were kept inverted and kept in an incubator at 23°C ± 1°C with a 12:12 L:D photoperiod. Mortality assessment was made 48 h after treatment. Mites were checked by pushing them to lie on their sides and tested whether they could turn back and walk. Those that could not turn back were considered dead. All the replicates were pooled and LC50 values in ppm of the insecticides applied were calculated using a maximum likelihood probit program after Finney (1971). LC50 was obtained for the Rydalmere (susceptible) strain for Rogor[R] (dimethoate 300 g/L), Thiodan[R] (endosulfan 350 g/L) and Borer[R] (permethrin 100 g/L) and Nuvacron[R] (monocrotophos 400 g/L). The discriminating dose for each insecticide used was obtained by extrapolation from the dose-response lines obtained in the bioassays described above. Mites from strains Whitten 1 and Whitten 2 were treated with the discriminating dose of each insecticide.

F. Testing for varietal resistance to TRM

Processing tomato varieties Alta, Brigade, E6203, Hypel and UC82B were tested in the glasshouse for any possible resistance to TRM. Variety Glossey Lesse, which is used to culture TRM in the glasshouse, was used as the standard susceptible variety. Young potted tomato plants (5 leaves stage) were used for these tests. Two methods were used.

In the first method plants were infested with mites by pinning a 2 cm diameter leaf disc with 50 female TRM onto each plant. One such infested plant was assigned as a replicate. In an experiment five such plants from each variety were used. A completely randomised design was used. The experiments were conducted in the glasshouse and the temperature range in the glasshouse was maintained to remain around 27°C and with natural daylight. Four weeks after infesting the plants, the first leaf from the bottom of each plant was clipped off and all the mites on the last leaflet from the tip of the leaf were counted and recorded. Leaf area of each leaf was measured in cm^2 using a leaf area meter and the number of mites per unit area was estimated. Data were analysed using a Generalised Linear Models (GLM) procedure.

In the second method plants were infested with mites by pinning a 2 cm diameter leaf disc with 10 female TRM on it onto each plant on the second leaf from the top. To restrict these mites and the progeny to the same leaf a band of sticky material (Birdoff^R) was placed around the base of the leaf. The experiment was set up the same as in the first method.

Twelve days after infecting the plants, the whole leaf was removed and the number of TRM on all the leaflets were counted and recorded. Total leaf area of all the leaflets was measured and the number of mites per unit area was estimated as before. Data were analysed using a GLM procedure.

G. Field trial

A field trial was conducted at Somersby Horticultural Research Station to determine the best insecticide treatment strategy for *Helicoverpa* control that can reduce TRM flaring up. Treatment plots were arranged in split plot design in randomised complete blocks with four replicates. Two varieties were used in the trial - Alta, a processing tomato variety, and Floradade, a fresh market variety. Treatments were as follows: weekly applications of Thiodan^R (endosulfan 350 g/L), weekly applications of Rogor^R (dimethoate 300 g/L), weekly applications of Thiodan^R and applications of Kelthane^R (dicofol 75 g/L) when mites first appear, weekly applications of Dipel^R (16,000 IU of *Bacillus thuringiensis* var. *kurstaki*) and nothing applied for control. Each replicate (block) had two plots with each one planted to one or the other of the two varieties. Each plot is subdivided into five sub-plots and the treatments were fully randomised within a plot. Each sub-plot had four rows of plants with 12 plants/row and the middle two rows were used for any assessment. A row of tomatoes separated two adjacent plots. Sprays were applied with a gas powered knapsack sprayer using a vertical boom equipped with Hardi nozzles (10x blue swirler) and applied at a pressure of 80 kPa. Spraying commenced soon after the plants started flowering. Endosulfan was used at the rate of 190 ml/100 L, dimethoate 75 ml/100 L, dicofol 250 ml/100 L and Dipel[R] 50 g/100 L. To detect the onset of the TRM infestation and to evaluate the effect of treatments on TRM population, weekly samples of leaflets were taken from each sub-plot before spraying. Six plants were selected randomly from each sub-plot and five leaflets were removed from each plant around the middle of the canopy, taken in polythene bags to the laboratory and the number of TRM found on a 2 cm diameter disc cut out from the basal region of each leaf was counted and recorded. When the fruits start to mature all the ripe fruits were harvested weekly from each sub-plot, assessed for *Helicoverpa* damage by visual inspection. Data were analysed using GLM procedure.

Results and discussion

A. Population dynamics

TRM started to appear in the crop in December for the first time (Figs 1 & 2). Whenever TRM infestation was observed for the first time in a crop mites were found at least at a height of 30 cm. General belief in the past has been that TRM damage first appears on the lower parts of the plant, with the inference that infestation of the plant commences in this region. However, our observations show that initial infestation occurs on the outer foliage and at any height between 30-90 cm from the ground. Mites were not found on the lower leaves until after they were established on the higher leaves. The mites are obviously blown into a crop with the wind. Often a concentration of mites would be found at one site during the initial stages of infestation and the mites would spread from here. The mites spread from the outer leaflet along the stem progressively infesting adjacent leaflets and leaves. From the time the first mite is observed there is a rapid spread of the mites through the crop and a rapid increase in density over a 3-4 week period. This leads to the fast deterioration of the growth and condition of the plant.

In the 1990-91 season observations were made throughout the winter and the population remained relatively high (Fig. 2). In spite of the few frosts TRM continued to reproduce until the plants died of old age.

B. Influence of weather on population fluctuations

Mean weekly rainfall for the 1989/90 season (10.32 mm) was much higher than that for the 1990/91 season (1.49 mm). Mean weekly mite scores for the same period (December-March) in both seasons were 1.54 and 3.86 respectively. During the same period there were 10 weeks which had more than 10 mm of mean weekly rainfall in 1989/90, but none of the weeks had more than 10 mm in 1990/91 (Figs 3 & 4). This shows that heavy rainfall has a negative effect on TRM population growth.

Mean weekly temperature for the 1989/90 season (18.72°C) was lower than that for the 1990/91 season (20.74°C). Mean weekly mite scores for the same period (December-March) in both seasons were 1.54 and 3.86 respectively.

Fig 1 : POPULATION DYNAMICS OF TRM 1989-1990

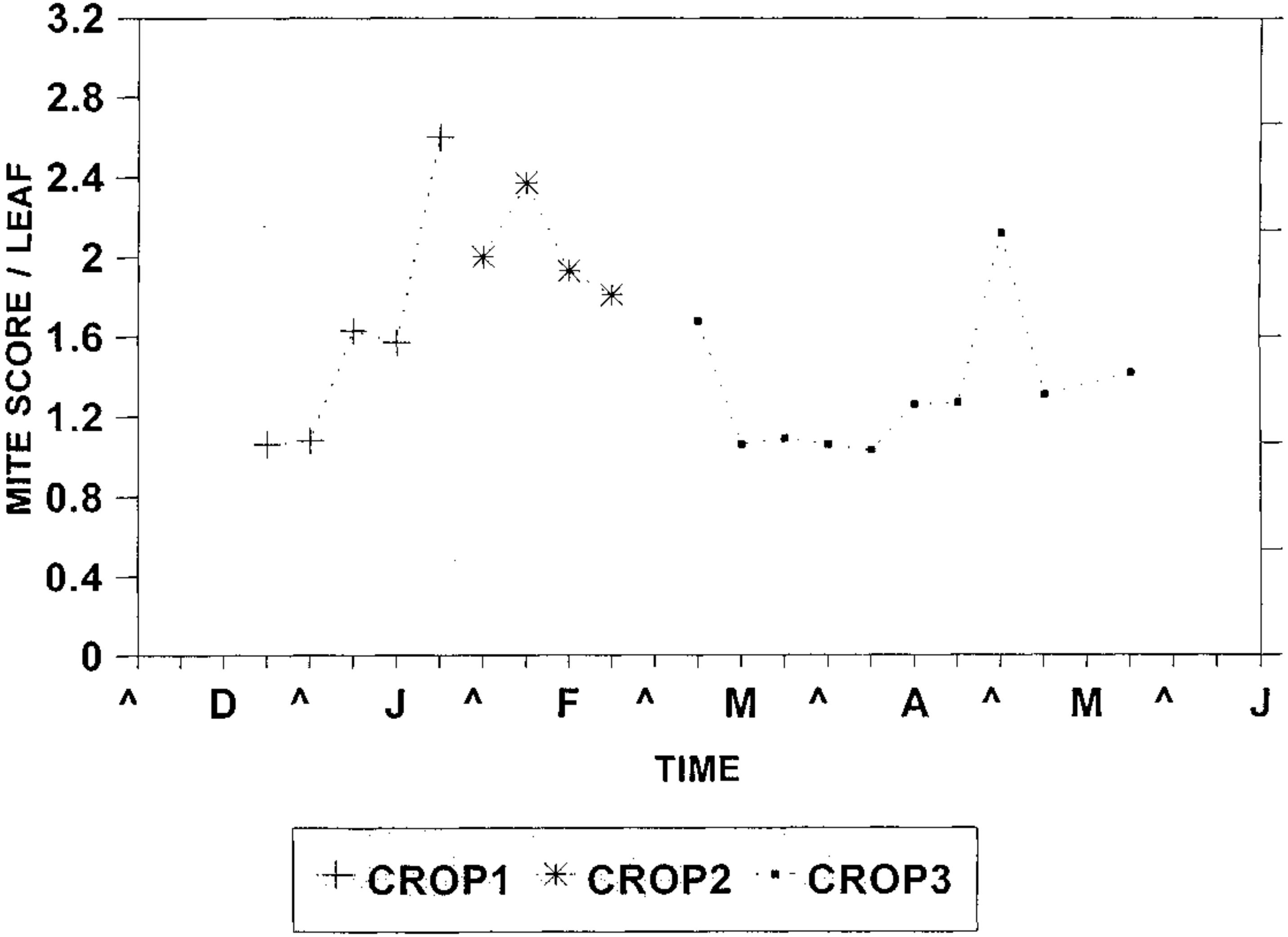


Fig 2 : POPULATION DYNAMICS OF TRM
199O-1991

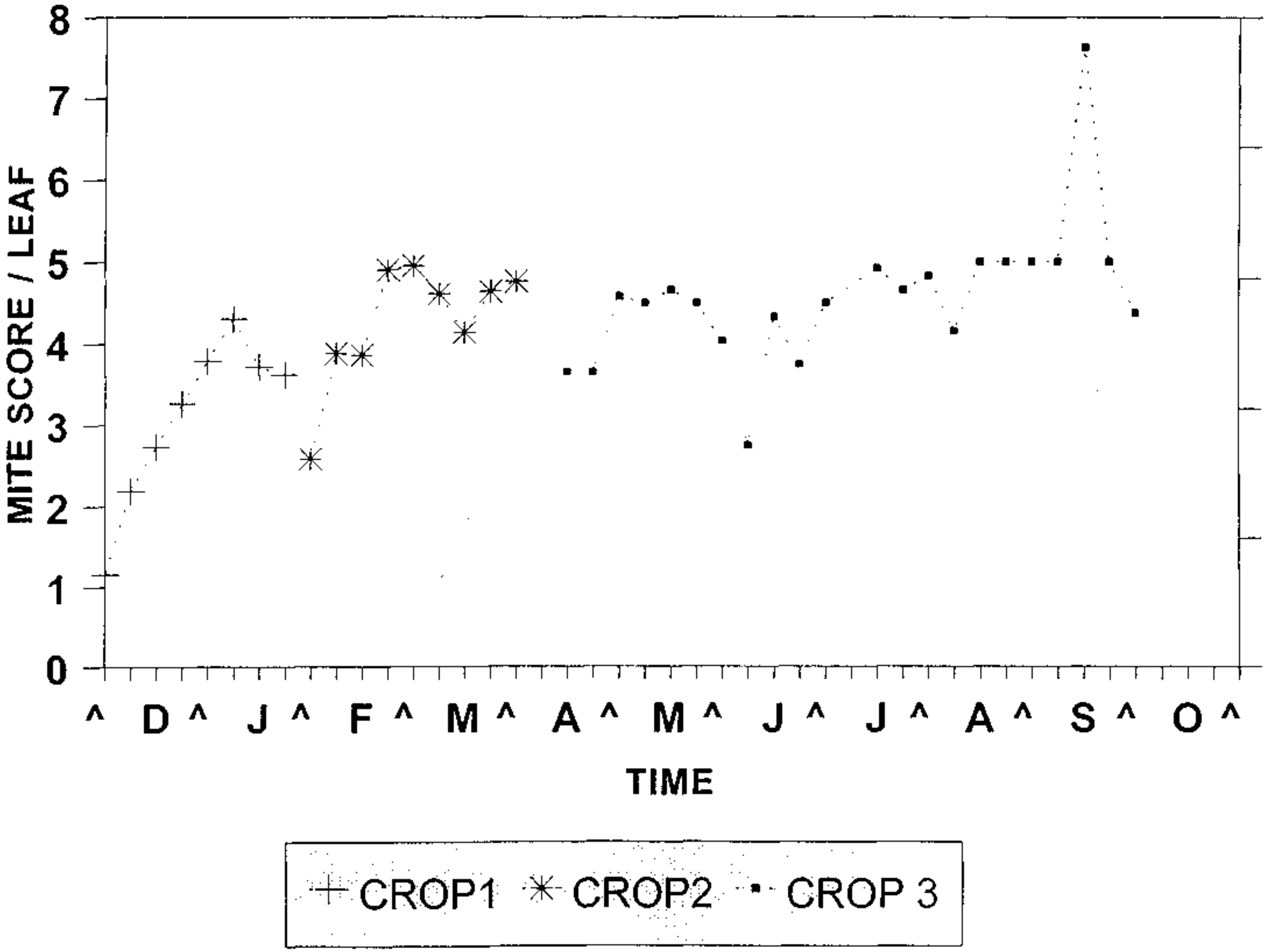


Fig 3 : INFLUENCE OF RAINFALL ON TRM POPULATION 1989-1990

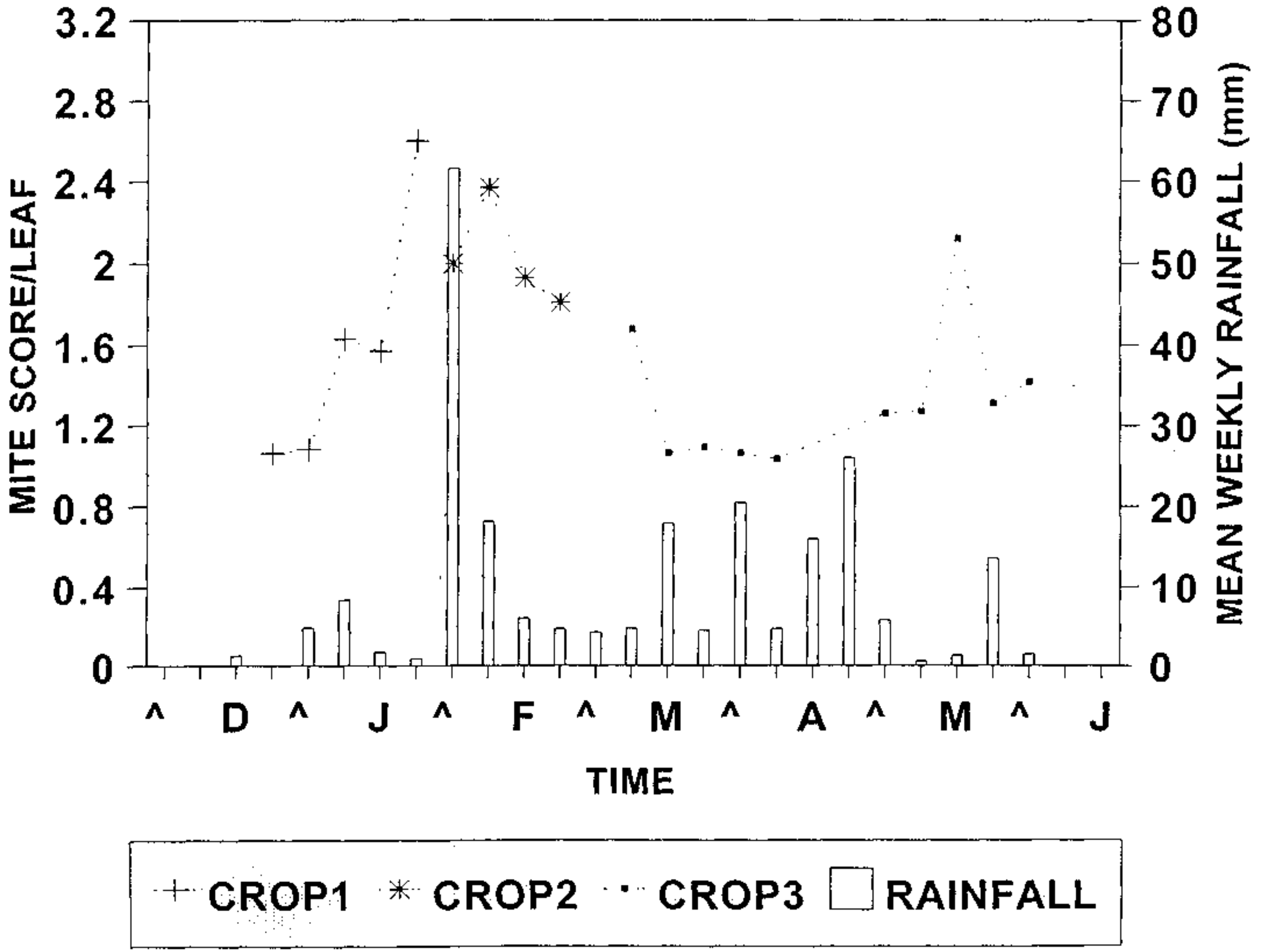
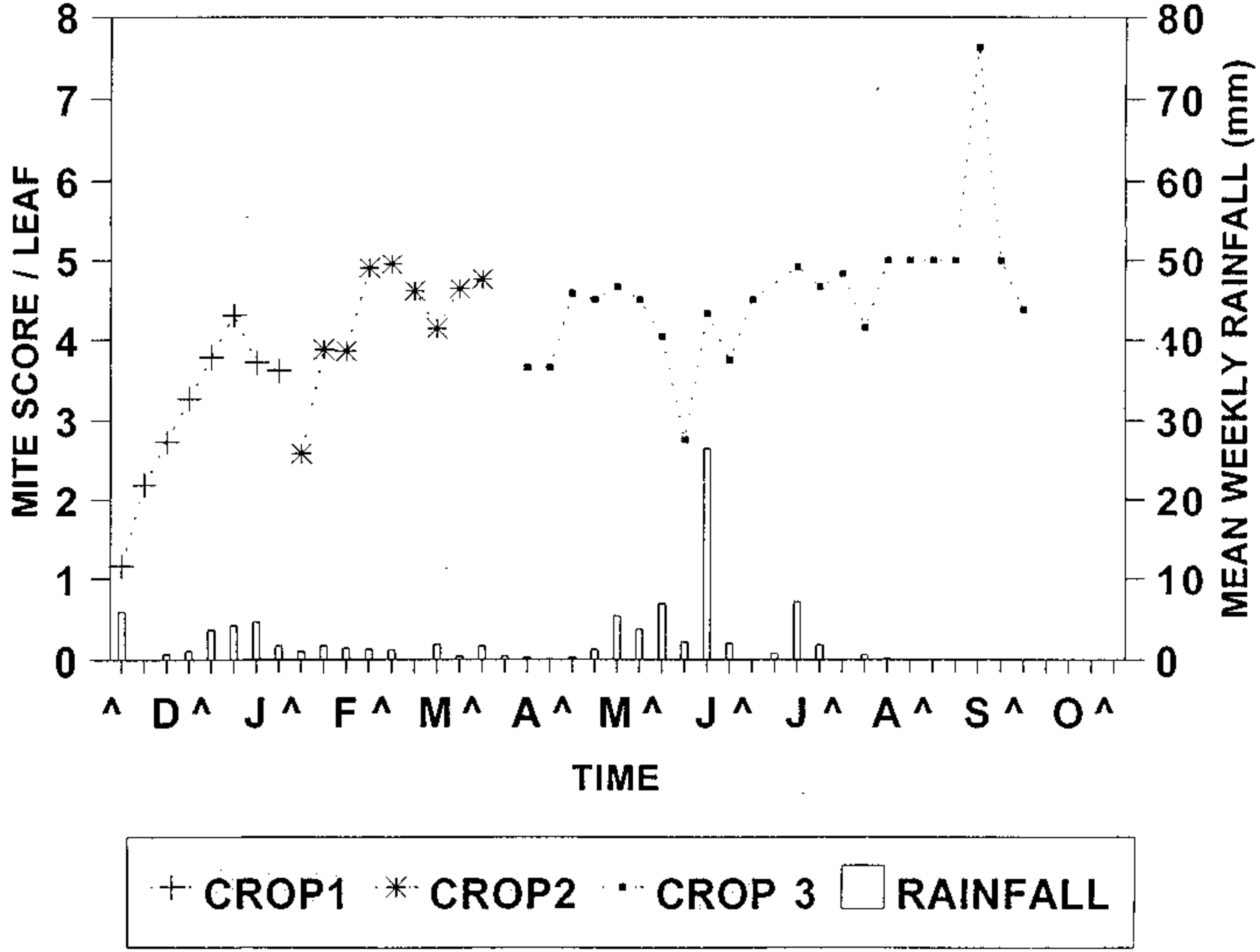


Fig 4 : INFLUENCE OF RAINFALL ON TRM POPULATION 1990-1991



This shows that hot summer conditions favour TRM population growth. However, fluctuations in mean weekly temperature failed to show any relationship to the weekly fluctuations in TRM population (Figs 5 & 6).

Mean weekly relative humidity for the 1989/90 season (91.82%) was higher than that for the 1990/91 season (80.01%). Mean weekly mite scores for the same period (December-March) in both seasons were 1.54 and 3.86 respectively. This shows that high humidity has a negative effect on TRM population growth. However, fluctuations in mean weekly relative humidity did not show any relationship to the weekly fluctuations in TRM populations (Figs 7 & 8).

Figure 9 shows the influence of leaf wetness on TRM populations for the 1990/91 season. As leaf wetness was not measured in the 1989/90 season a comparison between the seasons could not be made. However, fluctuations in mean weekly leaf wetness did not show any relationship to the weekly fluctuations in TRM population.

The above data show that low humidity, high temperature and low rainfall favour TRM population build-up and high humidity, low temperature and high rainfall is not favourable for high populations to build up.

C. **Natural enemies of TRM**

Many predators were found to be feeding on TRM during this study. Most of them were discovered during the 1991/92 season. The most interesting predator was a fly larva that belongs to the family Cecidomyiidae. According to the International Institute of Entomology Identification Services, this is possibly an undescribed species. This will be described when more specimens and more information on its biology become available. The adult fly lays its eggs on the undersurface of the leaves among TRM colonies. The young larvae, when they hatch out, start feeding on TRM eggs by piercing the egg and sucking out the contents. As the larvae grow older they feed on nymphs and sometimes on the adults. When they feed on nymphs and adults they lift the TRM up, pierce them, suck out the contents and throw away the empty exoskeleton (Fig. 10). There are many species of Cecidomyiids whose larvae prey on eriophyid and tetranychid mites in various parts of the world and one of them, *Therodiplosis persicae* Kieffer, has been used for biological control of glasshouse red spider mite in Europe (K.M. Harris, International Institute of Entomology, personal communication). Some of the cecidomyid larvae collected from the field were found to be parasitised by a hymenopteran wasp. This was identified as *Aphanogmus* sp. from the family Eraphronidae. This parasitism will reduce the efficiency of the cecidomyid larvae in controlling TRM.

Nymphal stages of the common 'plague thrips', *Thrips imaginis* Bagnall, was found to feed on TRM eggs. It was difficult to ascertain that the adults also feed on TRM because they will run away as soon as the microscope lights are turned on. Usefulness of these thrips in controlling TRM depends on the direct feeding damage they can cause to the tomato plants.

Fig 5 : INFLUENCE OF TEMPERATURE ON TRM POPULATION 1989-1990

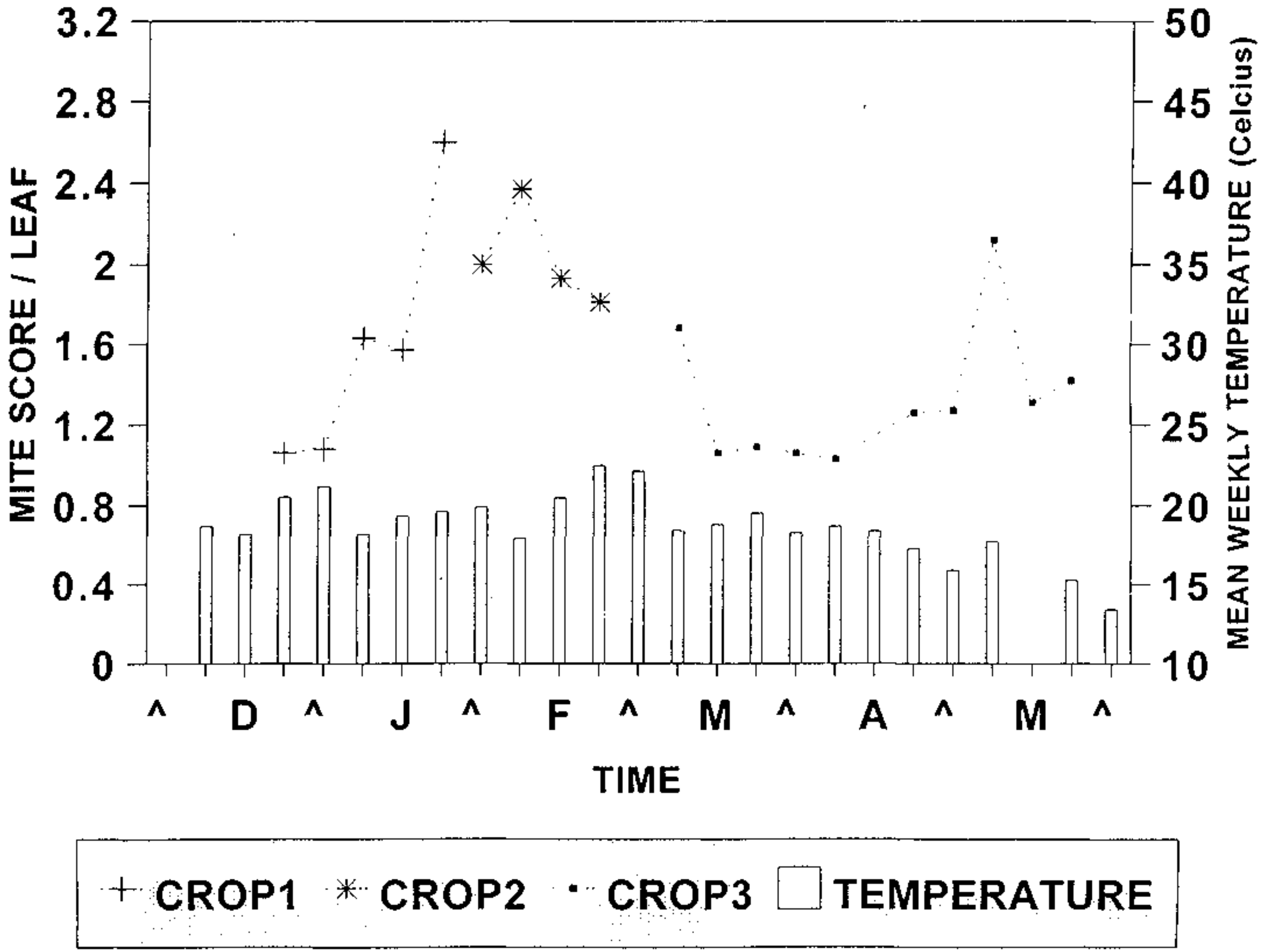


Fig 6 : INFLUENCE OF TEMPERATURE ON TRM POPULATION 1990-1991

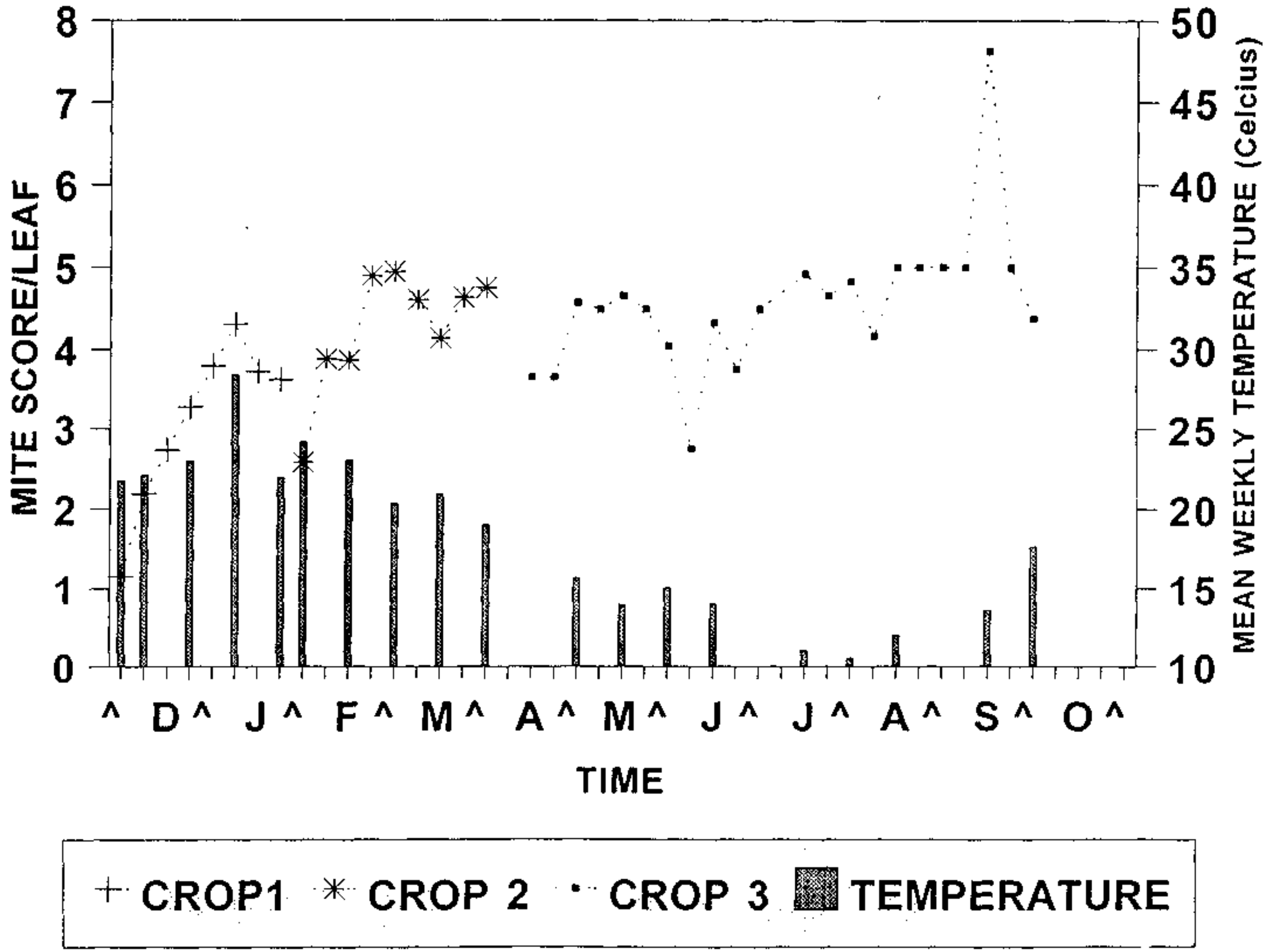


Fig 7 : INFLUENCE OF HUMIDITY ON TRM POPULATION 1989-1990

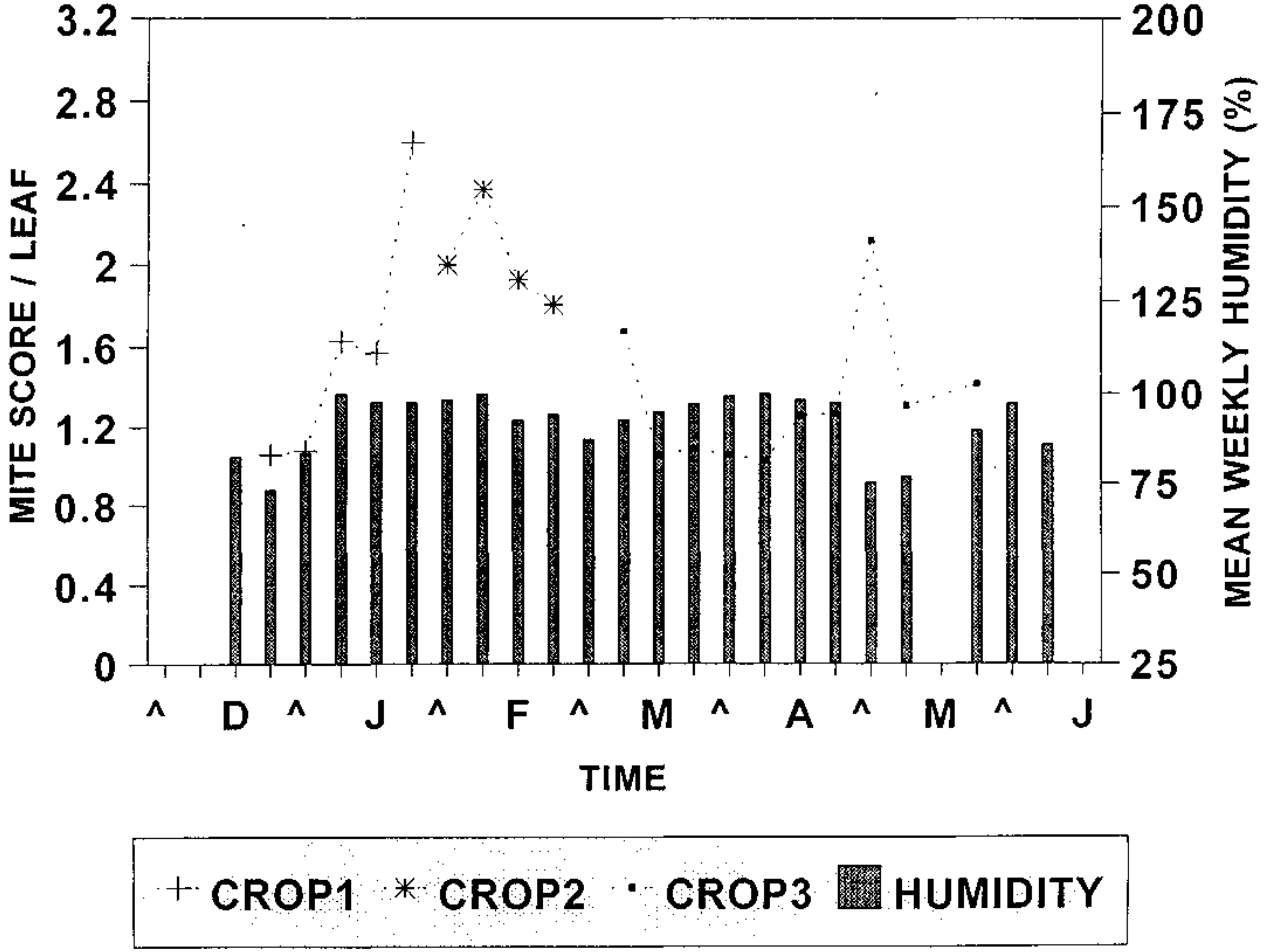


Fig 8 : INFLUENCE OF HUMIDITY ON TRM POPULATION 1990-1991

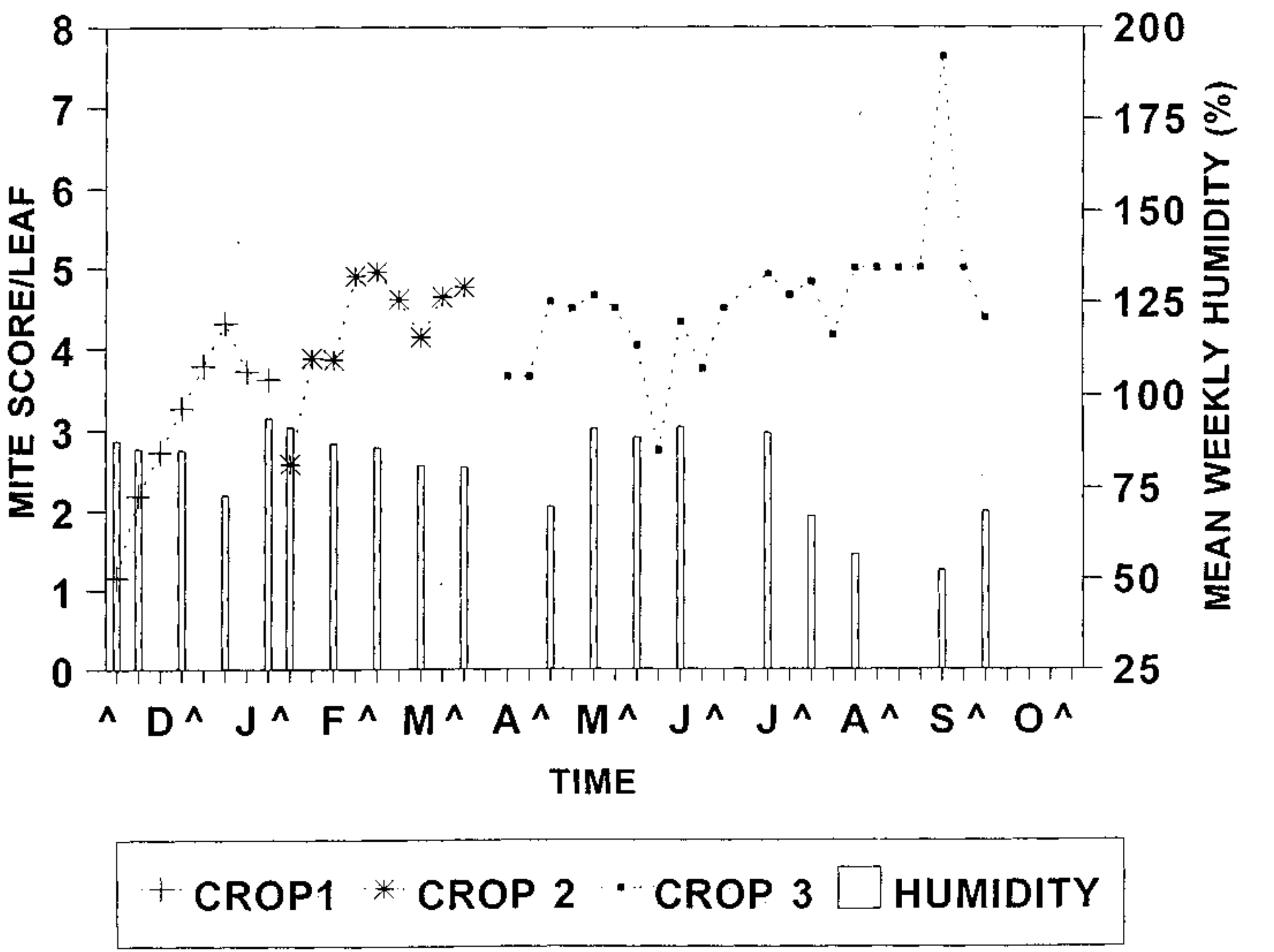
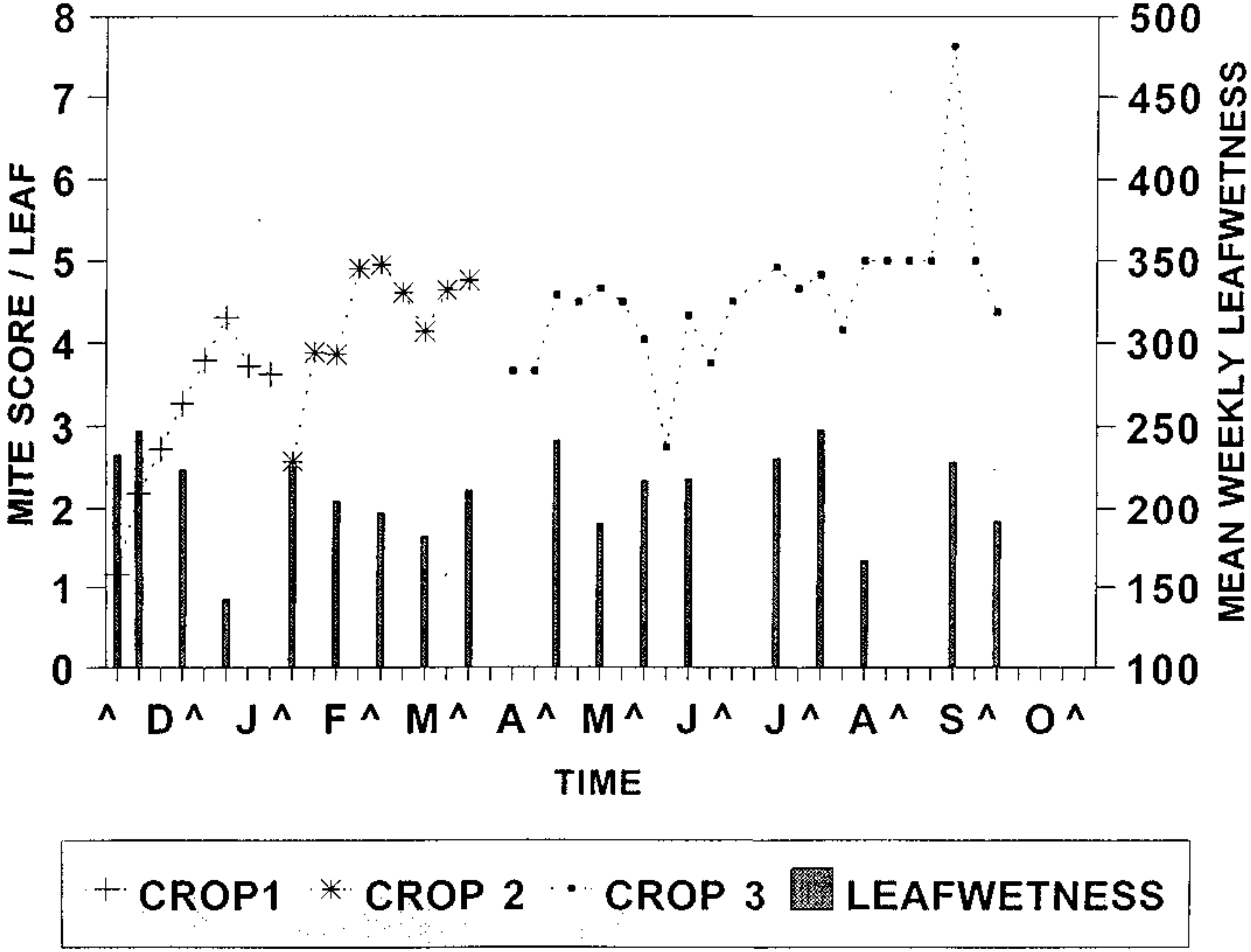


Fig 9 : INFLUENCE OF LEAFWETNESS ON TRM POPULATION 1990-1991



There were seven different species of mites found to be feeding predominantly on TRM eggs and occasionally on early nymphal stages.

A tydeid mite, *Homeopronematus* sp., was a very common predatory mite on TRM. This is the only predatory mite which has entered our TRM cultures in the glasshouse and sometimes it weakens the colony. Laboratory observations showed that immature as well as adult *Homeopronematus* sp. fed on many TRM individuals of various life stages (Fig. 10). Similar observations have been made in the USA (Hessein and Perring 1986; Knop and Hoy 1983).

Six different species of Phytoseiidae were observed to be predating on TRM life stages. They are *Amblyseius* near *walterseri* Schicha, *A.* near *lailae* Schicha, *A.* near *womersleyi*, *A. benjamini* Schicha and *Typhlodromus dossei* Schicha. An unidentified Stigmaeidae was also found to be predating on TRM.

Exclusion studies to test the efficacy of these predators in keeping TRM under check were beyond the scope of this project. However, this knowledge of the presence of nine different predators acting on TRM reflects the importance of judicious use of insecticides to control other pests of tomatoes in order to prevent secondary outbreaks of TRM.

In one of the crops grown at Rydalmere to observe predators, the TRM population suddenly crashed. Closer examination revealed the presence of a fungal infection. The fungus was later identified by Dr Richard Milner, CSIRO, Canberra as *Hirsutella thompsonii* (Fig. 11). The predatory mites, *Homeopronematus* sp., which were present among these infested TRM populations were not affected by the fungus. A similar infestation has been reported in Cuba (Cabreva and McCoy 1984). In that study, when a suspension of spores and mycelial fragments was sprayed onto mite-infested tomato plants, 54-90% of the mites were infected in six days. This is the first report of a fungal infection on TRM in Australia and more investigations are needed to determine its role in regulating TRM populations. The fact that the predatory mite *Homeopronematus* sp. was not affected by the fungus is very encouraging as the fungus can act complementary to the predator in controlling TRM.

D. **Efficacy of pesticides**

The results of a series of pot trials conducted under glasshouse conditions are given in Table 1. In the trials where the insecticides endosulfan, demeton-S-methyl, chlorpyrifos and cypermethrin were used complete control was obtained and all the values for mite counts were zero and therefore these trials were not included in the statistical analysis.

In all the trials where the miticide dicofol was included as a treatment it effectively controlled the mites. Results of trials 1, 2, 5, 6 and 9 indicated that the fungicides mancozeb, Bravo[R] and the insecticides permethrin, acephate, trichlorfon and malathion ere equally effective as the miticide dicofol. Results of trials 3, 4 and 8 indicated that the fungicide Kocide[R] and the insecticides malathion and dimethoate could significantly reduce TRM populations.

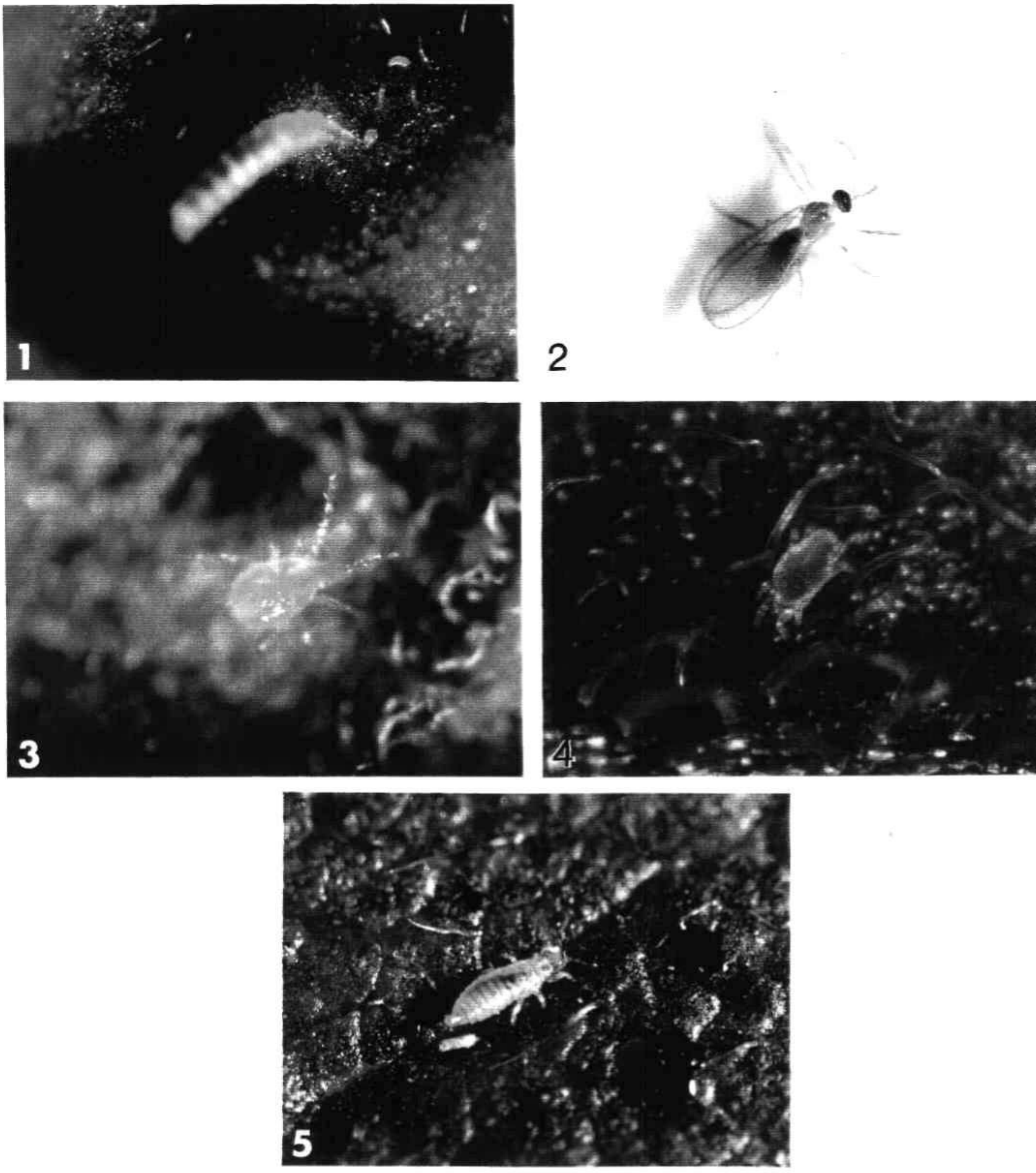


Fig. 10: Predators of TRM
(1) Cecidomyiid fly larva; (2) Cecidomyiid adult; (3) A phytoseiid mite; (4) Tydeid mite; (5) *Thrips imaginis* nymph

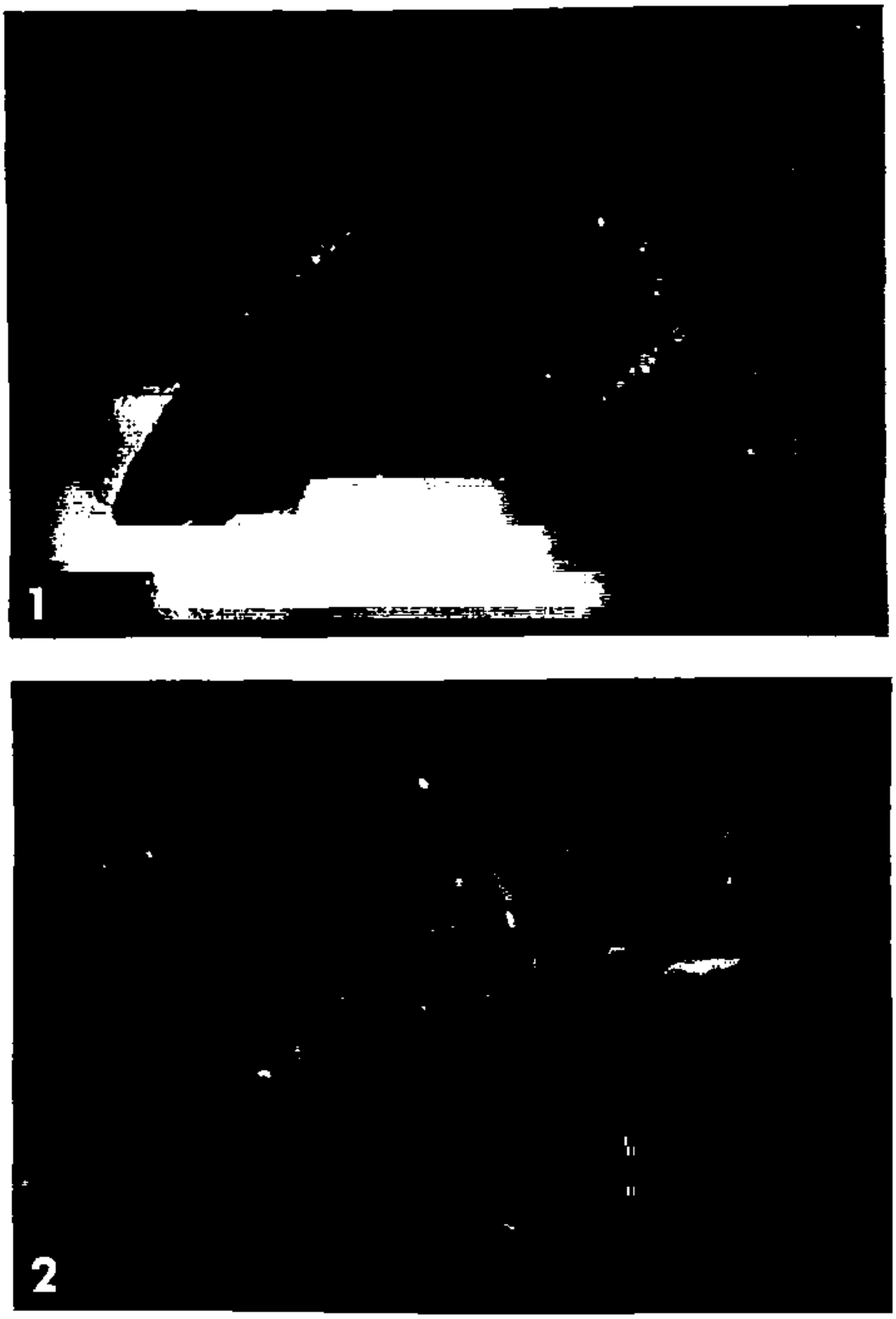


Fig. 11: Tomato russet mite infected with the fungus *Hirsutella thompsonii*
(1) A whole mite killed by the fungus;
(2) A section of the mite's surface magnified to show the fungal structure

Table 1. Efficacy of pesticides in reducing TRM numbers

Treatment	Mean mite count/leaf (3.2x field of view) at petiole region for 11 trials										
	1	2	3	4	5	6	7	8	9	10	11
1. Sumisclex®	5.85										
2. Mancozeb®	2.70*										
3. Pirimicarb		4.13									
4. Permethrin		0.0*									
5. Kocide®			29.90*			26.60					
6. Dimethoate				11.27*					15.20*		
7. Acephate					8.20**						
8. Carbaryl					38.55						
9. Trichlorphon					0.0**						
10. Bravo®						11.65*					
11. Benlate®							37.91				
12. Malathion								14.25*	12.50**		
13. Deltamethrin										7.75	
14. Copper oxychloride										48.80**	
15. Thiometon											17.60
16. Dicofol	1.20*	0.0*			0.0**	0.0*	0.0*		0.0**	2.30*	0.0*
17. Control	7.27	6.60	52.60	64.30	61.45	26.33	19.67	37.20	34.10	10.30	25.50

** Statistically significant at $p < 0.01$
* Statistically significant at $p < 0.05$

However, it was evident from trials 6 and 9 that Kocide[R] and dimethoate were less effective compared with dicofol. It was interesting to note that the results of trials 7 and 10 showed that the fungicides Benlate[R] and copper oxychloride can cause an upsurge in TRM populations. The pesticides Sumisclex[R], pirimicarb, carbaryl, deltamethrin and thiometon did not have any significant effect on TRM populations as expressed in the results of trials 1,2,5, 7 and 10.

An overall ranking of all the 16 pesticides tested in these trials was established based on their effectiveness against TRM population build-up using GLM analysis (Table 2). Of the 16 pesticides ranked only trichlorfon was as good as the miticide dicofol. However, the four insecticides endosulfan, demeton-S-methyl, chlorpyrifos and cypermethrin which were not included in the analysis, gave complete control. Therefore, they are also as good as dicofol.

Results of the experiment to verify the effect of copper oxychloride on the TRM population are given in Table 3. Copper oxychloride significantly reduced the TRM numbers 14 days after treatment. Reasons for the increase in TRM numbers after copper oxychloride treatment in the earlier trials could be the detrimental effect of this fungicide on the predatory mite *Homeopronematus* sp.

which was very common in the glasshouse cultures, and on the entomogenous fungus *H. thompsonii* if it was present. At the time of the trial we did not know whether this fungus attacked TRM, but now we have established that this fungus also causes mortality in TRM populations. In the earlier trials when copper oxychloride was sprayed it must have killed all the predatory mites, but not all the TRM. Therefore, after the treatment predatory mites would have limited the TRM from increasing in the control plants, but in the copper oxychloride treated plants TRM that survived would have multiplied without any limitation. It would have been ideal to have included another treatment in the experiment to include some predatory mites with TRM, treated with copper oxychloride and then compared. This was not possible because of the difficulty in transferring the predatory mites.

The above results show that when choosing insecticides for pest management in tomatoes in places where TRM flare-up usually occurs, it is advisable to choose from one of the following insecticides: endosulfan, demeton-S-methyl, chlorpyrifos, cypermethrin and trichlorfon. Also, it is advisable to avoid copper oxychloride as a fungicide on tomatoes as it could help the flare-up of TRM.

E. **Resistance to insecticides**

Consistent results were obtained for different replicates with the new bioassay technique. Table 4 gives the toxicity data for four different insecticides which are commonly used for tomatoes. Based on the LC50 and LC90 values monocrotophos is the most toxic of the four insecticides tested and dimethoate is the least toxic. Endosulfan was more toxic than permethrin. This bioassay technique is thus proved to be a reliable and simple one.

Table 2. Ranking of insecticides and fungicides tested in 11 pot trials based on their effectiveness in reducing TRM numbers

TYPE	NAME	RANKING*
1. Organochlorine	Dicofol	0.3 a
2. Organophosphate	Trichlorphon	0.3 a
3. Organophosphate	Acephate	3.2 b
4. Organophosphate	Dimethoate	5.8 bc
5. Fungicide	Kocide[R]	8.5 bc
6. Fungicide	Mancozeb	8.8 bcd
7. Organophosphate	Malathion	8.9 cd
8. Fungicide	Bravo[R]	10.5 cd
9. Carbamate	Pirimicarb	14.9 cde
10. Carbamate	Carbaryl	14.9 de
11. Organophosphate	Thiometon	16.3 de
12. Synthetic pyrethroid	Deltamethrin	17.9 de
13. Fungicide	Sumisclex[R]	19.1 de
14. Synthetic pyrethroid	Permethrin	27.3 ef
15. Fungicide	Benlate[R]	45.0 f
16. Fungicide	Copper oxychloride	112.6 g

* These are expected values of mean mite numbers estimated using GLM analysis. Numbers followed by same letter do not differ significantly at $P<0.05$.

Table 3. Effect of copper oxychloride on TRM population build-up

Treatment	Mean number of mites/plant
3.75 $\mu g/cm^2$	22.41 b
7.50 $\mu g/cm^2$	14.89 b
Control	60.18 a

Table 4. Toxicity of insecticides to TRM

Insecticide[a]	Slope ± SE	LD50 (ppm)	LD90 (ppm)
Dimethoate	2.399 ± 0.3006	2719.719 (3125.468-2366.645)[b]	9585.075 (12543.93-7324.155)
Monocrotophos	2.085 ± 0.1219	108.546 (126.73-92.971)	446.122 (619.064-321.493)
Endosulfan	1.593 ± 0.2299	114.614 (139.432-94.213)	729.274 (1172.978-453.409)
Permethrin	2.579 ± 0.4586	585.8742 (662.397-518.192)	1837.042 (2502.695-1348.436)

[a] Each regression was estimated from the response of 90 individuals.
[b] Figures in parentheses indicate 95% FL.

Discriminating dosages of different insecticides used to test whether there was any resistance to these insecticides in the two different strains brought from the field is given in Table 5. There was complete mortality at these dosages in the Rydalmere strain as well as the Whitten 1 and Whitten 2 strains for all the four insecticides used. Therefore, there was no difference between the Rydalmere strain (susceptible) and Whitten 1 and Whitten 2 in susceptibility to these insecticides at the time of testing. Unless these strains have lost their resistance over the period of time they were in culture (these were in culture for one year before testing) the failure in chemical control in the field had to be due to the poor application technique used. Very seldom insecticides sprayed on tomatoes reach the under surface of the leaves where TRM is found.

F. **Varietal resistance**

Table 6 gives the mean number of mites/cm^2 recorded on different varieties four weeks after infesting the plants by method 1 and 12 days after infesting the plants by method 2.

In experiment 1 in method 1 there was no significant difference in mean number of mites/cm^2 between the standard variety Glossey Lesse and others. However, in experiment 2 in method 1 the number of mites/cm^2 was significantly higher in variety Hypel than Glossey Lesse. Also, the variety Hypel had significantly higher numbers of mites/cm^2 than any other varieties. In experiment 1 in method 2 the number of mites/cm^2 was significantly lower in variety UC82B than in Glossy Lesse. Also, the number of mites/cm^2 in UC82B did not significantly differ from other varieties. In experiment 2 in method 2 there was no significant difference in mean number of mites/cm^2 between the standard variety Glossy Lesse and others.

In method 1 the variation in mite numbers in a leaflet varied very much from plant to plant. This is because there was no control over the number of mites moving onto a leaf initially. Therefore, there was no consistency in the results between the two experiments. In method 2 the variation in mite numbers did not vary much from plant to plant because all the 10 female mites released were confined to the same leaf until assessment was done. However, here again, there was no consistency in the results between the two experiments. Although these results tend to indicate that Hypel is more susceptible than Glossy Lesse, and UC82B is a little more resistant than Glossy Lesse, due to the inconsistency in the results between experiments a definite conclusion cannot be drawn from these results.

G. **Field Trial**

Insecticide treatments for *Helicoverpa* control were selected with the aim of having different effects on the TRM. Endosulfan followed by dicofol when mites appear was selected to give a thorough chemical control of TRM. Dipel^R was selected so that while *Helicoverpa* is controlled, this will not affect the natural enemies of TRM and they in turn can prevent a TRM flare-up. Endosulfan alone was used as the standard practice which, while controlling *Helicoverpa*, usually creates TRM flare-up. Dimethoate was selected because it is not effective

Table 5. Discriminating dosages of different insecticides used against different TRM field strains

Insecticides	Discriminating dose (ppm)
Dimethoate	26937.98
Monocrotophos	1422.307
Endosulfan	3327.634
Permethrin	4690.857

Table 6. Influence of varieties on TRM population build-up

Treatments	Mean mite numbers/cm^2			
	Method 1		Method 2	
	Experiment 1	Experiment 2	Experiment 1	Experiment 2
Glosse Lesse	14.64 a	4.78 b	0.630 a	0.905 a
Alta	15.00 a	12.76 b	0.273 ab	0.700 a
Brigade	6.20 a	17.52 b	0.528 ab	0.095 a
E6203	14.98 a	11.08 b	0.372 ab	0.335 a
Hypel	10.38 a	99.22 a	0.440 ab	0.308 a
UC82B	12.88 a	16.98 b	0.199 b	0.583 a

Means followed by the same letter are not significantly different at $P<0.05$.

against TRM, but will wipe out the natural enemies and hence can induce a TRM flare-up.

Even in the control plots TRM appeared very late in the season and as a result there were only two samples to be compared which had mites. Tables 7 and 8 give the effect of insecticides on fruit damage by *Helicoverpa* in tomato varieties Alta and Floradade. Dipel^R and dimethoate failed to protect the fruits from *Helicoverpa* damage. Also, these insecticides did not significatnly reduce the TRM population compared with the other treatments (Table 9). Although endosulfan treatments have reduced the TRM numbers there was no difference between endosulfan/dicofol and endosulfan treatments.

Because TRM appeared only for a short period the indirect effect of Dipel^R and dimethoate on TRM through their effect on the natural enemies could not be ascertained. For the same reason, the additional efect of mixing dicofol with endosulfan also could not be ascertained.

Table 7. Effect of insecticides on *Helicoverpa* fruit damage in tomato variety Alta

Treatments	Proportion of fruit damage															
	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7		Total	
Endosulfan/ dicofol	0.0	b	0.0256	b	0.0737	a	0.01148	a	0.00889	b	0.01195	a	0.00702	a	0.01174	c
Dipel[R]	0.4	a	0.0333	ab	0.0899	a	0.01526	a	0.01794	ab	0.02516	a	0.01036	a	0.02036	abc
Endosulfan	0.02	ab	0.0175	b	0.1047	a	0.01100	a	0.00745	b	0.02493	a	0.01237	a	0.01695	bc
Dimethoate	0.05	a	0.1688	a	0.0476	a	0.03636	a	0.03333	ab	0.02037	a	0.01907	a	0.03395	ab
Control	0.05	a	0.0857	ab	0.0463	a	0.04288	a	0.04421	a	0.03319	a	0.03146	a	0.03988	a

A generalised linear model with a binomial distribution assumed to underline the errors and with a logit link function was used to relate treatment factors on fruit damages.

Table 8. Effect of insecticides on fruit damage by *Helicoverpa* in tomato variety Floradade

Treatments	Proportion of fruit damage															
	Sample 1		Sample 2		Sample 3		Sample 4		Sample 5		Sample 6		Sample 7		Total	
Endosulfan/ dicofol	0.1071	a	0.1064	a	0.2687	a	0.0686	a	0.02985	bc	0.03743	a	0.00480	b	0.03656	a
Dipel[R]	0.0909	a	0.0484	a	0.2576	a	0.0529	a	0.02381	bc	0.02273	a	0.00276	b	0.02961	a
Endosulfan	0.1818	a	0.1111	a	0.1977	a	0.0412	a	0.00702	c	0.00957	a	0.00218	b	0.02253	a
Dimethoate	0.1143	a	0.1250	a	0.2857	a	0.0703	a	0.13636	a	0.06198	a	0.033303	a	0.07802	a
Control	0.2174	a	0.0784	a	0.3077	a	0.0870	a	0.10078	ab	0.04570	a	0.05368	a	0.07433	a

A generalised linear model with a binomial distribution assumed to underline the errors and with a logit link function was used to relate treatment factors on fruit damages.

Table 9. Effect of insecticides on tomato russete mite population build-up in tomato varieties Alta and Floradade

Treatments	Mean mite numbers/15 leaflets			
	Sample 1		Sample 2	
	Alta	Floradade	Alta	Floradade
Endosulfan/dicofol*	16.444 b	42.948 a	21.477 c	22.488 b
Dipel[R]	25.790 b	54.598 a	76.630 a	102.104 a
Endosulfan	8.935 b	33.448 a	33.481 bc	22.309 b
Dimethoate	28.502 b	48.910 a	55.645 ab	69.616 a
Control	106.697 a	117.919 a	106.059 a	79.997 a

* Dicofol was mixed with endosulfan and sprayed only after the first sample was taken.
Means followed by the same letters are not significantly different at $P<0.05$.

Recommendations

- As hot and dry conditions are favourable for quick TRM build-up frequent inspection of the crop and early detection of TRM is important under these conditions to initiate additional control measures.

- Because TRM can continue to reproduce throughout the winter on plants, any plants left over in the field or nearby can become the source of initial infestation in the following season. Therefore, such sources have to be eradicated before winter, depriving the TRM of the chance for their continued survival.

- Since there are many predators feeding on TRM any disruption to this complex can cause TRM outbreaks. Therefore, when devising Integrated Pest Management programs for a pest complex of tomatoes the importance of these predators has to be taken into consideration.

- All the insecticides recommended for *Helicoverpa* control are not effective for controlling TRM. Therefore, in areas where TRM is a potential problem, insecticides which are effective in controlling TRM have to be selected for routine *Helicoverpa* control.

- Further work needs to be supported to:

  Evaluate the role of predators in suppressing TRM populations

  Investigate the use of the entomogenous fungus to control TRM populations

  Test more field populations for any resistance to insecticides

  Evaluate materials such as petroleum oils which are less harmful to the predators and an appropriate spray application technology.

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