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Integrated Management of Two-Spotted Spider Mite Infesting Beans

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INTEGRATED MANAGEMENT OF TWO-SPOTTED SPIDER MITE INFESTING BEANS

THESIS SUBMITTED FOR THE DEGREE

OF

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RAJSHAHI UNIVERSITY, BANGLADESH

By

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M Sc

MARCH 2005

INTEGRATED PEST MANAGEMENT LABORATORY

INSTITUTE OF BIOLOGICAL SCIENCES

RAJSHAHI UNIVERSITY

BANGLADESH

Certificate

This is to certify that Najmoon Naher has been working under our supervision for the degree of Doctor of Philosophy. We are pleased to forward her thesis entitled Integrated management of two-spotted spider mite infesting beans. Najmoon Naher has fulfilled all the requirements of the regulations relating to the nature and prescribed period of research for submission of thesis.

03.3.05

(Dr Md Wahedul Islam)

2.3.05

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Declaration

I do hereby declare that the research work submitted as a thesis entitled **Integrated management of two-spotted spider mite** infesting **beans** in the institute of Biological Sciences, Rajshahi University, for the degree of **Doctor of Philosophy** is the result of my own investigation carried out under the supervision of Dr Md Wahedul Islam, Professor, Institute of Biological Sciences and Dr M Khalequzzaman, Professor, Department of Zoology, Rajshahi University. The thesis has not been currently submitted for any other degree to any other University.

Najmoon Naher

March 2005

Najmoon Naher

Candidate

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Authoress

ABSTRACT

The extensive and intensive survey of two-spotted spider mite (TSSM), *Tetranychus urticae* Koch, its biology and management on host plant, bean (*Lablab purpureus* L.) in Rajshahi City Corporation area were studied. The predation efficiency of three predators is discussed in considerable details.

T. urticae eggs hatched to six legged larvae in the shortest duration of 1.07 ± 0.26 days in the month of April. It took the longest duration of 11.67 ± 2.33 days in the month of January. The high temperature shortened the duration of hatching period.

The larval period of *T. urticae* took the shortest time of 0.55 ± 0.50 days in the month of May. The longest duration required to transform into protonymph from larva was 2.93 ± 1.07 days in December. The higher temperature significantly ($P<0.001$) reduced the larval duration.

The protonymphal duration was 0.89 ± 0.32 day in May and 3.71 ± 1.94 and 3.71 ± 1.75 days in December and January. The increase of temperature decreased the protonymphal duration remarkably.

The deutonymph required the shortest duration of 0.92 ± 0.41 days in August and the longest 10.26 ± 1.48 days in January. The temperature played significant ($P<0.001$) role on the duration of deutonymphal period. The high temperature accelerated the developmental rate and reduced the deutonymphal period.

The temperature greatly affected the duration of developmental period of *T. urticae.* Its life cycle completed within 4.22 ± 0.46 days at 28.53 ± 3.17°C but 28.33 ± 2.36 days at 13.78 ± 2.36°C. A female *T. urticae* deposited 82.46 ± 4.11 eggs in autumn, 62.96±12.09 eggs in summer and 58.21±13.65 eggs in winter.

The highest number of TSSM (59.69/leaf) was prevailed in April followed by 36.97/leaf in August. The lowest number (4.05/leaf) was recorded in February. The number of mite/leaf in three different areas (Motihar, Boalia and Paba) differed significantly ($P<0.001$) among different months. The temperature had significant ($P<0.05$) impact on the abundance of TSSM on bean leaves. The TSSM number/leaf increased with the increase of temperature.

The number of eggs was higher on three type (young, mature and old) of leaves than other stages. The population of immature stages was several times greater than the adult population. The number of TSSM/leaf differed significantly ($P<0.001$) among different months. The percentage of females were 75.73, 66.88 and 54.33% on young, mature and old leaves respectively. The immature stages were several times greater than adult and it was 81.27, 82.90 and 80.23% on young, mature and old leaves respectively. Temperature had significant ($P<0.05$) effect on the total number of TSSM/leaf. The increase of temperature increases the number of TSSM on bean leaves. The relative humidity, rainfall and sunshine had no significant effect on the population different stages of TSSM.

Three predators are recorded to predate adults and larvae of *T. urticae.* The predators are *Scolothrips sexmaculatus* Pergande, *Phytoseiulus persimilis*

Athias-Henriot and *Stethorus punctillum* Weise. Both adults and larvae of *S. punctillum* and *S. sexmaculatus* consumed eggs, immature stages and adults of *T. urticae*. Adult *P. persimilis* consumed all the stages of *T. urticae*, the immature did not consumed any stages of *T. urticae*. A female *P. persimilis* consumed 27.53 ± 1.16 eggs, 18.13 ± 1.51 immatures and 11.33 ± 0.82 adults. *S. punctillum* devoured 119.67 ± 15.12 eggs, 73.67 ± 13.58 immatures and 54.33 ± 3.00 adults and *S. sexmaculatus* consumed 58.80 ± 5.71 eggs, 38.47 ± 2.82 immatures and 15.60 ± 1.65 adults of *T. urticae*/day. In all cases a male comparatively consumed fewer preys than a female. The result of the present research suggests that *S. punctillum* can effectively reduce the population of *T. urticae*.

Different insecticides were tested against *T. urticae* through leaf disc and vial residue methods. Among 13 tested chemicals, LC_{50} value for lambda-cyhalothrin was the minimum in both the methods applied. The order of toxicity of the used chemicals in leaf disc method is: lambda-cyhalothrin > dicofol cypermethrin > primiphosmethyl > malathion > diazinon > carbosulfan > propoxur > chlorpyrifos > dimethoate > ~~dicofol~~ > imidacloprid > carbaryl > azadirachtin and in vial residue method is: lambda-cyhalothrin > cypermethrin > diazinon > carbosulfan > malathion > primiphosmethyl > chlorpyrifos > imidacloprid > dimethoate > propoxur > dicofol > azadirachtin > carbaryl. It is obvious from the results that lambda-cyhalothrin was the most effective against *T. urticae*.

Among three tested fungicides the LC_{50} value for carbendazim was the lowest in the leaf disc method and mancozeb in the vial residue method. The order toxicity of the used chemicals in leaf disc method is carbendazim > sulphur > mancozeb and in vial residue is mancozeb > carbendazim > sulphur.

General Introduction

GENERAL INTRODUCTION

The subclass Acari, which includes mites and ticks, forms an important part of the arthropodan class Arachnida, to which also belong the scorpions, spiders, and harvestmen. Mites are small arthropods that are more closely related to spiders and ticks than to insects. Mites in this group are web spinners, hence the name "spider" mites. They are one of the most important and destructive group of pests to agricultural crops worldwide. Mites have a worldwide distribution; they are rival insects in the extent of their habitation. They live in salt and fresh water, in organic debris of all kinds, and on plants and animals. They are among the dominant animals in pastures and in arable soils. In forests they greatly outnumber all other arthropods. Some species even live in caves and some in thermal springs. Their associations with other animals include commensalisms, predation, and true parasitism. Therefore, they may cause serious damage to livestock, agricultural crops, ornamental plants, and stored products; they may even bring sickness and death to man; or they may be parasites, predators, or saprophytes destroying animals, plants, or their products and adversely affecting man or his possessions (Johnson and Lyon 1991). Thus their importance to man covers all phases of his life.

Of more than 130 species of spider mites known, among which red spider mite or two-spotted spider mite (TSSM) *Tetranychus urticae* Koch (Acari: Tetranychidae) is the major pest species on agricultural crops worldwide (Asada 1978, Wu *et al.* 1990, Ho 2000, Takafuji *et al.* 2000). It looks like tiny spiders having eight legs and spin webs. However, unlike spiders, they feed on plants; the webbing they produce covers the plants and is

not used to catch prey. TSSM feed by sucking the contents of plant cells and damage includes webbing, fine stippling, leaf yellowing, leaf drop, and even plant death (Helle and Sabelis 1985a). They belong to the family Tetranychidae, which includes other plant-feeding mites and contains about 900 species worldwide (Wilson 1993).

TSSM feed on a wide range of introduced host plants, more than 180 have been recorded (Sim *et al.* 2003). It is common in greenhouses where it is an important pest of vegetables (beans, capsicum, cucumbers, egg plant, tomato), fruit (melon, grapes and strawberries), cut flowers and ornamental plants (e g carnations, roses, chrysanthemums, cymbidium orchids, ficus, palms). Outdoors it causes damage to sweet corn, beans, peas, hops, grapes, deciduous fruit trees (e.g. apples, nashi, peaches and nectarines), strawberries and many other fruit, vegetables, flowers and ornamental plants (Johnson and Lyon 1991). Most other species of tetranychid mites have only a narrow host range and this can help distinguish them from two-spotted mite.

The differentiation between *Tetranychus urticae* Koch and *Tetranychus cinnabarinus* (Boisduval) using morphological characters is often difficult because they are both polymorphic and there is significant intraspecific variation among populations on different host plants and from different geographic locations (e g van de Bund and Helle 1960, Wang 1981). This has been extremely unfortunate because both species are economically very important throughout the world.

Boudreaux (1956) first revived *T. cinnabarinus* as a distinct species and separated it from *T. urticae* using breeding experiments as well as morphological characters: (a) the shape of dorsal integumentary lobes in the

diamond-shaped area between the third and fourth dorsal central setae on female opisthosoma, (b) the shape of male aedeagus and (c) the colour of live summer females and newly laid eggs. The separation of the two species was supported by some subsequent studies (e g Parr and Hussey 1960, van de Bund and Helle 1960, Jordaan 1977, Brandenburg and Kennedy 1981) but rejected by others (e.g. Dupont 1979, Mollet and Sevacherian 1984). Meyer (1987), after reviewing studies known to her by then, followed. Dupont (1979) in considering *T. cinnabarinus* as a synonym of *T. urticae*. This was generally accepted in several subsequent books by specialists of the Tetranychidae (e.g. Ehara 1993, Baker and Tuttle 1994, Bolland *et al.* 1998).

A detailed study using morphological, biological and molecular data (Kuang and Cheng 1990) showed distinctions between *T. urticae* (populations from UK and China) and *T. cinnabarinus* (from China). Unfortunately this important study was not noticed/considered by subsequent authors (e g Bolland *et al.* 1998). Kuang and Cheng (1990) confirmed the usefulness of the three morphological characters a-c mentioned above in separating *T. urticae* and *T. cinnabarinus* in their study. In addition, they showed that *T. urticae* females have 10 setae on tibia I but *T. cinnabarinus* has 10-13 setae (addition of up to three solenidia) on tibia I. The difference in this fourth character was also noted earlier by Keh (1952), Boudreaux (1956) and van de Bund and Helle (1960), but ignored by subsequent authors (e g Dupont 1979, Mollet and Sevacherian, 1984, Meyer 1987) who questioned and debated the value of characters a-c for separating the two species. The value of leg setation in the classification of the Tetranychidae has been underestimated in the past. After a very detailed comparative study, Lindquist (1985) revealed a wealth of information in leg setation in this family and called for more study on leg setation.

Variation in seven female morphological characters were examined for 18 populations of spider mites of the *T. urticae* and *T. cinnabarinus* complex from greenhouse tomatoes in various locations in the UK and *T. cinnabarinus* could be readily separated from *T. urticae* by variation in the number of setae on tibia I (10-13 setae, or addition of 1-3 solenidia normally present in males) in females (Zhang and Jacobson 2000).

Several species of tetranychid mites, including TSSM, are resistant to many pesticides and often growers find them difficult to control. For effective and sustainable pest control it is important to know the species of mite present and to understand the mites' biology and the full range of control options. The expense of new acaricides and the loss of production time associated with pesticide applications has made frequent acaricide applications costly. Development of resistance by *T. urticae* to numerous acaricides has caused difficulties in controlling outbreaks (Carbonaro *et al.* 1986).

Tetranychus urticae

Tetranychus urticae (Koch), belongs to the group of acarines known as Acarifórmes, in the suborder Prostigmàta, and the family Tetranychidae (Borror *et al.* 1989). The TSSM is about 0.5mm long with an oval shaped body which varies in colour from greenish-yellow, to virtually transparent, brown, and red-orange (Fasulo and Denmark 2000). The TSSM was first described by Koch in 1836 (Pritchard and Baker 1955). It is thought to originate from temperate climates (Fasulo and Denmark 2000).

Biology *of T. urticae*

The TSSM passes through five developmental stages during its life cycle: egg, larva, protonymph, deutonymph, and adult (Huffaker *et al.* 1969). Each active immature stage is followed by a quiescent period. One TSSM generation is completed in about 19 days when the temperature is between 21° C and 23° C (Mitchell 1973). However, when temperatures are higher (30° C), development time from egg to adulthood can be reduced to seven days (Thomas 2001).

The TSSM exhibits arrhenotokous parthenogenesis (Brandenburg and Kennedy 1987). Fertilized eggs results in female offspring, whereas unfertilized eggs produce male offspring. Males typically complete the last quiescent stage before adulthood earlier than females (Mitchell 1973). Instead of feeding, the males actively search out female deutonymphs and await their emergence from the quiescent period into adulthood. Just before the female emerges, the male stays in close contact with the female, often touching her (Laing 1969). When the exoskeleton splits open, the male often assist the female in freeing herself from the exuvium. Mating sometimes take place as soon as the anterior portion of the exoskeleton is released. Copulation can last from a few seconds to several minutes (Cagle 1949). When a female mates with more than one male, sperm precedence is given to the first male (Potter *et al.* 1976). The average oviposition period per female is about 2.4 to 2.5 days (Cagle 1949, Laing 1969). Females generally lay an average of 38 eggs in total, but it is possible for a single female to lay well over one hundred eggs during the oviposition period (Laing 1969). Higher number of eggs generally occur when relative humidity is low (25-30%).

While on uninjured plants, TSSM are uniformly distributed over the leaf surfaces. When the plant begins to decline, resulting in a reduced food supply, the mites enter a dispersal phase and aggregate in the uppermost parts of the plants (Suski and Naegele 1963). Mites in the dispersal phase show a greater directional response to light than in the sedentary phase. The declining condition of the plant partially triggers the change from the sedentary phase to the dispersal phase (Suski and Naegele 1963).

Dispersal is movement away from the colony in which the TSSM developed (Brandenburg and Kennedy 1987). It includes both intraplant and interplant movement. Crawling is a common means of dispersal through the host plant, however, it can also be an effective means of interplant dispersal (Brandenburg and Kennedy 1987). TSSM often climb over intertwined foliage of adjacent plants or simply crawl over the ground to reach new plants, which they colonize. Aerial dispersal begins with the mites aggregating on the uppermost portions of the plants (Suski and Naegele 1963). The mites face the opposite direction of the light source with their forelegs raised upward above their bodies (Brandenburg and Kennedy 1987). The mites produce a thread of silk, which they use to "balloon" into the wind, sometimes carrying them great distances. Another method of dispersal, phoresy, is common when mites move by hitchhiking on other organisms (Weeks *et al.* 2000).

The tetranychid mites maximize fitness in several ways (Mitchell 1970). When the host plant begins to decline, reproductive rates of females are greatly increased. Since mating of females usually occurs just after emergence of the quiescent deutonymph stage, most are mated before they disperse, which increases their probability of founding new colonies. When a dispersing female

reaches a new resource, she immediately begins to feed close to a leaf vein and produce webbing (Brandenburg and Kennedy 1987). Eggs are deposited beneath the webbing and larvae and nymphs develop within it. The webbing basically defines the colony boundaries, and as the colony grows, the webbing also expands (Brandenburg and Kennedy 1987). In addition to providing the boundaries of the colony, the webbing also serves as a means of protection from rain, wind, and predators. It is thought that the webbing and deposition of fecal pellets within the webbing, is a mechanism to regulate humidity (Hazan *et al.* 1974). When a heavy infestation occurs, the plants often become matted with webbing (Cagle 1949). If the webbing is dense enough, protection may also be provided from acaricide sprays (Brandenburg and Kennedy 1987).

TSSM feeding on the underside of leaves (Cagle 1949) generally results in the typical stippling damage, which is white or grayish coloured spots due to the punctures made by feeding (Brandenburg and Kennedy 1987). Mites insert their stylets into the plant cells and suck out the cell contents. Feeding can damage protective leaf surfaces, stomata, and the palisade layer (Huffaker *et al.* 1969). They may also damage the lowest parenchymal layer (Brandenburg and Kennedy 1987). Defoliation, leaf burning and even plant death can occur due to direct feeding damage. Indirect effects of feeding may include decreases in photosynthesis and transpiration (Brandenburg and Kennedy 1987). However, moderately damaged leaves may have increased transpiration. This combination of direct and indirect effects often reduces the amount of harvestable material (Huffaker *et al.* 1969).

Diapausing females or eggs are the most common overwintering stage for tetranychids (Mitchell 1970). In warm areas during the winter, some mites may

continue to reproduce and diapause is facultative (Brandenburg and Kennedy 1987, Mitchell 1970). Diapause is often in response to short daylengths and cooling temperatures (Mitchell 1970). During diapause, TSSM do not feed or oviposit, and they generally seek shelter in crevices in tree bark and shrubs, clods of dirt, and in leaf litter (Brandenburg and Kennedy 1987). Longer daylengths and warming temperatures terminate diapause.

The TSSM is an important economic pest of many host plants including, but not limited to, peanut, cotton, corn, soybean, and many orchard crops and ornamentals (Cagle 1949). Host plant species, cultivar, or phenological stage can affect TSSM developmental rate, survival, reproduction and longevity (Brandenburg and Kennedy 1987). There is also evidence that the nitrogen-phosphorus-potassium ratio can influence TSSM female weight, preoviposition period and oviposition rate (Brandenburg and Kennedy 1987). High levels of nitrogen improve host quality, which results in higher female weight, shorter preoviposition period, and a high oviposition rate. Water stress can enhance plant susceptibility to TSSM because it causes an accumulation of soluble leaf carbohydrates, which can increase fecundity.

Natural Enemies of *T. urticae*

Diverse natural enemies have an important role in the ecology of TSSM (Brandenburg and Kennedy 1987). The orders of arthropods that prey on TSSM include Thysanoptera, Coleoptera, Hemiptera-Heteroptera, Neuroptera, Diptera, Acarina and Araneida. TSSM is also attacked by emtomopathogenic fungi (Brandenburg and Kennedy 1987), including *Neozygites* spp.,

Verticillium lecanii (Zimmerman), *Entomophthora* spp. and *Paecilomyces terricola* (Miller, Giddens, and Foster) (Helle and Sabelis 1985a). Most research has been focused on phytoseiid mite predators because they possess a number of characteristics that allow them to control TSSM at low densities (Brandenburg and Kennedy 1987).

Biological control programs on ornamental plants have had varying degrees of success. *Encarsia formosa* is a parasitic wasp that has been used to control greenhouse whitefly and has been successful in certain situations (Gill and Sanderson 1998). Predatory mites in the family Phytoseiidae have been used to suppress *T. urticae* populations (Gill and Sanderson 1998). One species of phytoseiid mite that is widely used and is commercially available is *Phytoseiulus persimilis* Athias–Henriot. Trials conducted in Florida utilizing *P. persimlis* to control *T. urticae* on Crotons and Areca palms reduced the number of acaricide applications by 87 -92% in Crotons, and 100% in Areca palms (Cashion *et al.* 1994). Releases of *P. persimilis* in interiorscapes to suppress mite populations have performed with varying degrees of success (Lindquist 1981).

P. persimilis can be an effective tool of an integrated pest management program for *T. urticae.* Despite successful suppression of *T. urticae*, limitations to the effectiveness of *P. persimilis* arise under certain conditions because their fecundity may be reduced. The optimum conditions for rapid population development of *P. persimilis* is a temperature of 27° C and relative humidity (RH) of 60-85% (Stenseth 1979). A temperature of 27°C with RH less than 40% reduces the reproductive rate of *P. persimilis* by increasing egg mortality

(Stenseth 1979). This is an important disadvantage because most greenhouses have temperatures and humidity levels that are outside these optima for part of the day. Another limitation to *P. persimilis* effectiveness is related to *T. urticae* density. When *T. urticae* density is too high, *P. persimilis* predation will not reduce *T. urticae* populations to acceptable levels (Helle and Sabelis 1985b). Trumble and Morse (1993) demonstrated that adequate suppression of *T. urticae* populations was achieved by releasing *P. persimilis* in combinations with abamectin applications. In their study, after threshold levels are surpassed, predator release combined with compatible acaricides was more effective than using chemical or biological control tactics alone.

Predators can effectively suppressing spider mite populations (Brandenburg and Kennedy 1987), however, when pesticides are applied to crops, outbreaks of high numbers of TSSM can occur. In crops such as peanut, where fungicides are applied throughout the growing season, serious outbreaks can occur. Predators are not capable of suppressing the high densities of TSSM, which results in yet another application of pesticide.

Chemical control of *T. urticae*

Several acaricides listed for the control of TSSM include propargite, aldicarb, lambda-cyhalothrin, and fenpropathrin (Herbert 1999). While these acaricides are effective against mobile forms of TSSM, little is known about their ovicidal properties. Campbell *et al.* (1974) reported that in laboratory tests, several pesticides have ovicidal properties, including triphenyltin

hydroxide, chlordimeform and carbophenothion. Studies by Smith and Mozingo (1983) have shown that some fungicides can increase mite populations. Development of resistance by *T. urticae* to numerous acaricides has caused difficulties in controlling outbreaks (Carbonaro *et al.* 1986). Many new acaricides are available on the market but they have a high cost associated with their use and associated application restrictions listed on the label to prevent the development of resistance.

Treatment with acaricides that have long residual toxicity may be required to suppress high-density spider mite populations. However, use of acaricides with long residual periods may promote resistance in spider mite populations. Low-density populations may be suppressed with acaricides that have short residual toxicity. Biological control may be enhanced through careful selection of acaricides and releasing predators into the crop once residues are no longer toxic to them (Cote 2001).

Abamectin has been reported to provide excellent suppression of *T. urticae* at low concentrations (Zhang and Sanderson 1990). Abamectin residues can kill *T. urticae* adults up to two weeks after application (Wright *et al.* 1984). Certain pyrethroids may suppress *T. urticae* populations while others may stimulate outbreaks by causing in increase in the density of a *T. urticae* population. Bifenthrin is a pyrethroid, which provides excellent suppression of mites. Many pyrethroids stimulate mites by increasing respiration which can increase mite feeding and egg laying (Mckee and Knowles 1984). However, there are differences in the structure activity relationships of pyrethroids and

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the pharmacokinetics among individual pyrethroids (Mckee and Knowels 1985). Chlorfenapyr provided quick and long term suppression of two-spotted spider mite populations. There was not any resurgence in the number of mites during the two week period of the trial. Other studies have found no short term resurgence in mite populations after application in the field (Allen and Kharboutli 1999).

Chlorfenapyr is a mitochondrial toxicant that affects the production of ATP by acting as an uncoupler at the site of ATP synthase. Pyridaben is also a mitochondrial toxicant that is a site 1 inhibitor on the electron transport system. However, pyridaben did not produce the positive results that chlorfenapyr did. Experiments conducted by Sekulic (1995) demonstrated that pyridaben has an LC 50 of 0.33 ug/ml for larval *T. urticae* and an LC 50 of 2.96 ug/ml for deutonymphs. This suggests that pyridaben can control younger stages of *T. urticae* more easily than older stages. Neem oil provided suppression with a slight resurgence in spider mite populations seven days after application. The 2 % application rate may have had a mechanical mode of action and physically suffocated the mites. Many neem products are known to have antifeedant effects on arthropod pests (Govindachari *et al.* 2000).

Aim of the Work

TSSM is an extremely polyphagous pest that has been reported from more than 900 host species and is described as a serious pest of at least 30 economically important agricultural and ornamental plants, including corn, cotton, cucumber, beans, tomato, eggplant, peppers and roses (Helle and Sabelis 1985a,b, Navajas *et al.* 1998). Unfortunately, chemical control of this pest can be compromised because of resistance (Gould *et al.* 1982, Croft *et al.* 1984, Cranham and Helle 1985, Cranshaw and Sclar 2001, Tsagkarakou *et al* .2002). As a result, a more integrated approach utilizing biological control with predatory insects or mites are increasingly being recommended (Hamlen and Lindquist 1981, Osborne and Petitt 1985, Osborne *et al.* 1985, Grafton-Cardwell *et al.* 1997, Pratt and Croft 1998, 2000a,b,c, Pratt *et al.* 1999, 2002; Nicetic *et al.* 2001, Skirvin and Fenlon 2001). Biological control of spider mites has centered on the use of predatory mites in the family Phytoseiidae (Helle and Sabelis 1985a, b, Blackwood *et al.* 2001, Schausberger and Croft 1999, 2000a,b; Schausberger and Walzer 2001, Shrewsbury and Hardin 2003).

In the present study the biology of the TSSM was done in laboratory conditions. The effectiveness of predators *Stethorus punctillum* Weise, *Scolothrips sexmaculatus* Pergande and *Phytoseiulus persinilis* Athias-Henriot has been studied. Also the chemical control methods with different groups of insecticides/mitecides and a botanical, Azadirachtin have been tested to observe their effectiveness.

Chapter 1

Biology of TSSM

CHAPTER 1

BIOLOGY OF *TETRANYCHUS URTICAE*

Introduction

T. urticae is one of the most serious pests in Agro-ecosystem crop and vegetables. It is also a serious pest of ornamental plants and fruit trees in both greenhouse and field crops. *T. urticae* was first reported from the USA by Tuttle and Baker (1968). Its host range includes numerous herbaceous and woody landscape plants such as rose, ivy and winged euonymus (Johnson and Lyon 1991). It has been recorded to feed more than 180 plant species.

The life cycle of TSSM is typical of warm weather spider mites, including the tumid spider mite. *T. urticae* complete development from egg to adult within 7 – 8 days at 27.5 – 32.5°C and all the life stages present throughout the year, depending on the environmental conditions (Helle and Sabelis 1985a). Development proceed more slowly when temperatures are minimum, requiring upto four weeks for completion. Host plants, plant nutrition, leaf edge, and moisture stress also influence development of *T. urticae*. In temperate climates, TSSM overwinter as adult in the soil, while most other common spider mites on trees and shrubs as tiny round eggs on leaves or bark. Many generations passes in each year, depending on the species of spider mites. Some species of spider mites, the Southern red mite and the European red mite occurring on conifers and broad-leaved evergreen plants are cool weather pests. They feed heavily and reproduce quickly in spring and fall (FMC 2000).

T. urticae abundantly occurs on bean plants in the City Corporation area of Rajshahi. This mite causes serious damage to bean plants. Its control is very much essential to get maximum and quality yield of bean. Before any control measure against a pest have to be taken, the through knowledge about biology of the pest is necessary. Keeping this in mind an experiment was designed to know the biology and fecundity of *T. urticae* infesting bean plants.

Materials and Methods

Developmental stages

The duration of developmental stages was studied on excised leaf disc in the laboratory. Leaf discs were made with fresh bean (*Lablab purpureus* L.) leaf without mite infestation. Each disc was circular in appearance with 2cm diameter (Plate 1). The leaf discs were placed on cotton bed in petri dish (5cm X 1cm) facing under surface upward. The cotton bed was kept wet by soaking with water twice daily so that the discs remained fresh.

Two adult female *T. urticae* were transferred to each disc for laying eggs. The adult female mites were collected from the laboratory maintained in the of Institute of Biological Sciences by rearing *T. urticae* on potted bean plants for more than one year.

The discs containing adult females were checked after two hours of mite transfer. The mites were removed if at least one egg was found. In that way more than 30 eggs were collected on leaf discs. Keeping only one egg on each disc the others were destroyed by pin. The petri dishes were covered by lid leaving a small gap to avoid excessive moisture inside the petri dish. The discs were checked after every 24 hours and the stages of development were noted

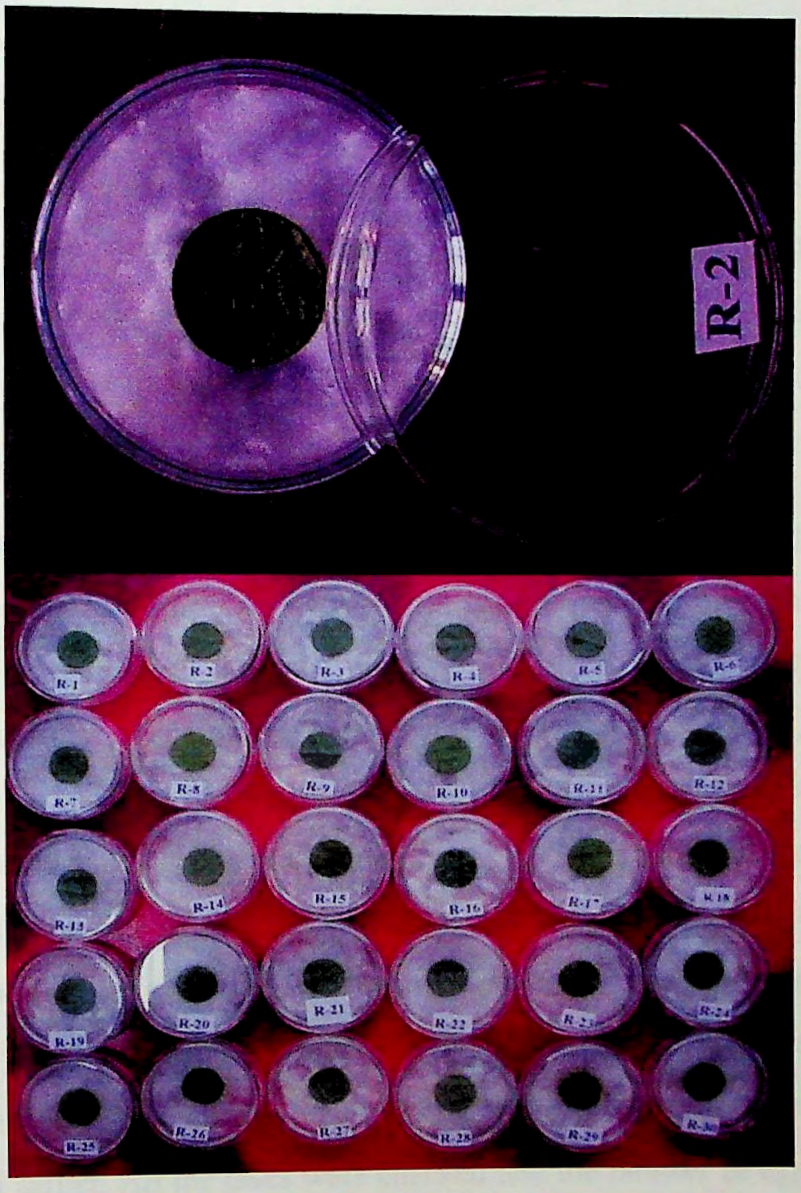


Plate 1. Rearing of TSSM on excised bean leaf.

till the appearance of adulthood. The leaf disc were changed after 3 to 4 days when necessary considering the freshness of them. The immatures were transferred to new disc very carefully with the help of camel hair brush. The room temperature and relative humidity were recorded twice daily.

The experiment was conducted from March 2002 to January 2003 and the duration of different developmental stages was recorded for 11 generations. But every times the eggs were collected from fresh adult female of laboratory culture and maintained in the same way. The developmental success of different developmental stages in different generations were calculated.

Fecundity of *T. urticae*

Deutonymphs of *T. urticae* were collected from the potted bean plants of laboratory culture. Five to six deutonymph were transferred on each leaf disc. The discs were made in the same way as in the experiment of developmental stages. The disc containing deutonymphs were observed twice daily. The time of adulthood of the deutonymphs was recorded. All the mites were removed keeping one male and one female on each disc. The male was also removed after laying the first egg by the female. In that way more than 30 discs with ovipositing females were prepared for this experiment. The discs were checked after every 24 hours interval with the aid of a stereo binoculor microscope. The leaf discs were also changed after every three days in the same way as described earlier. All the discs were checked and the number of eggs laid was counted till the death of the adult. The room temperature and relative humidity was also recorded twice daily. The experiment was conducted in three seasons viz. summer, autumn and winter.

Results

Developmental stages

TSSM adults are about 0.5 mm length, four pairs of legs, greenish to pink or cream coloured, and different black spots on the body. Colour varies according to the diet and environmental conditions. Male have pointed abdomens and are more slender than the rounded and plump females. Under warm conditions spider mites move rapidly within the colony area. Spider mites have four stages of development:

(1) the oval, somewhat translucent egg,

(2) a six-legged translucent larval stage,

(3) an eight-legged nymphal stage, and

(4) the eight-legged adult stage.

A resting or quiescent stage occurs at the end of the larval and nymphal stages. Females laid upto 110 eggs during their lifetime. A generation complete within 5 - 7 days in mid-summer, or in a month during winter periods. Under hot and dry conditions the two-spotted spider mites deposited maximum number of eggs, development completed within short time and survival of adults is extended.

The duration of different developmental stages of *T. urticae* in different generations conducted in different months is presented in Table 1.

Table 1. Duration (day ± S E) of various developmental stages of *T. urticae* in different months reared on bean leaf in laboratory condition.

Months (Temp.°C)	Egg to larva	Larva to protonymph	Protonymph to deutonymph	Deutonymph to adult	Egg to adult
Mar-02 (25.82)	3.50[a]±1.00	2.00[a] ±0.72	1.89[a] ±0.42	2.24[a] ±0.44	9.62[a]±1.56
Apr-02 (27.46)	1.07[a]±0.26	1.21[a] ±0.42	1.81[a] ±0.40)	1.68[a] ±0.48	5.77[a]±0.75
May-02 (28.53)	1.62±0.49)	0.55[a] ±0.50	0.89[a] ±0.32	1.15[a] ±0.37	4.22[a]±0.46
Jun-02 (29.60)	1.60[a] ±0.58	1.00[a] ±0.00	1.09[a] ±0.29	1.18[a] ±0.40	4.87[a]±0.81
Jul-02 (30.06)	2.10[a] ±0.66	1.14[a] 0.36)	1.14[a] ±0.36	1.68[a] ±0.56	6.07[a]±0.80
Aug-02 (29.41)	2.66 [a] ±0.67	1.00 [a] ±0.00	1.04 [a] ±0.19	0.92 [a] ±0.41	5.61[a]±0.48
Sep-02 (29.36)	2.07 [a] ±0.49	0.93 [a] ±0.26	1.00 [a] ±0.00	1.44 [a] ±0.51	5.44[a]±0.75
Oct-02 (27.07)	2.62 [a] ±0.70	1.63 [a] ±0.65	1.79 [a] ±0.42	2.09 [a] ±0.43	8.11[a]±0.95)
Nov-02 (23.32)	4.89 [a] ±0.81	2.46[b]±0.51	2.17 [a] ±0.38	2.70 [a] ±0.47	12.21[a]±1.23
Dec-02 (18.59)	11.40[b]±2.01	2.93[b]±1.07	3.71[b]±1.94	8.89[b]±2.08	26.93[b]±2.45
Jan-03 (13.78)	11.67[b]±2.33	2.69[b]±1.05	3.71[b]±1.75	10.26[b]±1.48	28.33[b]±2.36
F value	355.66***	47.88***	37.44***	319.51***	875.39***
LSD	5.46	1.17	1.78	4.28	10.99

*** = P<0.001, Means followed by different letters indicate significant difference

T. urticae eggs hatched to six legged larvae (Plate 2) in the shortest duration of 1.07 ± 0.26 days in the month of April (Figure 1). It took the longest duration of 11.67 ± 2.33 days in the month of January (Figure 1). The eggs of *T. urticae* hatched rapidly in April when the temperature was 25.82 ± 3.17°C. But the eggs hatched slowly in January when the temperature was 13.78 ± 3.21°C. The relationship between the hatching period and temperature was studied and found a significant ($P<0.001$) negative relationship. The high temperature shortened the duration of hatching period. The temperature affected inversely on the duration of hatching period and the 'r' value was calculated as –0.952** (Table 2). The regression equation was established and the regression line was fitted and shown in the Figure 2. The relative humidity exerted no significant effect on the duration of development to larva from egg (Table 2).

Table 2. The 'r' values between environmental factors and duration of different developmental stages of *T. urticae*.

Environmental factors	Developmental stages				
	Egg	Larva	Protonymph	Deutonymph	Adult
Temperature	-0.952	-0.884	-0.960	-0.958	-0.968
Relative humidity	-0.126	-0.395	-0.322	-0.134	-0.181

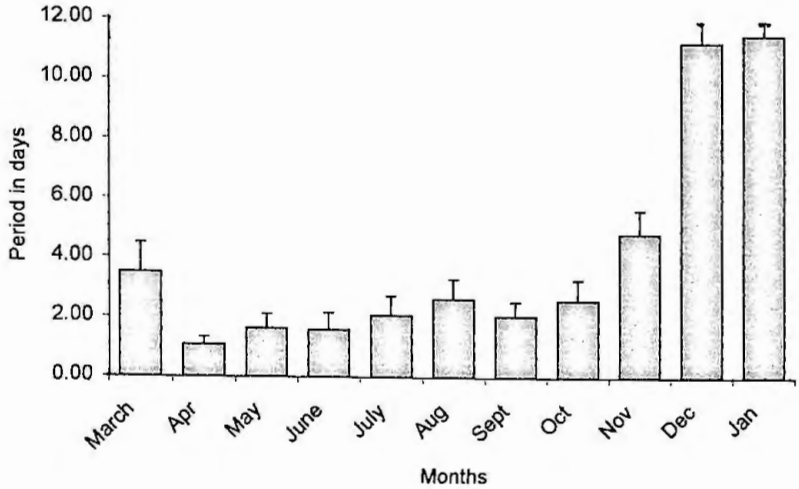


Figure 1. Hatching period of *T. urticae* egg in different months.

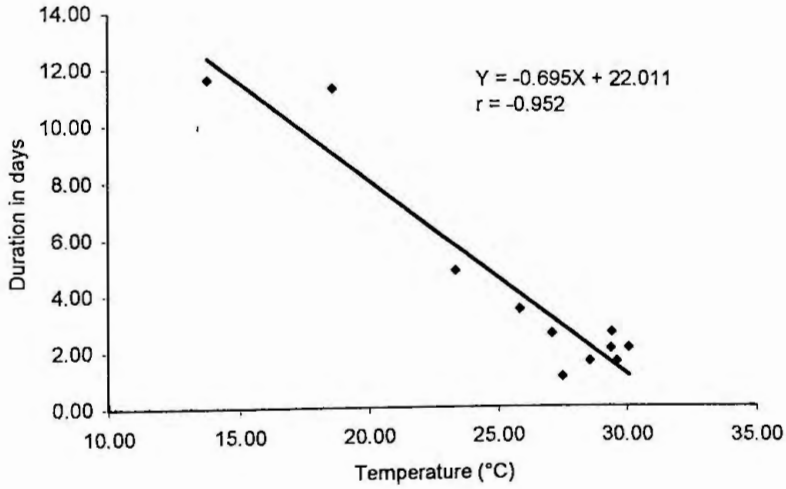


Figure 2. Regression line of hatching period of *T. urticae* on temperature.

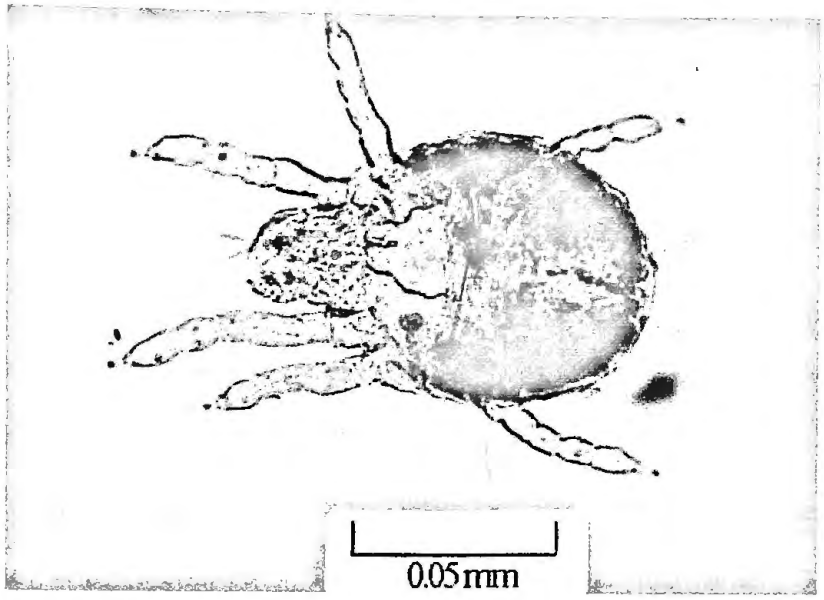


Plate 2. Larva of TSSM.

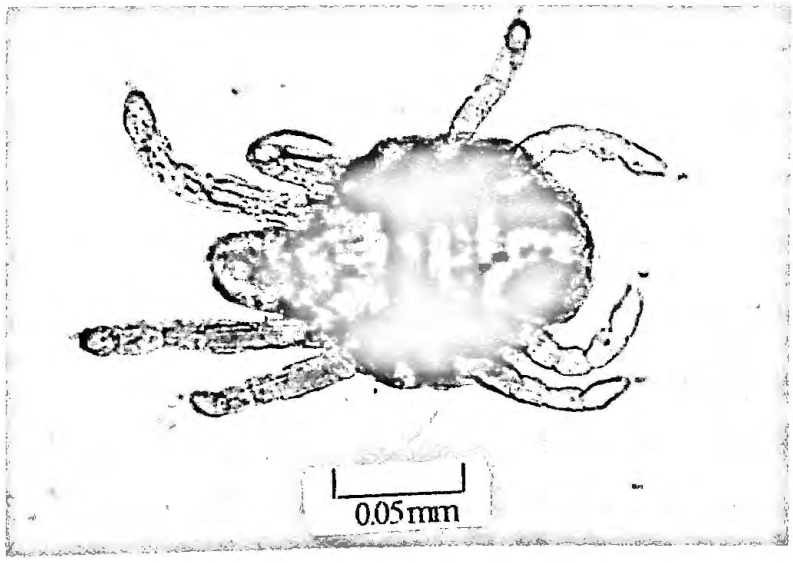


Plate 3. Protonymph of TSSM.

T. urticae larvae transferred to eight legged protonymph (Plate 3) after a while. Before transforming to protonymph it passed a short inactive period which called crysalis. It left an exuvie to transform into protonymph. The larval period was the shortest in duration among all the developmental stages. It took 0.55 ± 0.50 days in the month of May. The duration of larval period of *T. urticae* in different months is shown in Figure 3. The longest duration required to transform into protonymph from larva was 2.93 ± 1.07 days in December. Higher temperature significantly ($P<0.001$) reduced the larval duration. The value of coefficient of correlation between the temperature and larval development was calculated. The regression line was drawn and shown in Figure 4. There was no significant effect of relative humidity on the duration of larval period of *T. urticae*.

The protonymphal duration of *T. urticae* was also the shortest in the month of May. It took 0.89±0.32 days from protonymph to deutonymph (Plate 4). The highest duration was 3.71 ± 1.94 and 3.71 ± 1.75 days in December and January. The average time required to develop deutonymph from protonymph in different months is shown in Figure 5. Effect of temperature and relative humidity on the protonymphal duration was studied. The increase of temperature decreased the protonymphal duration remarkably. The value of coefficient of correlation between temperature and protonymphal duration was calculated, the regression equation and line was made and shown in Figure 6. The 'r' value between the relative humidity and protonymphal duration was also calculated. But it showed no significant relationship between relative humidity and protonymphal duration.

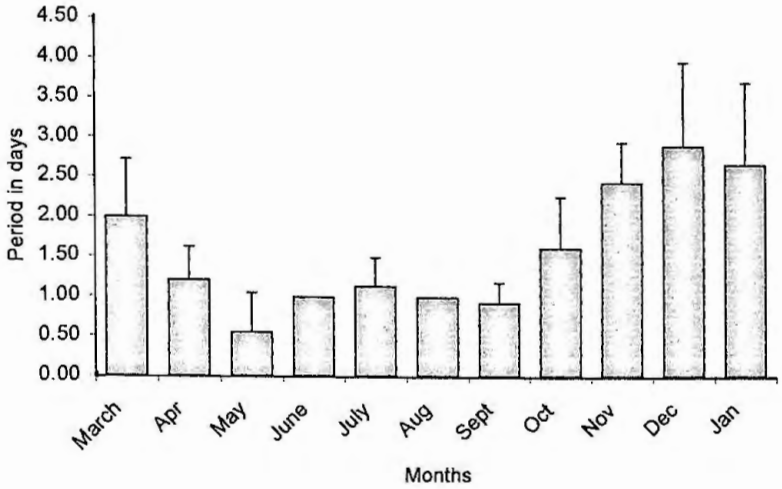


Figure 3. Larval durarion of *T. urticae* in different months.

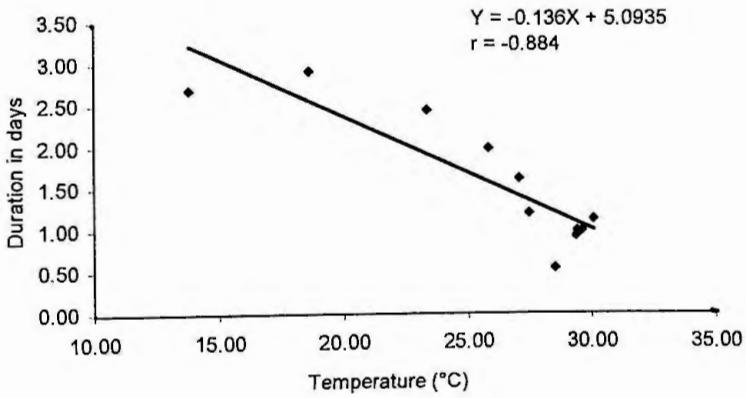


Figure 4. Regression line of larval duration of *T. urticae* on temperature.

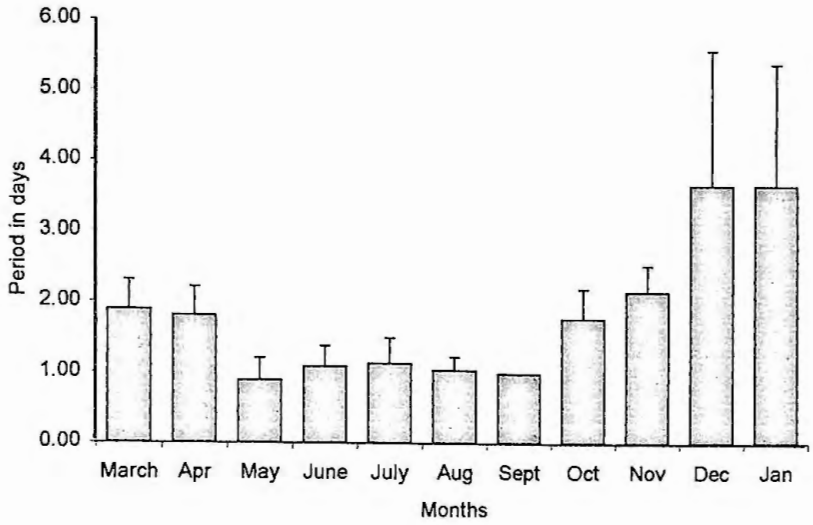


Figure 5. Protonymphal duration of *T. urticae* in different months.

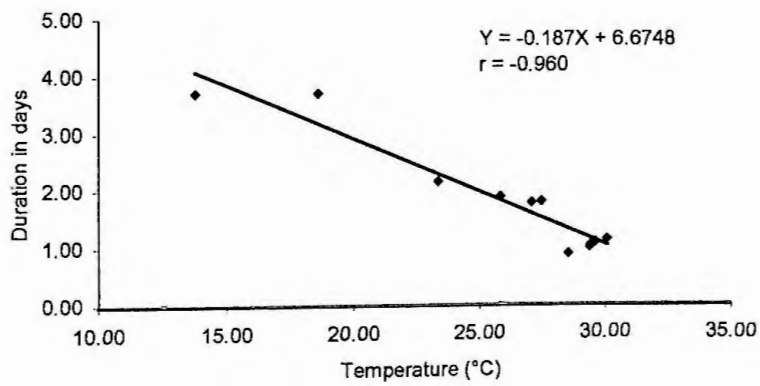


Figure 6. Regression line of protonymphal duration of *T. urticae* on temperature.

The deutonymph is the last immature stage of *T. urticae* life cycle. The time required to reach the adulthood (Plate 5) from deutonymph in different months is shown in Figure 7. It required the shortest duration of 0.92 ± 0.41 days in August and the longest 10.26 ± 1.48 days in January. During May the average temperature was 28.53 ± 3.17°C and very favourable for mite development. The lowest average temperature 13.78 ± 3.21°C was prevailed in the month of January retarded the developmental rate and lengthened the transformation of deutonymph to adult. The relationship between the temperature and the duration of deutonymphal period was studied and the 'r' value was calculated. Temperature played significant ($P<0.001$) role on the duration of deutonymphal period. The higher temperature accelerated the developmental rate and reduced the deutonymphal period. The regression equation and the regression line made between the temperature and deutonymphal duration are shown in Figure 8. The relative humidity exerted no significant role on the duration of deutonymphal period (Table 2).

T. urticae completed its life cycle within 4.22 ± 0.46 days at temperature 28.53 ± 3.17°C. But it took the longest time (28.33 ± 2.36 days) at temperature 13.78 ± 3.21°C. The average time to complete the life cycle from egg to adult at different room temperature observed in different months is shown in Figure 9. The temperature greatly affected the duration of developmental period. The gradual increase of temperature decreased the developmental duration gradually.

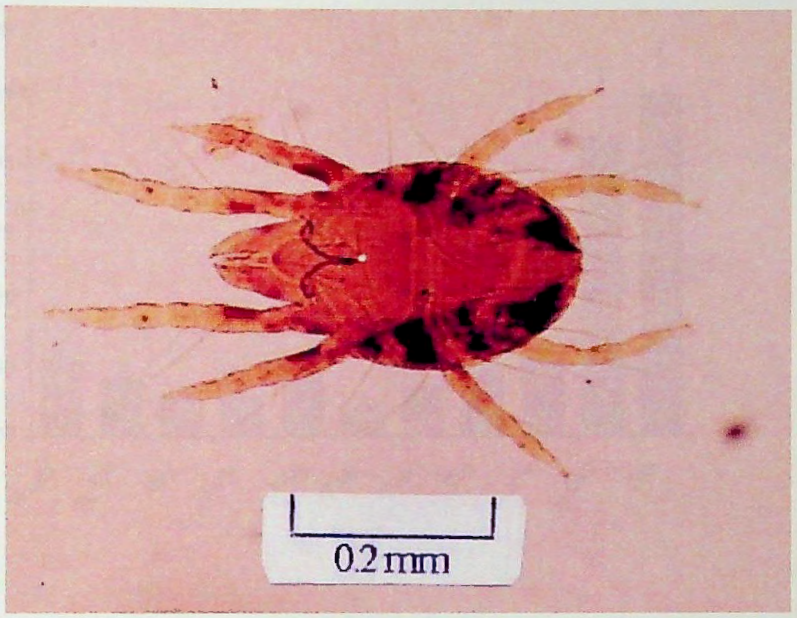


Plate 4. Deutonymph of TSSM.

Plate 5. Adult TSSM.

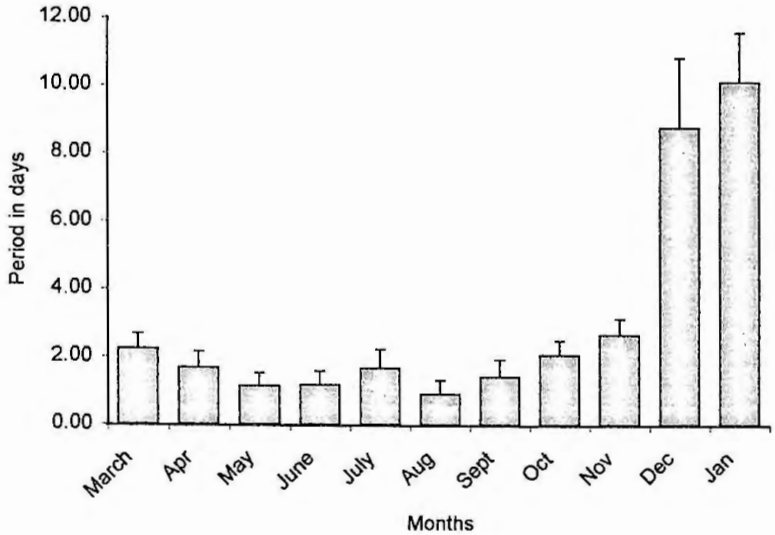


Figure 7. Deutonymphal duration of *T. urticae* in different months.

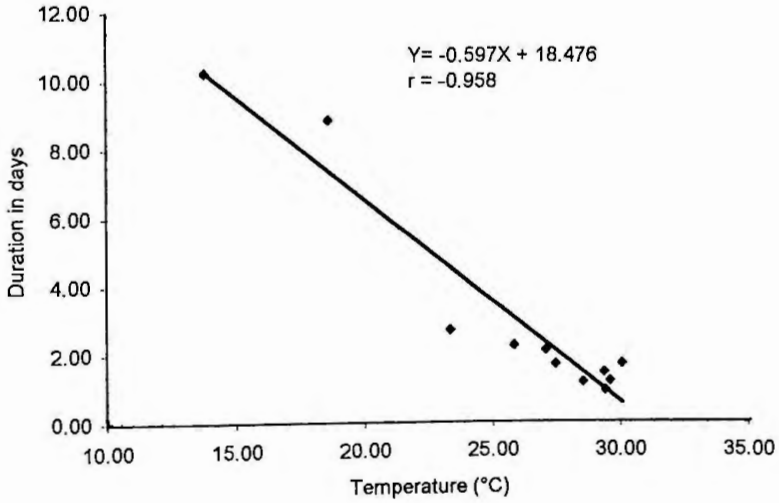


Figure 8. Regression line of deutonymphal duration of *T. urticae* on temperature.

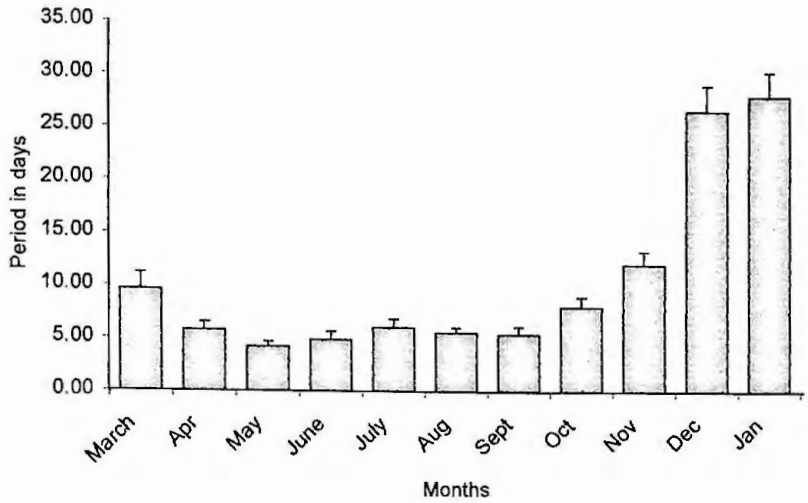


Figure 9. Duration from egg to adult of *T. urticae* in different months.

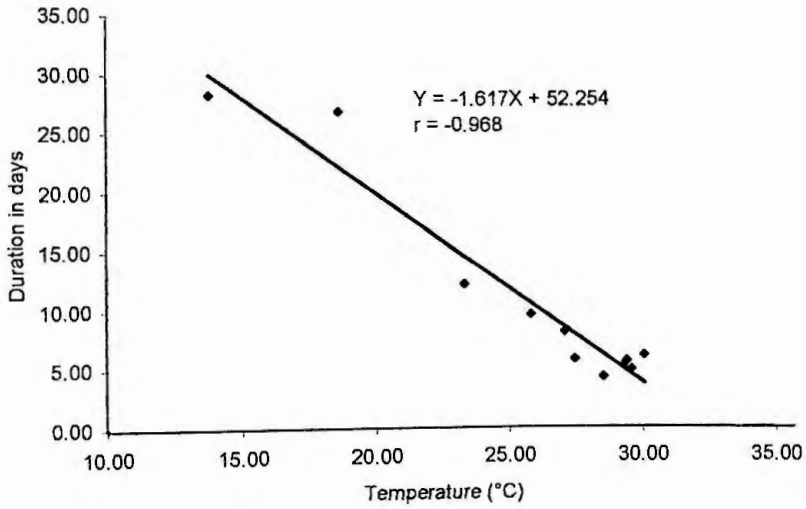


Figure 10. Regression line of egg to adult duration of *T. urticae* on temperature.

The value of coefficient of correlation between the relationship of temperature and the developmental duration from egg to adult was calculated, the regression equation and regression was made and shown in Figure 10. The relative humidity was found to exert no significant effect on it (Table 2).

The developmental success of different developmental stages are calculated and presented in Table 3. The developmental success was not significantly different between months. The relative humidity exerted no effect on the survivability of *T. urticae* when rearing in the laboratory. In all conditions the developmental success of egg, larva and protonymph was more than 92%. The developmental success of deutonymph was somewhat reduced in December and January when the average temperature was below 20°C. The survivability from egg to adult was also abruptly reduced in December and January. The above findings shows that the extreme cold temperature affect the survivability of late stages only.

Table 3. Developmental success of different stages of *T. urticae.*

Month	Developmental success					Temp. (°C)	Relative Humidity (%)
	Egg	Larva	Proto-nymph	Deuto-nymph	Egg to adult		
March	0.966	1.000	1.000	0.929	0.897	25.82	67.48
April	1.000	1.000	0.929	0.962	0.893	27.46	76.75
May	0.967	1.000	0.931	0.963	0.867	28.53	82.90
June	0.926	0.960	0.917	1.000	0.815	29.60	85.49
July	1.000	0.933	1.000	0.893	0.833	30.06	87.41
Aug	1.000	0.966	0.964	0.889	0.828	29.41	85.82
Sept	1.000	0.967	0.966	0.964	0.900	29.36	85.92
Oct	0.929	0.923	0.958	0.957	0.786	27.07	82.31
Nov	0.964	0.963	0.923	0.958	0.821	23.32	80.35
Dec	1.000	0.967	0.966	0.643	0.600	18.59	81.83
Jan	1.000	0.967	0.966	0.679	0.633	13.78	80.21

F value = 0.95

Fecundity of *T. urticae*

The mean number of eggs laid by a female, the daily fecundity and average duration of reproductive period is presented in Table 4. A female *T. urticae* laid 82.46 ± 4.11 eggs during autumn at average temperature of 25.23 ± 2.65°C (Table 4) but it laid 58.21 ± 13.65 eggs during winter. The eggs deposited per day was only 1.35 ± 0.36 in winter but it was higher 11.01 ± 1.92 during summer.

Table 4. Fecundity and reproductive period of *T. urticae* in three seasons.

Season	Egg/female ± S E	Egg/female/day ± S E	Reproductive period day ± S E
Winter	58.21 ± 13.65	1.35 ± 0.36	29.11 ± 1.85
Autumn	82.46 ± 4.12	4.80 ± 0.55	18.75 ± 1.07
Summer	62.96 ± 12.09	11.01 ± 1.92	9.28 ± 1.17
F value	50.45***	12.95***	1140.01***

*** = P<0.001.

The eggs deposition per day in different days of reproductive period in different seasons is presented in the Table 5.

The daily fecundity of *T. urticae* in winter is shown in Figure 11. On the 5th day *T. urticae* deposited the highest number of eggs (3.37 ± 0.29). The egg deposition was 2 to 4 from 2nd to 14th day. The females laid eggs upto 30th day of adulthood. A single female laid upto 9 eggs in a day. The average was 1.35 ± 0.36/day/female.

Table 5. Daily mean fecundity of female *T. urticae* in different seasons.

Day	Winter		Autumn		Summer	
	Egg	± SE	Egg	± SE	Egg	± SE
1st	2.320	1.29	1.625	0.294	0.600	0.183
2nd	2.530	0.32	2.167	0.200	2.200	0.311
3rd	2.420	0.28	3.792	0.288	4.440	0.388
4th	1.890	0.26	4.875	0.393	10.000	0.648
5th	3.370	0.29	6.542	0.364	14.640	0.954
6th	2.790	0.49	6.875	0.404	8.280	0.626
7th	2.630	0.33	6.167	0.238	4.560	0.614
8th	1.470	0.23	7.333	0.351	2.792	0.665
9th	2.890	0.26	7.917	0.249	2.118	0.620
10th	2.210	0.39	7.500	0.204	1.917	0.618
11th	2.160	0.27	4.375	0.239	1.000	0.200
12th	2.790	0.29	4.583	0.157		
13th	2.950	0.41	3.833	0.286		
14th	1.840	0.26	3.500	0.281		
15th	1.000	0.27	3.250	0.234		
16th	1.530	0.23	3.833	0.229		
17th	0.470	0.23	2.458	0.347		
18th	0.950	0.16	1.300	0.225		
19th	1.050	0.22	0.375	0.109		
20th	0.530	0.30	0.200	0.098		
21st	0.390	0.14				
22nd	0.630	0.12				
23rd	0.470	0.16				
24th	0.370	0.16				
25th	0.370	0.14				
26th	0.260	0.14				
27th	0.350	0.13				
28th	0.210	0.16				
29th	0.230	0.13				
30th	0.110	0.10				
31st	0.000	0.08				
32nd	0.000	0.00				
Average	1.350	0.490	4.798	1.200	11.013	0.531

The daily fecundity of *T. urticae* in autumn is shown in Figure 12. The female laid more than 6 eggs per day from 6th to 11th. The average number of egg deposition per day was 4.80 ± 0.55 Table 4). Egg laying continued from the first to 20th day of adulthood. The average highest deposition was 7.92 ± 0.25 on 9th day. Several females laid 10 eggs on different days.

The daily fecundity of *T. urticae* in summer is shown in Figure 13. It laid more eggs from 4th to 7th day and egg laying continued only up to the 11th day of adulthood. But in summer the highest average eggs laid by a female mite was 14.64 ± 0.95 on 5th day. The average was 11.01 ± 1.92 (Table 4) egg/female/day.. The duration of reproductive period was longer in winter and shorter in summer.

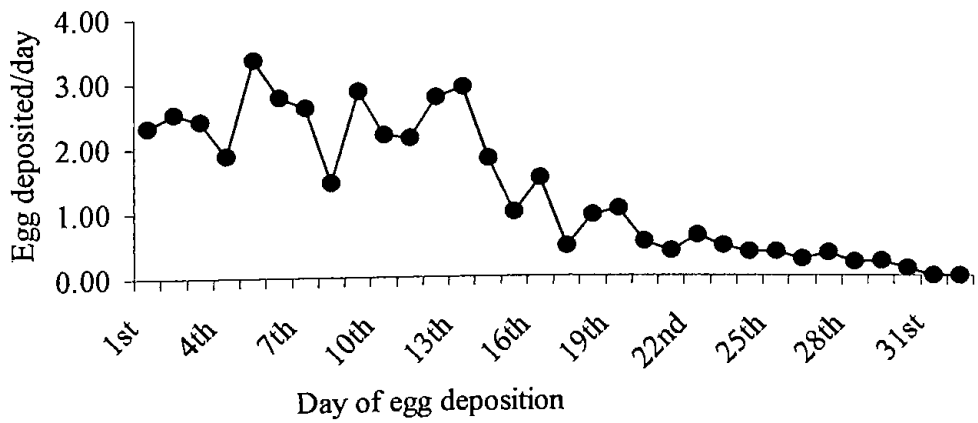


Figure 11. Daily fecundity of *T. urticae* during winter.

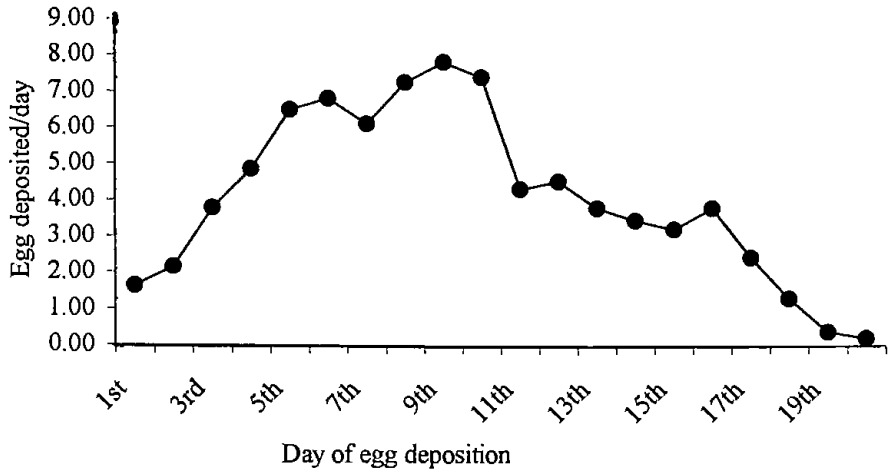


Figure 12. Daily fecundity of *T. urticae* during autumn.

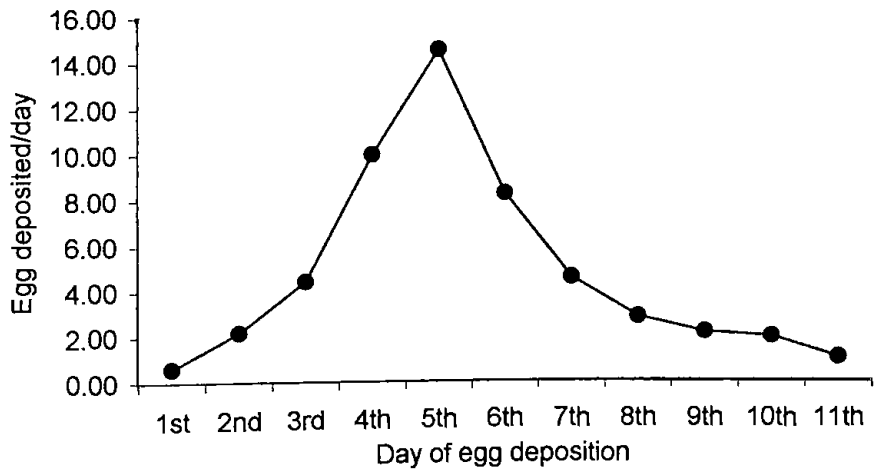


Figure 13. Daily fecundity of *T. urticae* during summer.

Discussion

Extensive research had been done on the biology of different species of spider mites. Most of the works are related to the effect of temperature.

Sabelis (1981) reported that a female *T. urticae* develop from egg to adult in 6.5 days at 30°C. Helle and Sabelis (1985a) found a female *T. urticae* lay as many as 60 eggs in five days.

The effect of five constant temperatures (15 - 37°C) at 80% relative humidity on the biology of *T. neocaledonicus* Andre in the laboratory was studied by Pande and Sharma (1986). They observed that *T. neocaledonicus* could not survive beyond 37°C, but with the increase of temperature above 20°C, development was faster. They also added that 30°C was the optimal temperature for the development of *T. neocaledonicus*.

Northcraft and Watson (1987) studied the developmental biology of *T. cinnabarinus* at three fluctuating temperatures having the means 22.7, 26.6 and 30.5 °C. They reported that the developmental time, longevity and survival rate of adult females significantly decreased with the increase of temperature. Preoviposition periods and rate and duration of oviposition also tended to decrease with the increase of temperature. The mean generation time was 17.7, 14.3 and 11.6 days respectively at 22.7, 26.6 and 30.5°C, they calculated.

T. cinnabarinus infesting cotton in Henan, China completed 10 generations annually (Qui and Li 1988). The duration of each generation lasted 19 and 26 days at temperatures 16 and 20°C. The generation time was 10 and 13 days at 22 and 28°C temperatures. Development was optimal at 26°C and

ceased completely at 10°C. The effective accumulated temperature was 163.25 day-degree C (Qui and Li 1988).

Deciyanto *et al.* (1989) studied the life cycle of *Tetranychus* sp. on six cultivars of *Mentha piperita* and *M. arvensis*. They found that the life cycle averaged within 10.6 to 14.4 days and a female laid 35.2 to 77 eggs. They also observed that the life cycle was the longest on *M. piperita* Newzealand but shortest on *M. arvensis* Jombang.

Tsai *et al.* (1989) studied the duration of developmental stages of *T. kanzawi* infesting tea at 15, 20, 25 and 30°C. They found the lowest development at the lowest temperature and highest development at the highest temperature. The duration of the developmental stages were shorter at 30°C but longer at 15°C. *T. kanzawi* was short lived at 30°C but long lived 15°C. A female laid 27.8 eggs at 15°C but 76.0 eggs at 30°C. The mean generation time ranged from 12.4 days at 30°C and 53.9 days at 15°C.

Al-Mallak and Abdalla (1990) studied the biology of strawberry mite, *T. turkestani* in laboratoyry condition at 25°C and 60% R. H. They reported the average egg laying capacity was 81.7±1.17 per female. The larval, nymphal and adult stages lasted 6.2, 6.1 and 13.3 days respectively.

Ansari and Power (1992) studied the biology of *T. ludeni*, a pest of several vegetables in India, at 26±2°C. They observed that a female *T. ludeni* laid 30 to 90 eggs and the eggs hatched to larva within 2.00 - 2.70 days.

Berry (1998) stated that extreme cold temperature ceases the development of the spider mite. He reported that two-spotted spider mites over-

winter as female under loose bark, crack, soil, and other protected places in the orchard. Females that over winter emerge in the spring, disperse, and begin laying eggs on the leaves. Eggs hatched in the leaves in four to six days. Development continued through proto and deutonymph stages to the adult. A complete life cycle required one to three weeks. During summer life cycle completed rapidly and there were seven to eight generations each year.

Shih (1999) observed *T. urticae* laid maximum 100 eggs in 10 days. He stated that the temperature 23 – 30°C was the optimal for the development of *T. urticae*. The larval and nymphal stage lasted 16 days at 20°C but only seven days at 31°C.

The present investigation agreed with the findings of the above results. The temperature affected developmental stages of two-spotted spider mite. The higher temperature accelerated the developmental rate and reduced the duration of developmental stages. In the present investigation the fecundity was also higher at 25.23 ± 2.65°C.

At 30.46°C the oviposition period was 9.28 days but it was 18.75 days at 25.23°C. The life cycle of *T. urticae* completed within 4.22 days at 28.53°C. So the present results suggest that favourable temperature of *T. urticae* was 25.23°C to 28.53°C which is very similar to the findings of other investigators of different species on spider mites.

Chapter 2

Abundance of TSSM on bean plant

CHAPTER 2

ABUNDANCE OF TSSM ON BEAN PLANT

Introduction

Many physical and environmental factors interact to influence the livelihood of TSSM outbreak. Identifying a single factor as solely responsible for a population explosion of mites is too simplistic. Huffaker *et al.* (1970) listed the following elements that contribute to TSSM dynamics :

(a) features of the life cycle, particularly with regards to movement phases and potentials, reproduction, and diapause;

(b) meteorological condition, including photoperiod effects;

(c) the nutrition afforded by the host plant and its relative susceptibility or resistance to the mites; and

(d) action of natural enemies, particularly predators.

In addition to these components, the manner in which TSSM populations are managed when they reach potentially damaging levels may also play a crucial role in the success of insecticides / miticides applications (Huffaker *et al.* 1970)

The understanding the TSSM populations, their cycles, and outbreaks require a knowledge of many factors. These factors include the biotic potential of the species, the influence of meteorological factors, the availability and relative susceptibility of hosts, competition between mite species and structural and chemical adaptations of each kind of mite.

TSSM species are well adapted to cyclic weather changes through behavioural and anatomical modifications than enable them to survive. The species that find hot dry summer undesirable retire to moist ground crevices, retreat under bud scales, or develop a generation with exterior anatomy more resistant to temperature and humidity extremes. Females of some species, with the onset of unfavourable conditions, enter a stage of arrested development, or they deposit weather resistant eggs that survive during the unfavourable conditions (Jeppson *et al.* 1975).

Populations of tetranychid mite species obviously become self limiting in relation to food supply, if their increase in number is not controlled by some form of environmental or artificial resistance (Devis 1952, Watson 1964). As mite numbers well, extensive feeding damages their host, especially the leaves, which become yellowish, and many began to dry out. Various tetranychid species show divergent responses to over crowding, and to changing environmental conditions (Boudreaux 1963, Pickett and Gilstrap 1996).

Bean is a very popular and important vegetable crop in Bangladesh. TSSM attacks bean plants and cause great damage to the plant resulting yield loss (Gapud 1981). In any control measure the survey of the pest species is a must and as such the abundance of TSSM on bean plant at RCC area has been done.

Materials and Methods

Extensive survey

The extensive survey of *T. urticae* was conducted on bean plants at three localities in RCC area. The localities were Motihar, Paba and Boalia thanas. The bean plants were selected randomly of the above localities. Samples of the bean leaves were collected weekly from each locality. During sampling, a bean plant was never duplicated at least in a month. The young, mature and old leaves were collected from each plant. The leaves were brought within polyethylene bags to the laboratory. In each sampling, three young, three mature and three old leaves were selected randomly. Total number of *T. urticae*, both adult and nymph, were counted on upper and lower surfaces of each leaf with the help of a stereo-binocular microscope. The observation was continued for one year starting from January to December 2002.

Intensive survey

An intensive survey *T. urticae* was conducted on a bean plant in the experimental plots of the Institute of Biological Sciences (IBSc). The bean seed was bedded in the first week of July 2002. The plant was allowed to grow on bamboo -framed platform placed at a height of 1.75m from the ground. No insecticide, miticide or any other chemicals were applied to control the pest during the survey period. The plant was attacked naturally by TSSM. The survey was made by bringing three bean leaves every day from the bean plant. The leaves were selected as one young, one mature and one old. The leaves were collected randomly. The leaves were examined under stereo-binocular microscope in the laboratory. All stages of mite viz.. egg, larva, nymph and

adult were considered for counting. Different stages were recorded separately. The survey was began from the first week of September 2002 and continued for one year till August 31, 2003.

Results

Extensive survey

The monthly average number of TSSM per leaf on different type of bean leaves in three localities are presented in Table 6. The highest number of TSSM (59.69/leaf) was prevailed in April followed by 36.97/leaf in August. The lowest number (4.05/leaf) was recorded in February.

The average number of TSSM per leaf in three areas of RCC are shown in Figure 14. The number of mite/leaf in three different areas differed significantly ($P<0.001$) among different months. The population of TSSM was highest in the month of April. There was no significant difference between the number of TSSM of different areas (ANOVA Appendix Table 14).

Average number of TSSM in different type of leaves viz. young, mature and old in three areas of RCC is shown in Figure 15. The mature leaves contained the highest number of mites and it differed significantly ($P<0.001$) from young and old leaves The number of mites on young and old leaves does not differ significantly (ANOVA Appendix Table 15).

The mean number of TSSM/leaf from January to December 2002 along with temperature and relative humidity is shown in Figure 16. The highest peak (59.69/leaf) was observed in April and the next peak (36.97/leaf) was in August. After the first peak, the population fall abruptly and decreased gradually after the second peak.

Table 6. Average number of *T. urticae* per leaf on different type of bean leaves in three areas of RCC during the year 2002.

Month	Value	Motihar			Paba			Boalia			Mean (Average)		
		Y	M	O	Y	M	O	Y	M	O	Y	M	O
Jan.	Mean	5.67	5.47	7.07	1.40	2.39	1.51	6.53	9.07	9.57	4.53	5.64 (5.40)	6.04
	±SE	4.57	3.84	3.62	0.82	1.09	0.54	3.99	3.71	5.43		)	
Feb.	Mean	7.46	10.63	12.00	0.67	2.25	1.17	0.92	0.92	1.42	2.56	4.74 (4.05)	4.86
	±SE	4.98	8.06	8.89	0.38	0.88	0.55	0.92	0.71	1.42			
Mar.	Mean	3.17	11.75	10.75	1.17	4.84	3.25	0.42	1.75	2.33	1.59	6.11 (4.38)	5.44
	±SE	4.98	8.06	8.89	0.38	0.88	0.55	0.92	0.71	1.42			
Apr.	Mean	39.92	65.17	49.59	49.50	97.50	46.92	61.67	87.50	39.42	50.36	83.39 (59.69)	45.31
	±SE	22.99	32.81	31.27	17.21	35.58	17.11	46.75	66.08	30.43			
May	Mean	9.22	12.78	14.33	15.22	9.00	17.00	2.22	7.89	5.11	8.89	9.89 (10.31)	12.15
	±SE	6.30	9.90	9.31	16.46	7.73	17.46	1.40	6.00	2.01			
Jun.	Mean	35.42	44.42	26.25	9.17	15.75	8.25	7.00	24.25	14.67	17.20	28.14 (20.58)	16.39
	±SE	21.80	18.40	7.23	5.60	10.01	2.80	5.08	16.13	10.11			
Jul.	Mean	16.55	52.89	20.11	10.11	2.22	0.44	0.11	7.33	8.56	8.92	20.81 (13.15)	9.70
	±SE	10.32	35.96	15.75	11.65	1.42	0.54	0.13	8.88	10.36			
Aug.	Mean	34.00	43.33	7.33	16.25	63.75	23.42	41.00	62.33	41.33	30.42	56.47 (36.97)	24.03
	±SE	19.35	30.07	3.67	14.42	59.35	16.15	28.03	45.25	29.70			
Sep.	Mean	14.53	16.93	29.13	22.73	36.93	38.73	19.07	37.00	56.67	18.78	30.29 (30.19)	41.51
	±SE	6.30	8.17	14.60	14.27	24.39	23.11	10.79	17.58	17.24			
Oct.	Mean	9.66	17.73	19.73	15.47	45.27	33.87	29.20	50.20	37.60	18.11	37.73 (28.75)	30.40
	±SE	2.75	6.83	4.65	7.59	12.76	9.80	11.56	16.33	15.10			
Nov.	Mean	14.47	33.27	34.67	12.60	28.60	21.00	6.13	10.87	7.00	11.07	24.25 (18.73)	20.89
	±SE	2.75	6.83	4.65	7.59	12.76	9.80	11.56	16.33	15.10			
Dec.	Mean	4.80	10.27	7.67	8.40	12.87	11.73	2.33	6.00	7.80	5.18	9.71 (7.99)	9.07
	±SE	2.43	3.31	2.55	5.38	8.44	6.56	0.77	1.69	2.64			
Avr.		16.12	27.09	19.89	13.56	26.78	14.27	14.72	25.43	19.29	14.80	26.43	18.82

Y=Young leaf, M=Mature leaf and O=Old leaf, Avr.=Average.

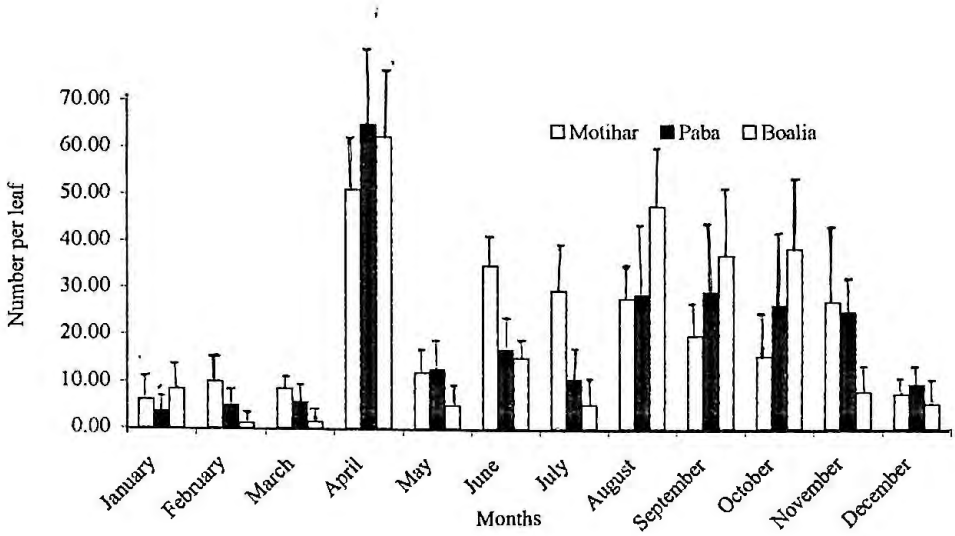


Figure 14. Number of TSSM/leaf of bean in different areas of RCC.

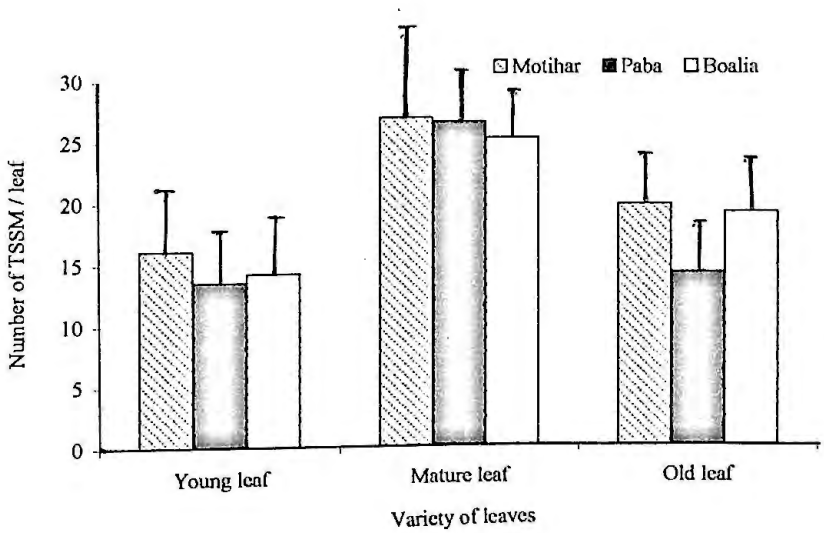
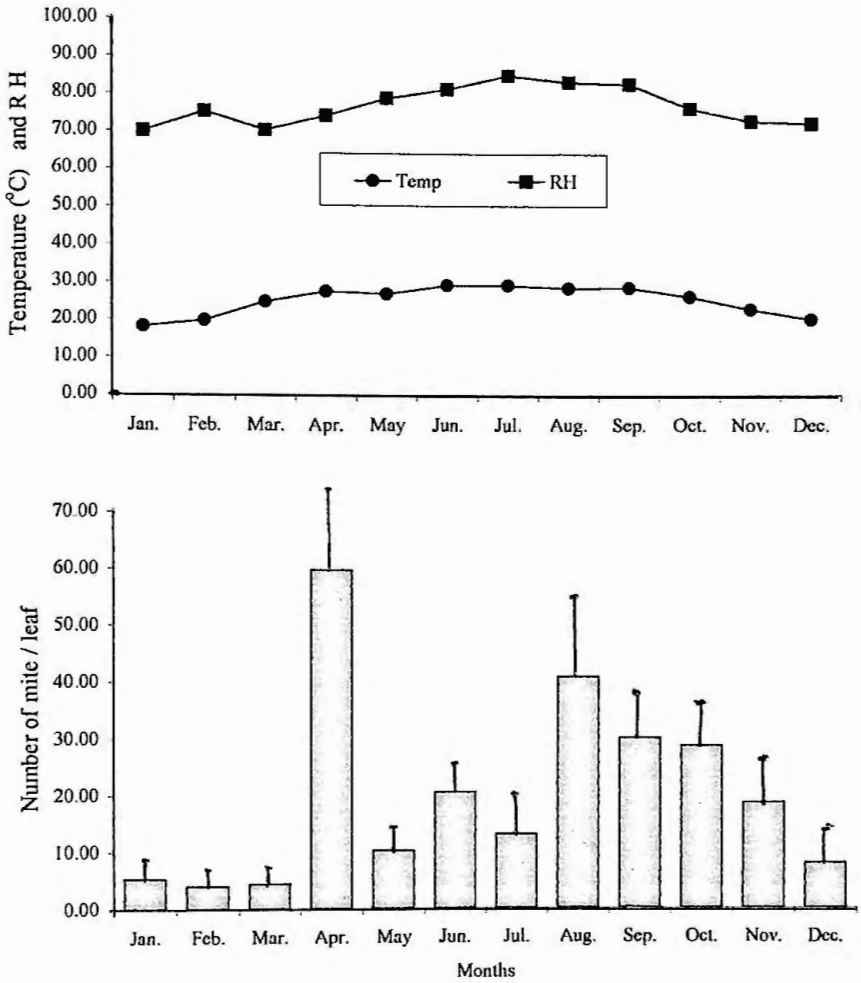


Figure 15. Number of TSSM/leaf on three type of leaves in three areas.



Figere 16. Mean number of TSSM/leaf along with mean temperature and rerlative humidity.

To find out the impact of physical factors on TSSM population the data were analyzed by correlation. The values of coefficient of correlation are calculated and presented in Table 7. The temperature had significant ($P<0.05$) impact on the abundance of TSSM on bean leaves. The TSSM number per leaf increased with the increase of temperature. The regression line is drawn and shown in Figure 17. The relative humidity, rainfall and sunshine (hours) played no significant effect on the abundance of TSSM on bean leaves. But the relationship of relative humidity and rainfall with TSSM abundance was positive. Sunshine had little negative impact on the abundance of TSSM.

Table 7. Co-efficient of correlation (r) between the number of TSSM per leaf and different physical factors.

Parameter	Temperature	Relative humidity	Rainfall	Sunshine
TSSM per leaf	0.567*	0.378	0.410	-0.185

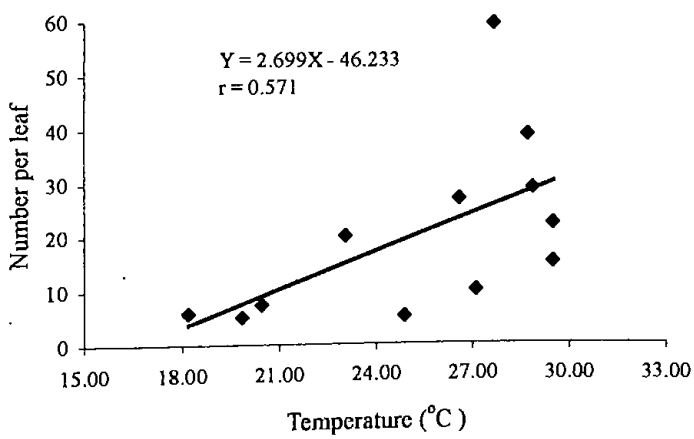


Figure 17. Regression line of number of TSSM/leaf on temperature.

Intensive survey

The average number of different stages of TSSM / leaf on young, mature and old leaves is presented in Table 8. The number of eggs was higher on three type of leaves than other stages. The adult and immature stages of TSSM on different type of leaves are presented in Table 9. The population of immature stages was several times greater than adult population of all type of leaves. The number of TSSM/leaf differed significantly ($P<0.001$) among different months (Appendix Table 16). But the number of TSSM/leaf did not differ significantly between different leaf types (Appendix Table 17).

The percentage of male and female TSSM on three type of leaves are shown in Figure 18. On young leaves, the females were 3.12 times of male but on mature leaves, the females were 2.02 times of male Table 8). Whereas the females were only 1.19 times of male on old leaves. Female population is comparatively lower on old leaves than other two type of leaves. The percentage of females were 75.73, 66.88 and 54.33% on young, mature and old leaves respectively.

The percentage of adult and immature stages of TSSM is shown in Figure 19. The immature stages was several times greater than adult and it was 80.79, 82.93 and 76.29% on young, mature and old leaves respectively. The percentage of number of eggs on different type of leaves is shown in Figure 20. The egg number was higher on young and mature leaves but more or less same on old leaves.

Table 8. Mean (±S E) number of different stages of *T. urticae* per leaf on different type of bean leaves.

Months	Leaf	Male	Female	Nymph	Larva	Egg
Sep. 02	Young.	0.27±0.13	1.70±0.39	1.00±0.53	1.73±0.93	16.93±6.43
	Mature	0.33±0.27	1.00±0.35	2.13±1.13	2.23±1.34	14.67±5.92
	Old	1.40±0.57	1.50±0.71	2.03±0.77	0.77±0.34	3.40±1.47
Oct. 02	Young.	1.35±0.36	1.65±0.30	0.90±0.28	1.19±0.13	7.42±0.02
	Mature	0.83±0.25	3.00±0.72	0.68±0.26	0.52±0.22	8.77±2.55
	Old	0.48±0.16	0.84±0.29	0.45±0.14	0.10±0.00	5.90±2.42
Nov. 02	Young.	0.47±0.26	2.17±0.64	1.10±0.62	1.03±0.58	8.93±2.91
	Mature	1.43±0.43	2.77±0.73	5.50±1.54	3.03±0.84	13.97±4.14
	Old	1.47±0.37	1.63±0.45	4.30±1.22	5.37±1.49	11.67±2.41
Dec. 02	Young.	0.06±0.07	0.35±0.27	0.00±0.00	0.00±0.00	1.58±0.94
	Mature	0.23±0.13	1.61±0.70	0.97±0.60	0.48±0.26	5.00±1.78
	Old	0.52±0.31	0.84±0.47	0.55±0.36	0.00±0.00	0.83±0.45
Jan. 03	Young.	0.07±0.05	0.43±0.37	0.07±0.05	0.10±0.10	2.30±1.35
	Mature	0.37±0.13	1.03±0.31	0.83±0.36	0.60±0.34	3.43±0.98
	Old	0.37±0.21	1.43±0.66	1.10±0.87	0.43±0.24	3.93±2.22
Feb. 03	Young.	0.79±0.36	5.93±1.70	1.46±0.79	0.46±0.30	12.07±4.34
	Mature	1.29±0.37	5.46±1.32	2.39±0.80	3.14±1.26	25.79±8.94
	Old	2.04±0.73	2.43±0.96	2.71±0.76	1.86±0.72	17.75±8.08
Mar. 03	Young.	0.19±0.11	6.35±1.58	0.94±0.34	2.97±1.26	17.68±4.24
	Mature	2.52±0.60	4.39±1.54	10.52±1.66	3.45±1.12	17.10±3.78
	Old	2.16±0.47	3.97±0.68	3.26±0.75	3.45±1.03	11.74±2.48
Apr. 03	Young.	2.67±0.95	9.83±1.49	6.23±1.63	2.87±0.80	38.47±6.60
	Mature	4.33±1.07	7.67±1.44	14.13±378	10.43±8.18	42.43±8.18
	Old	4.57±0.74	7.07±1.03	8.73±1.89	7.03±1.48	35.47±6.27
May. 03	Young.	7.00±1.65	10.74±1.95	10.13±2.75	6.77±1.46	54.84±8.47
	Mature	8.03±1.45	12.16±2.43	9.10±1.52	12.10±2.57	42.16±6.96
	Old	10.70±2.25	11.10±2.48	14.53±2.94	16.70±3.02	44.27±7.86
Jun. 03	Young.	2.50±0.96	6.47±1.43	6.13±1.64	2.63±0.84	28.33±5.90
	Mature	3.43±1.05	5.63±1.38	10.83±3.64	7.97±2.95	30.53±7.82
	Old	3.70±0.78	3.10±0.73	5.30±1.24	5.50±1.48	25.10±5.93
Jul. 03	Young.	0.10±0.07	1.16±0.45	0.06±0.05	0.00±0.00	5.71±1.58
	Mature	0.19±0.10	0.32±0.12	0.39±0.17	0.26±0.13	4.52±1.40
	Old	1.16±0.56	0.77±0.36	1.10±0.61	0.06±0.07	2.06±1.55
Aug. 03	Young.	0.42±0.27	2.71±0.48	1.42±0.65	5.06±2.20	35.26±10.00
	Mature	1.26±0.37	3.90±0.87	6.90±1.98	2.39±0.70	34.84±8.69
	Old	1.74±0.36	1.48±0.36	7.94±2.59	2.48±0.86	11.94±3.45
Average	Young	1.32	4.12	2.45	2.07	19.13
	Mature	2.02	4.08	5.36	3.88	20.27
	Old	2.53	3.01	4.33	3.65	14.51
Female (%)	75.73 on young, 66.88 on mature and 54.33 on old leaf.					

Table 9. Adult and immature stages of *T. urticae* on different type of leaves of bean plant.

Months	Young leaf			Mature leaf			Old leaf		
	Adult	Immature stage	Total	Adult	Immature stage	Total	Adult	Immature stage	Total
Sep. 02	1.97	19.66	21.63	1.33	19.03	20.36	2.90	6.20	9.10
Oct. 02	3.00	9.51	12.51	3.83	9.97	13.80	1.32	6.45	7.77
Nov. 02	2.64	11.06	13.70	4.20	22.50	26.70	3.10	21.34	24.44
Dec. 02	0.41	1.58	1.99	1.84	6.45	8.29	1.36	1.38	2.74
Jan. 03	0.50	2.47	2.97	1.40	4.86	6.26	1.80	5.46	7.26
Feb. 03	6.72	13.99	20.71	6.75	31.32	38.07	4.47	22.32	26.79
Mar. 03	6.54	21.59	28.13	6.91	31.07	37.98	6.13	18.45	24.58
Apr. 03	12.50	47.57	60.07	12.00	66.99	78.99	11.64	51.23	62.87
May. 03	17.74	71.74	89.48	20.19	63.36	83.55	21.80	75.50	97.30
Jun. 03	8.97	37.09	46.06	9.06	49.33	58.39	6.80	35.90	42.70
Jul. 03	1.26	5.77	7.03	0.51	5.17	5.68	1.93	3.22	5.15
Aug. 03	3.13	41.74	44.87	5.16	44.13	49.29	3.22	22.36	25.58
Average	5.45	23.65	29.10	6.10	29.52	35.61	5.54	22.48	28.02
(%)	18.73	81.27		18.13	82.90		19.77	80.23	

F- value of total number of TSSM between months = 41.04*** ($P<0.001$).

F- value of total number of TSSM between leaf varieties = 0.274.

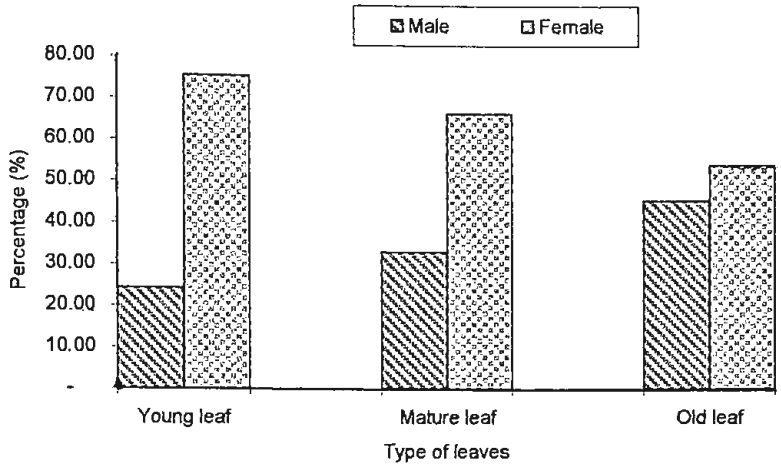


Figure 18. Percentage of *T. urticae* male and female on different type of leaves.

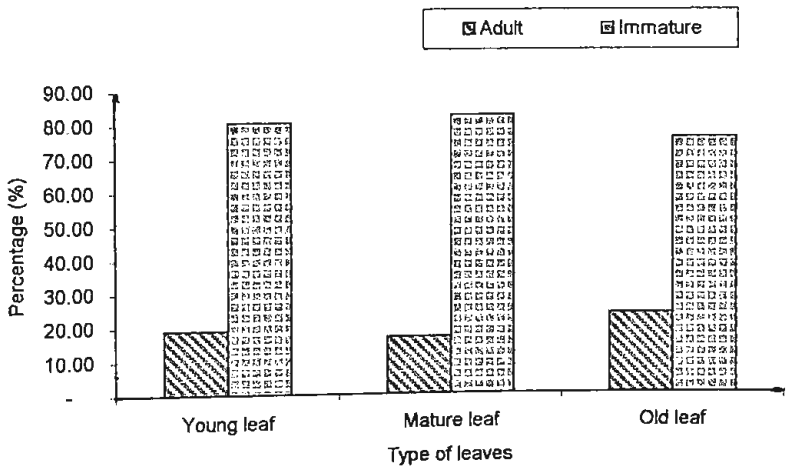


Figure 19. Percentage of adult and immature in different type of leaves.

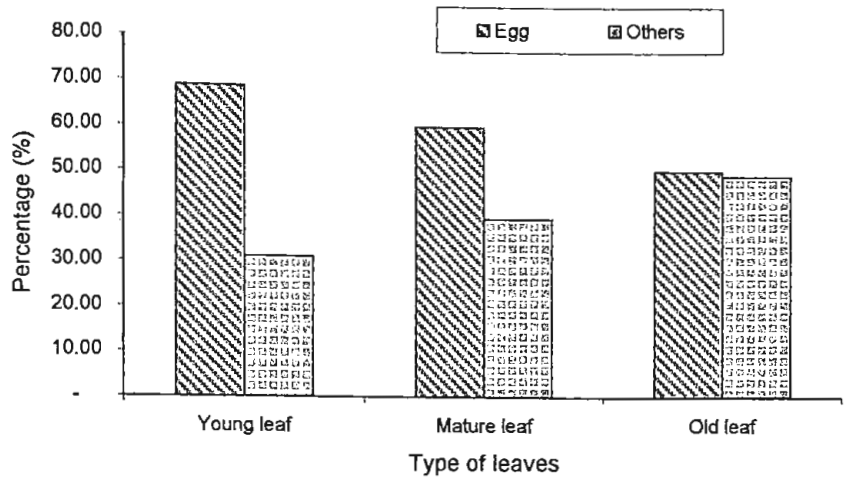


Figure 20. Percentage of egg and other stages of *T. urticae* on different type of leaves.

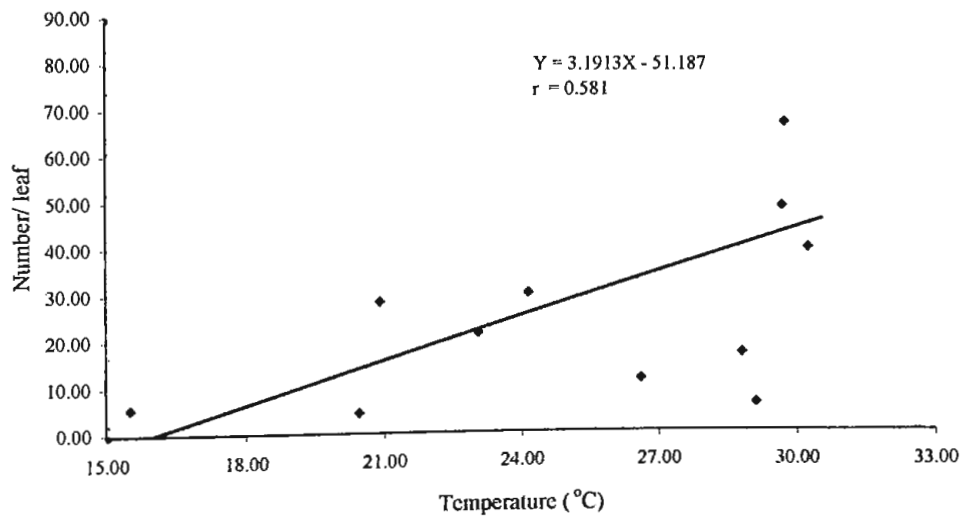


Figure 21. Regression line of number of TSSM/leaf on temperature.

The impact of climatic factors on the abundance of different stages of TSSM on bean leaves was studied. The data were analyzed by regression and the values of coefficient of correlation are presented in Table 10. Temperature had significant ($P<0.05$) effect on the total number of TSSM per leaf. The regression line is drawn and shown in Figure 21. The figure shows the increase of temperature increases the number of TSSM on bean leaves. The temperature also had somewhat positive relationship on the abundance of other stages of TSSM. The relative humidity, rainfall and sunshine had no significant effect on the abundances of different stages of TSSM.

Table 10. Co-efficient of correlation (r) between number of different stages of TSSM and different climatic factors.

Parameter	Temperature	Relative humidity	Rainfall	Sunshine
Total number of TSSM per leaf	0.581*	0.042	-0.311	0.111
Active stages of TSSM per leaf	0.366	-0.134	0.121	0.227
Immature stages of TSSM per leaf	0.240	-0.072	0.139	0.192
Egg of TSSM per leaf	0.214	-0.045	0.129	0.175

Discussion

Simpson and Connel (1973) examined rainfall data over a seven years period and found that total summer precipitation could explain 51.3 % of the population variation of the spider mite *T. turkestani* in soyabean fields. The period of the low infestations proceeded by a substantial amount of rainfall, while the more severe infestations proceeded by less than normal rainfall. Population of any organism is influenced by an array of biotic and abiotic factors and their subsequent interaction. The result of Simpson and Connel (1973) indicated that rainfall may be an extremely important limiting factors in spider mite population dynamics.

Most tetranychids behave as if rain does not adversely affect them, unless rain continues over prolonged periods, or is specially heavy. Heavy rains sometimes washes mites off their host, but most mites move during rain to leave undersides or to sheltered places. Natural pubescence on some plants helps mite to hold or during summer. But powerful rainfalls, such as Asiatic monsoons, do cause major reduction in some mite populations (Jeppson *et al.* 1975).

The present investigation shows no significant effect of rainfall on the abundance of TSSM on bean leaf. Though it was observed that immediately after heavy rainfall, the TSSM number decreased but after very few days again increased as normal.

According to Hollingsworth and Berry (1982) *T. urticae*, increased more rapidly on peppermint plants that were under moisture stress than on non-stressed plants. They also reported that at the leaf surface, the useful environment of the tetranychid mites, the relative humidity is usually higher,

and webbing produced by the mites has the further effect of maintaining the humidity immediately adjacent to the leaf surface.

Gotoh (1997) studied the population of *T. urticae* in four different Japanese pear orchards in Ibaraki prefecture. He found the seasonal prevalence's of mite populations in the four pear orchards were similar, but their abundances varied greatly. He observed two types of seasonal population trends in *T. urticae*. In one pear orchard there was a population peak from September to early October, and in the other there were two peaks in July and September. In orchards, there was a population peak in July, a relatively large number of mites infesting the ground cover vegetation the proceeding spring, showing that the population peak originated from the mites that migrated from weeds to pear trees. Thereafter, mite densities remained at lower levels throughout summer, but a second peak in September was produced by the mites remaining on the pear leaves. In orchards where only one peak occurred in either September or early October, a few or no mites were found on pear leaves in spring through summer. Takafuji and Kamibayashi (1984) also reported the similar phenomenon in the population trend of *T. urticae* while studying the population in Okkayama, Japan.

Gotoh (1984) studied the annual life cycle of hawthorn spider mite, *T. viennensis* Zacher on deciduous oak in Sapporo and reported occurrence of this mite from early June to mid October. He found the peak in the month of August.

Gotoh (1986a) studied the annual life cycle of *T. urticae* on red currant plant, *Ribes rubrum* L. in Sapporo, Japan. The mite appeared on leaves in late April, and the occurrence ended between mid and late November, he reported.

He finally studied the population from 1982 to 1983 and found that the population remained higher from April to August and then decreased gradually.

Hare and Phillips (1992) reported the peak density of citrus red mite *Panonychus citri* (McGregor) on September in 1989 and October in 1990. Gotoh and Kubota (1997) studied the population dynamics of the citrus red mite, *P. citri* in Japanese pear orchards in 1993 and 1994. They observed the maximum density of the mite in late May 1993 and mid-June 1994 respectively.

Hill and Foster (1998) studied the population of European red mite *P. ulmi* (Koch) during 1994 and 1995 with treatment of different chemicals and oils. The authors found higher population of red mite in untreated plots in summer seasons. Besides these, many other workers have done extensive research on spider mites relating population fluctuation and these are Gotoh (1986b, 1987a,b,c,d, 1988a,b, 1989), Grafton-Cardwell *et al.* (1997), Kim *et al.* (1997), Stanyard *et al.* (1997, 1998), Walsh *et al.* (1997), Beers *et al.* (1998), Sclar *et al.* (1998).

In the present study the extensive survey was done from January to December 2002. Higher number was recorded in April and August. The preferred temperature for the rapid development of *T. urticae* is 25 to 27°C (Jeppson *et al.* 1975). In this study, the average temperature was between 25 to 27°C during April and August. After April, temperature increased rapidly during May. After August temperature decreased gradually to welcome winter. The population then decreased gradually in relation to temperature fall.

The intensive survey of TSSM on a single bean plant throughout a year reveals the higher population in April and May. In the month of July, the

population became comparatively lower. The heavy rainfall washed off the mite population from the leaves and decreased the number of TSSM. Jeppson *et al.* (1975) recorded the similar findings regarding the role of heavy rainfall on spider mite population.

This study also shows that the higher population of female was observed on young and mature leaves but relatively lower on old leaves. It might be due to the young and mature leaves are better for mite feeding, shelter and egg deposition.

The immature TSSM population was more or less same in all type of leaves. The larvae and nymphs were relatively less active and remained on the same leaves where they were developed. On the other hand the number was higher on young and mature leaves. Most females remained on leaves and deposited their eggs. The present observation reveals the higher proportion of immature stages on all three type of leaves.

Chapter 3

Efficiency of Predators on TSSM

CHAPTER 3

EFFICIENCY OF PREDATORS ON TSSM

Introduction

Phytoseiulus persimilis Athias-Henriot is an important predator of spider in various parts of the world (Battablia *et al.* 1990, Bonomo *et al.* 1991, Castagnoli and Simoni 1999, Cross 1984, Cross *et al.* 1996, McMurtry and Croft 1997, McMurtry *et al.* 1978, , Oatman *et al.* 1977, Osborne *et al.* 1985, Pickel *et al.* 1996, Sabelis 1981, Spicciarelli *et al.* 1992, Strong and Croft 1995, Roy *et al.* 1999, Trumble and Morse 1993). This predaceous mite was accidentally introduced in Germany from Chili in 1958 (Dosse 1958). From Germany, it was subsequently shipped to other parts of the world (McMurtry *et al.* 1978).

The smallest lady beetle *Stethorus punctillum* Weise is another active predator of TSSM. This predator is used for the suppressin of TSSM. Due to its high voracity on TSSM it is known as the mite destroyer. An adult can eat 75 – 100 mites per day (Raworth *et al.* 1998).

The six spotted thrips *Scolothrips sexmaculatus* Pergande is one of the predator of spider mite. The larva of this thrips is also active predator of mite. An adult *S. sexmaculatus* consumes 1000 – 3000 *T. urticae* during its lifetime (Hoodle 2004). In Bangladesh huge amount of chemicals have been used for management of various insect pests in different crops. It is necessary to use the alternatives of chemicals to minimize the pollution hazards. But unfortunately, the possibilities of using the biological agents in our country to control pests remained quite unexplored.

The present work was designed to find out the predation efficiency of *P. persimilis*, *S. punctillum* and *S. sexmaculatus* on *T. urticae* in laboratory condition.

Materials and Methods

TSSM Culture: TSSM was collected from naturally infested bean plants in Rajshahi City Corporation area. A mass culture of TSSM was maintained on potted bean plants in the laboratory, Institute of Biological Sciences, Rajshahi University for more than one year.

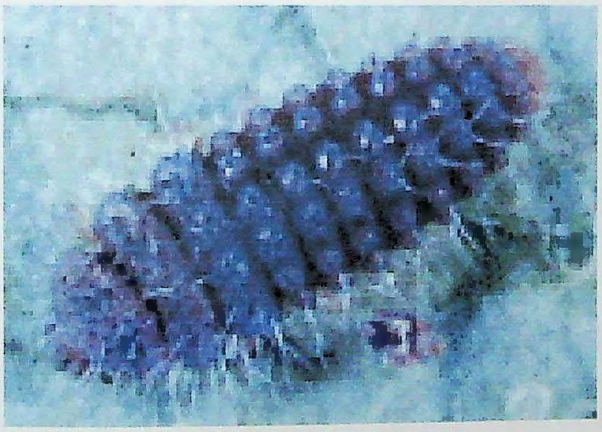
Predator Culture: The predators *P. persimilis*, *S. punctillum* and *S. sexmaculatus* were explored from bean plants in RCC area where they appeared naturally. They were collected and brought to the laboratory. Later they were studied and identified. Several pilot experiments were made with those predators to confirm their predation efficiency. After being confirmed of their predation on mites they were released on potted bean plants which were infested earlier by TSSM. The different predators were released on different bean plants. They were maintained for six months before testing their efficiency.

Predation test: The test for predation efficiency of the above mentioned three predators on different stages of TSSM were conducted in the following ways:

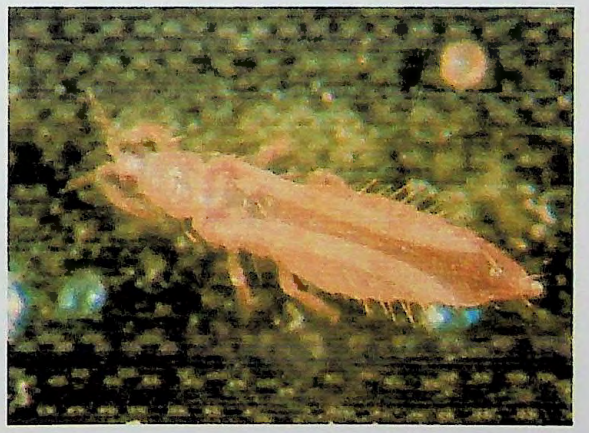
1. a. Adult female *P. persimilis* as predator on eggs of TSSM
   b. Adult female *P. persimilis* as predator on immature stages of TSSM
   c. Adult female *P. persimilis* as predator on adult TSSM
   d. Adult male *P. persimilis* as predator on eggs of TSSM
   e. Adult male *P. persimilis* as predator on immature stages of TSSM
   f. Adult male *P. persimilis* as predator on adult TSSM

Stethorus punctillum (adult)

Phytoseiulus persimilis (adult)



Stethorus punctillum (larva)



Scolothrips sexmaculatus (adult)

Plate Predators of *Tetranychus urticae*

2. a. Adult female *S. punctillum* as predator on eggs of TSSM
   b. Adult female *S. punctillum* as predator on immature stages of TSSM
   c. Adult female *S. punctillum* as predator on adult TSSM
   d. Larva of *S. punctillum* as predator on eggs of TSSM
   e. Larva of *S. punctillum* as predator on immature stages of TSSM
   f. Larva of *S. punctillum* as predator on adult TSSM

3. a. Adult female *S. sexmaculatus* as predator on eggs of TSSM
   b. Adult female *S. sexmaculatus* as predator on immature stages of TSSM
   c. Adult female *S. sexmaculatus* as predator on adult TSSM
   d. Larva of *S. sexmaculatus* as predator on eggs of TSSM
   e. Larva of *S. sexmaculatus* as predator on immature stages of TSSM
   f. Larva of *S. sexmaculatus* as predator on adult TSSM

The predation of each predator was conducted individually on an excised leaf disc ($2cm^2$). More than 200 preys were transferred on each leaf disc. Fifteen discs were prepared for each test. One predator was released per disc of 10 discs and the rest five was kept without predator as control. The discs were kept on water soaked cotton bed in a petri dish to maintain freshness. The discs were checked after 24 hours and the number of prey consumed by an individual predator was recorded. Six tests with one species of predator having 15 replications were conducted in a day.

Results

Daily consumption of *P. persimilis* is presented in Table 11. A female *P. persimilis* consumed 27.53 ± 1.16 eggs, 18.13 ± 1.51 immatures and 11.33 ± 0.82 adults *T. urticae*. A male comparatively consumed fewer preys than a female.

Daily consumption of *S. punctillum* is presented in Table 12. An adult female *S. punctillum* devoured 119.67 ± 15.12 eggs, 73.67 ± 13.58 immatures and 54.33 ± 3.00 adults *T. urticae* separately in 24 hours. The larvae of *S. punctillum* are also efficient voracious as the adults. A larva of *S. punctillum* consumed 114.33±17.19 eggs/day. It consumed 80.27±8.14 immatures but only 29.40±3.60 adults/day. The larva of *S. punctillum* is more or less equally efficient to feed eggs and immature stages of *T. urticae*. But its efficiency on adult prey is very lower in comparison to adult one.

Daily consumption of S. *sexmaculatus* is presented in Table 13. The adult female *S. sexmaculatus* consumed 58.80 ± 5.71 eggs, 38.47 ± 2.82 immatures and 15.60 ± 1.65 adults/day, when predated separately. The larvae of this predator are less voracious on TSSM than the adults. It consumed only 4.80 ± 1.00 eggs/day. The larva ate only 2.20 ± 0.28 immature stages of TSSM. *S. sexmaculatus* larva ate only 1.73 ± 0.30 adult TSSM in a day.

Table 11. Daily consumption of different stages of *T. urticae* by *P. persimilis.*

Predator	Female *P. persimilis*			Male *P. persimilis*		
TSSM	Egg	Immature	Adult	Egg	Immature	Adult
1	31	26	14	18	11	9
2	30	27	11	23	15	10
3	32	23	18	19	8	8
4	27	18	13	16	12	7
5	32	21	8	20	12	10
6	29	9	10	15	8	8
7	26	13	12	19	14	5
8	32	21	9	20	9	10
9	30	10	9	15	10	8
10	31	19	12	11	8	7
11	28	21	14	14	14	6
12	20	23	5	17	9	5
13	19	18	14	12	11	8
14	25	12	12	7	10	6
15	21	11	9	9	7	8
Mean	27.53	18.13	11.33	15.67	10.53	7.67
± SE	1.16	1.51	0.82	1.15	0.64	0.43

Table 12. Daily consumption of different stages of *T. urticae* by *S. punctillum*

Predator	Female *S. punctillum*			Larva of *S. punctillum*		
TSSM	Egg	Immature	Adult	Egg	Immature	Adult
1	167	20	50	51	134	15
2	148	71	53	47	125	13
3	169	86	44	58	13	22
4	59	143	63	107	75	17
5	86	82	74	116	77	39
6	98	49	36	205	113	25
7	23	34	61	129	82	41
8	45	37	74	195	49	31
9	212	24	49	25	73	53
10	107	98	57	138	104	16
11	81	50	50	31	48	14
12	134	36	34	53	72	49
13	84	62	58	173	87	47
14	176	92	61	191	93	37
15	206	221	51	196	59	22
Mean	119.67	73.67	54.33	114.33	80.27	29.40
±SE	15.12	13.58	3.00	17.19	8.14	3.60

Table 13. Daily consumption of different stages of *T. urticae* by *S. sexmaculatus*.

Predator	Female *S. sexmaculatus*			Larva of *S. sexmaculatus*		
TSSM	Egg	Immature	Adult	Egg	Immature	Adult
1	56	33	12	14	5	4
2	85	42	15	4	2	2
3	74	31	13	2	1	1
4	40	33	16	5	2	0
5	51	43	9	11	3	3
6	87	37	11	4	2	3
7	29	43	15	3	3	2
8	77	25	32	8	3	1
9	93	32	13	5	2	2
10	49	46	24	1	3	1
11	36	58	23	1	2	1
12	72	36	7	7	1	2
13	64	49	16	2	1	3
14	47	53	16	5	2	1
15	22	16	12	0	1	0
Mean	58.80	38.47	15.60	4.80	2.20	1.73
± SE	5.71	2.82	1.65	1.00	0.28	0.30

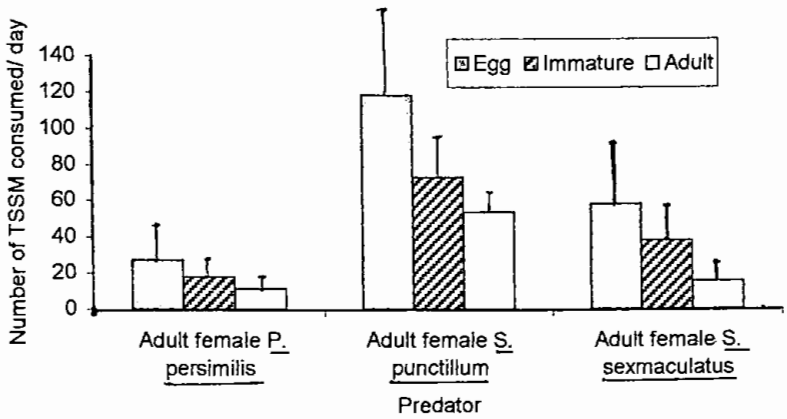


Figure 22. Predation efficiency of *P. persimilis, S. punctillum* and *S. sexmaculatus.*

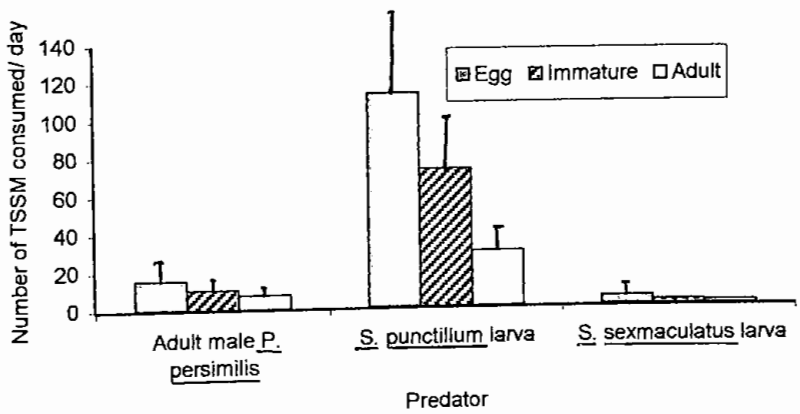


Figure 23. Predation efficiency of *P. persimilis, S. punctillum* and *S. sexmaculatus.*

Predation efficiency of female *P. persimilis*, female *S. punctillum* and female *S. sexmaculatus* are shown in Figure 22. The daily consumption of female *S. punctillum* is higher than others and that differ significantly ($P<0.001$). Predation of male *P. persimilis*, larva of *S. punctillum* and larva of *S. sexmaculatus* is shown in Figure 23. The larva of *S. punctillum* is also more efficient than others. The result of present research suggests that *S. punctillum* can effectively suppress the mite population.

Discussion

Research on the control of TSSM by phytoseiid predators has been done widely in various parts of the world. Grafton-Cardwell *et al.* (1997) observed the excellent control of *T. urticae* by phytoseiid predator. They found that the predators rapidly eliminated *T. urticae* eggs resulting the reduction of mite population. Port and Scopes (1981) showed that small number of *P. persimilis* could control TSSM on strawberries in walk in plastic tunnels in southern England. Cross (1984) showed that introductions of *P. persimilis* in March or early April at a rate of one mite per plant were consistently successful. Battablia *et al.* (1990) studied the biological control of TSSM by *P. persimilis* on strawberry in a greenhouse in Metropolitan area of Italy in 1988-1989.

Waite (1998) reported that *P. persimilis* gave effective control of the pest when it was released onto strawberry with low levels of TSSM infestation in south-east Queensland, Australia. Bonomo *et al.* (1991) also reported that releases of *P. persimilis* gave effective control of TSSM at lower density of TSSM. Spicciarelli *et al.* (1992) recommended that phytoseiid mites give good

control of TSSM, if one mite is released per plant when the infestation of TSSM has reached two individuals per leaf, and about 30% of the leaves are infested. Kim (2001) investigated the effectiveness of *P. persimilis* as a predator against TSSM on strawberry in five commercial greenhouses in Korea in 1999-2000 and got an excellent result by releasing the predator at a rate of $3/m^2$.

The present research was carried out to observe the efficiency of this predator on excised leaf discs. The findings of this test also agreed with the above results.

Raworth *et al.* (1998) obtained an excellent control of TSSM by releasing *S. punctillum* in tomato, pepper and cucumber greenhouse in Canada. He also reported that an adult beetle consumed 75 – 100 TSSM per day. The result of the present experiment is very much similar to the Raworth (1998). It also prevails that the beetle consumed more eggs and immatures than adult TSSM.

Shih (1999) reported that *S. sexmaculatus* primarily predated on TSSM eggs. The result of the present experiment shows the greater consumption of eggs than adult.

The comparison of predation efficiency of three predators shows that the lady bird beetle, *S. punctillum* is more predacious on TSSM than *P. persimilis* and *S. sexmaculatus*. The larvae and the adults of these beetles are equally efficient on predating TSSM.

Chapter 4

Control of TSSM by Chemicals

CHAPTER 4

CONTOL OF *T. URTICAE* BY CHEMICALS

Introduction

Development of resistance by *T. urticae* to numerous acaricides has caused difficulties in controlling outbreaks (Carbonaro *et al.* 1986). Some growers have attempted to use the predatory mite to control *T. urticae* populations. However, results from the release of phytoseiid mites are variable (Linquist 1981). When *T. urticae* density is too high, *P. persimilis* predation could not reduce *T. urticae* populations to acceptable levels (Helle and Sabelis 1985a, Herron *et al.* 1993). Acaricide applications are often necessary because of the demand for high quality ornamental crops and the inability of *P. persimilis* to reduce high-density populations of *T. urticae*.

Many new acaricides are now available in the market but they have a high cost associated with their use and associated application restrictions listed on the label to prevent the development of resistance. Treatment with acaricides that have long residual toxicity may be required to suppress high-density spider mite populations. However, use of acaricides with long residual periods may promote resistance in spider mite populations. Low-density populations may be suppressed with acaricides that have short residual toxicity.

In Bangladesh *T. urticae* is also an important pest of different vegetable crops including beans. But the research on this pest is still at infant stage. No works on the control of this pest either using chemicals or any other means has yet been done. The present investigation was, therefore, conducted to find out the effect of twelve (12) insecticides, three (3) fungicides and one (1) botanical pesticide in laboratory condition.

Materials and Methods

Chemicals

The acaricides/insecticides used on *T. urticae* were imidacloprid, dicofol, dimethoate, diazinon, chlorpyrifos, primiphosmethyl, malathion, carbaryl, carbosulfan, propoxur, cypermethrin, lambda-cyhalothrin, and azadirachtin. All these insecticides / acaricides are used to control various insect pests in Bangladesh and they were collected from the local market, distributed by ACI Crop Care, Syngenta, McDonald BD Ltd., Aventis and Auto Equipments Ltd.

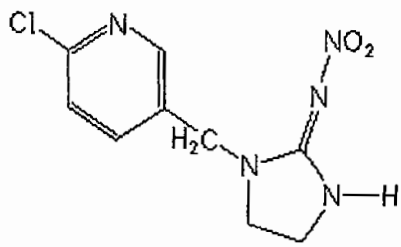
A brief description of these chemicals and the doses used for toxicological tests are given below:

Imidacloprid

Chemical formulae

Emperical formula: $C_9H_{10}ClN_5O_2$

Structural formula:



Chemical name: (IUPAC) 1-(6-chloro-3-pyridylmethyl)-N-nitroimidazolidin-2-ylideneamine; 1-[(6-chloro-3-pyridinyl) methyl]-N-nitro-2-imidazolidinimine (CA)

It is a systemic, chloro-nicotinyl insecticide with soil, seed and foliar uses for the control of sucking insects including rice hoppers, aphids, thrips, whiteflies, termites, turf insects, soil insects and some beetles. It is effective on contact and via stomach action (Kidd and James 1991).

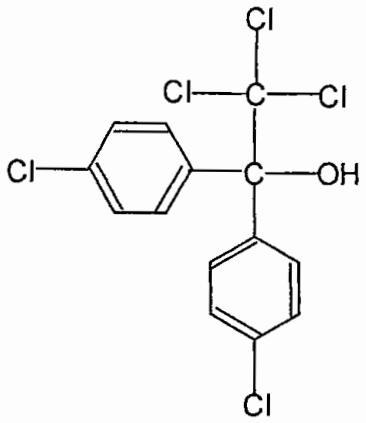
Imidacloprid was procured as Admire 200 SL of Crop Science, Germany. Four serial doses of 31.847, 15.924, 7.962 and 3.981 μg cm^{-2} in leaf disc method and 650.00, 325.00, 162.50 and 81.25 ng cm^{-2} in vial residue method was used.

Dicofol

Chemical formulae

Empirical formula: $C_{14}H_9OCl_5$ (370.5)

Structural formula:



Chemical name: (IUPAC): 2, 2, 2-trichloro-1, 1-bis (4 – chlorophenyl) ehanol. (C.A) 4 – chloro-α – dichloro- α- (trichloromethyl) benzhydrol (8Cl).

Its acaricidal properties is high and first introduced by Rohn and Haas Co. as Column FW – 293, trade mark Kelthane. Pure dicofol is a colourless solid; m.p. 78.5 – 79.5 °C. The technical grade is a brown viscous oil (c. 80% pure) d^{25} 1.45. Solubility: practically insoluble in water; soluble in most aliphatic and aromatic solvents. It is hydrolysed by alkali to 4.4′ – dichlorobenzophenone and chloroform, but is compatible with all but highly alkaline pesticides.

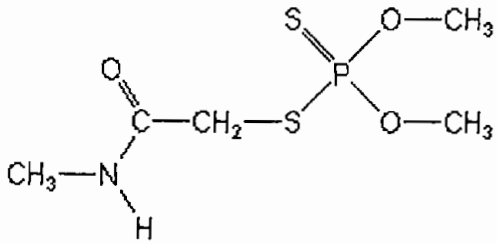
Dicofol was procured as Dicofol; 18.5 EC of Aco B V, Netherland. Four serial doses of 29.4586, 14.7293, 7.3645 and 3.6823 μg cm^{-2} in leaf disc method and 6.006, 3.003, 1.502 and 0.751 ng cm^{-2} in vial residue method was used.

Dimethoate

Chemical formulae

Emperical formula: $C_5H_{12}NO_3PS_2$

Structural formula:



Chemical name: (IUPAC) *O,O*-dimethyl *S*- methylcarbamoylmethyl phosphorodithioate; 2-dimethoxyphosphinothioylthio-*N*-methylacetamide (CA)

It is a colorless crystalline solid and soluble in water 5% at 70 degrees F (21 degrees C); 25 mg/ml. Soluble in methanol and cyclohexane. Slightly soluble in (Hill 1983, Worthing and Walker 1987)\ ketones. It should never be heated above 35 °C. (Meister 1992, OHS 1991, Cheminova 1991). Its boiling point is 5 mm Hg. Its melting point 45-48 °C; 124-126 °F (51-52°C). It is an insecticide used to kill mites and insects systemically and on contact.

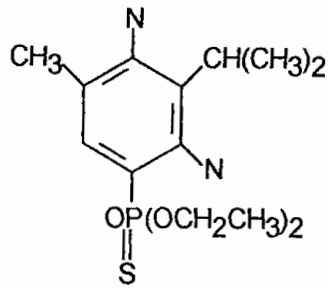
Dimethoate was procured as Tafgor 80 EC of Auto Equipment Limited. Four serial doses of 12.7389, 6.3694, 3.1847 and 1.5924 µg cm^{-2} in leaf disc method and 1300.00, 650.00, 325.00, and 162.50 ng cm^{-2} in vial residue method was used.

Diazinon

Chemical formulae

Empirical formula: $C_{12} H_{21} N_2 O_3 PS$ (304.3)

Structural formula:



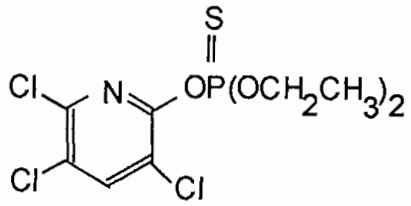
Chemical name: (IUPAC) O,O-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidin –4yl phosphorothioate; O,O-diethyl 0-(2-isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate (8Cl)

Pure diazinon is a clear colourless liquid and completely miscible in acetone, benzene, cyclohexane, dichloromethane, diethyl ether, ethanol, octan-1-01, and toluene. Its solubility in water at 20°C is 40 mg/l, boiling point 83-84°C at 0.0002 mmHg, vapour pressure 0.097 mpa at 20°C and density is 1.11 g/cu.cm. at 20°C. It is slowly hydrolyzed by water and dilute acids. It is a non-systemic insecticide with some acaricidal action. The commercial grade is 60% pure (Hill 1983, Worthing and Walker 1987).

Diazinon was procured as Diazinol EC of The Lemew Agroproducts Ltd. Four serial doses of 0.955414, 0.477107, 0.238854 and 0.119427 $\mu g\ cm^{-2}$ in leaf disc method and 97.40, 48.70, 24.35, and 12.18 $ng\ cm^{-2}$ in vial residue method was used.

Chlorpyrifos

Chemical formulae
Empirical formula: $C_9H_{11}Cl_3NO_3PS$ (350.6)
Structural formula:



Chemical name: (IUPAC) 0,0-diethyl-0-(3,5,6-trichloro-2-pyridyl)phosphorothioate (9Cl); 0,0-diethyl-0-(3,5,6-trichloro-2-pyridyl)phosphorothioate (8Cl)

Chlorpyrifos forms colourless crystals with a mild mercaptan odour; m.p. 42-43.5°C; v.p. 2.5 mPa (25°C). Solubility (25°C): 2 mg/l water; 6.5 kg/kg acetone; 7.9 kg/kg benzene; 6.3 kg/kg chloroform; 450 g/kg methanol. The rate of hydrolysis in water increases with pH, with temperature, the presence of copper and possibly of other metals that can form chalets. Under laboratory conditions, 50% hydrolysis takes from 1.5 d (water at pH8 and 25°C) to 100 d (phosphate buffer at pH 7 and 15°C). It is corrosive to copper and brass.

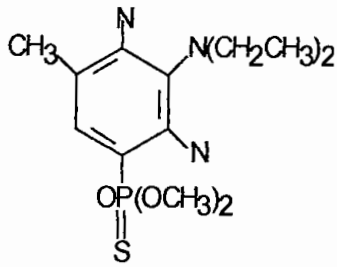
Chlorpyrifos was procured as Classic 20 EC of Lupin Agrochemicals. Four doses of 6.3694, 3.1847, 1.58924 and 0.7962 μg cm^{-2} in leaf disc method and 324.70, 162.30, 81.20 and 40.60 ng cm^{-2} in vial residue method was used.

Pirimiphosmethyl

Chemical formulae

Empirical formula: $C_{11} H_{20} N_3 O_3 PS$ (305.3)

Structural formula:



Chemical name: (IUPAC) *O*-2-diethylamino-6-methylpyrimidin-4-yl *O,O*-dimethyl phosphorothioate

It is straw-coloured liquid and miscible with most organic solvents. Its solubility in water at 30°C is 5 mg/l and very soluble in most organic solvents, vapour pressure 13 mpa at 30°C. It is a slight systemic insecticide and acaricide with both contact and fumigant action. It is hydrolysed by concentrated acid. The commercial product is 50% pure (Hill 1983, Worthing and Walker 1987).

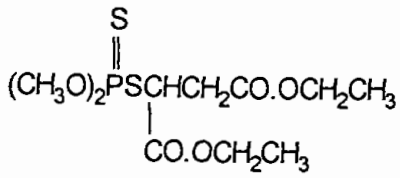
Primiphosmethyl was procured as Actellic 50 EC of Zeneca Agrochemicals, U K. Four serial doses of 0.79618, 0.39809, 0.19904 and 0.09952 $\mu g\ cm^{-2}$ in leaf disc method and 250.00, 125.00, 62.50 and 31.25 ng cm^{-2} in vial residue method was used.

Malathion

Chemical formulae

Empirical formula: $C_{10}H_{19}O_6PS_2$ (330.3)

Structural formula:



Chemical name: (IUPAC) diethyl (dimethoxyphosphinothioylthio) succinate; *S*-1,2-bis(ethoxycarbonyl)ethyl *O,O*-dimethyl phosphorodithioate

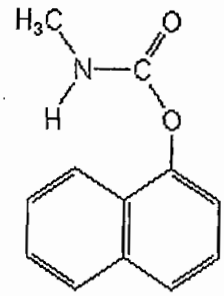
It is a clear colourless or pale brown liquid and miscible with most organic solvents. Its solubility in water at room temperature is 145 mg/l, boiling point 156-157°C at 0.7 mm Hg, melting point is 2.85°C and vapour pressure 4×10^{-5} at 30°C. It is a nonsystemic insecticide with moderate persistence. The commercial product is 57% pure, and technical product is 95% pure (Hill 1983, Worthing and Walker 1987). Technical grade malathion (*c.* 95% pure) is a clear amber liquid m.p. 2.85°C; b.p. 156 - 157°C/ 0.7 mm Hg; v.p.5.3 mPa (30°C).

Malathion was procured as Limithion 57 EC by Cheminova, Denmark. Four serial doses of 0.9076, 0.4535, 0.2267 and 0.1134 µg cm^{-2} in leaf disc method and 185.00, 92.50, 46.25 and 23.13 ng cm^{-2} in vial residue method was used.

Carbaryl

Chemical formulae

Empirical formula : $C_{12}H_{11}NO_2$
Structural formula:



Chemical name: (IUPAC) 1-naphthyl N-methylcarbamate

The crystals are odorless. This chemical is stable to heat, light and acids under storage conditions. It is a wide-spectrum carbamate insecticide which controls over 100 species of insects on citrus, fruit, cotton, forests, lawns, nuts, ornamentals, shade trees, and other crops, as well as on poultry, livestock and pets. It is also used as a molluscicide and an acaricide colorless to white to gray, depending on the purity of the compound. The crystals are odorless. This chemical is stable to heat, light and acids under storage conditions. It is moderately to very toxic. It can produce adverse effects in humans by skin contact, inhalation or ingestion.

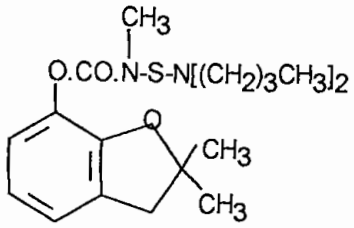
Carbaryl was procured as Sevin 85 SP of P T Bayer Indonesia, T B K. The doses were 67.675, 33.838, 16.919 and 8.459 μg cm^{-2} in leaf disc method and 21240, 10620, 5310, and 2665 ng cm^{-2} in vial residue method.

Carbosulfan

Chemical formulae

Empirical formula: $C_{20}H_{32}N_2O_3S$ (380.5)

Structural formula:



Chemical name: (IUPAC) 2,2-Dihydro-2,2-dimethyl-7-benzofuranyl (dibutylamino) thio) methylcarbamate; 2,3-dihydro-2,2-dimethylbenzofuran 7-yl (dibutylaminothio) methylcarbamate

It is a brown viscous liquid; v.p. 0.041 mPa. Solubility (25°C): 0.03 mg/l. Soil applications of the systemic insecticide carbosulfan control soil-dwelling insects (millipedes, Symphyla) and foliar pests (aphids, *Leptinotarsa decemlineata*) on maize, potatoes and sugar beet.

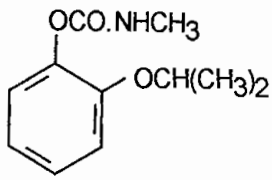
Carbosulfan was procured as Marshal 20 EC of Agriculture Chemical group, F M C Corporation, U S A. Limited. Four serial doses were 6.369, 3.185, 1.523 and 0.796 μg cm^{-2} in leaf disc method and 649.00, 324.50, 162.25 and 81.13 ng cm^{-2} in vial residue method.

Propoxur

Chemical formulae

Empirical formula: $C_{11}H_{15}NO_3$ (209.2)

Structural formula:



Chemical name: (IUPAC) 2-isopropoxyphenyl methylcarbamate

It is a colourless crystalline powder and soluble in most organic solvents. Its melting point is 84-87°C; vapour pressure is 1.3 Pascal at 120°C and slightly soluble in water at 20°C is 2 g/l. Unstable in highly alkaline media. It is a non-systemic insecticide with rapid knock-down, effective against ants, aphids, bugs, cockroaches, flies, jassids, millipeds, mosquitoes and other household pests (Hill 1983).

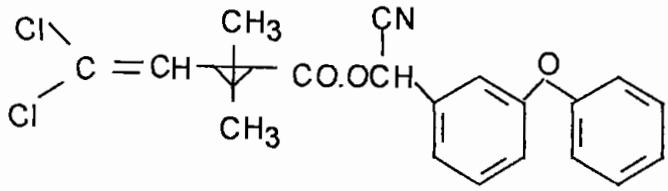
Propoxur was procured as Achokro 20 EC of Sundat (S) Pvt. Ltd., Singapore. Four serial doses of 3.1847, 1.5924, 0.7962 and 0.3981 μg cm^{-2} in leaf disc method and 6500, 3250, 1630 and 815 ng cm^{-2} in vial residue method was used.

Cypermethrin

Chemical formulae

Empirical formula: $C_{12}H_{19}CL_2NO_3$ (416.3)

Structural formula:



Chemical name: (IUPAC) (RS)-α-cyano-3-phenoxybenzyl (1RS, 3RS; 1RS, 3SR)-3-(2,2- dichlorovinyl) –2, 2 - = dimethyl cyclopropanecarboxylate

Cypermethrin was launched as a commercial insecticide in 1977. The majority of commercial cypermethrin formulation contain 100g/l of active ingredient. They are marketed by a number of agrochemical companies e.g., Ripcord (Shell). Ambush (ICI), Cymbush (ACI) and are compatible with a variety of other insecticide in tank mixes.

The technical grade is a viscous yellowish-brown semi-solid mass, which is liquid at 60°C. The pure compound has vapour pressure 190 npa at 20°C. Its solubility in water at 21°C is 0.01-0.2 mg/l; at 20°C;> 450 g/l acetone, chloroform, cyclohexanone, xylene; 337 g/l ethanol, 103 g/l hexane, cypermethrin is a stomach and contact insecticide Effective on a wide range of insect pest. The commercial product is 10% pure (Hill 1983).

Cypermethrin was procured as Cythrin 10 EC of Chimac Agri Pharma, Belzium. Four serial doses of 0.79617, 0.39808, 0.19904 and 0.09952 μg cm^{-2} in leaf disc method and 162.30, 81.15, 40.63, and 20.32 $ngcm^{-2}$ in vial residue method was used.

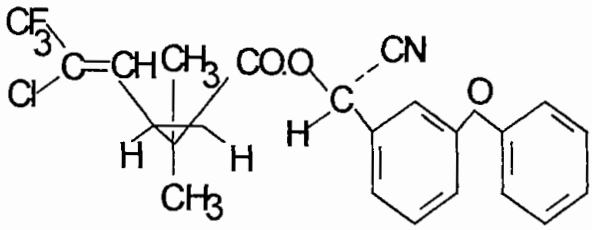
Lambda-cyhalothrin

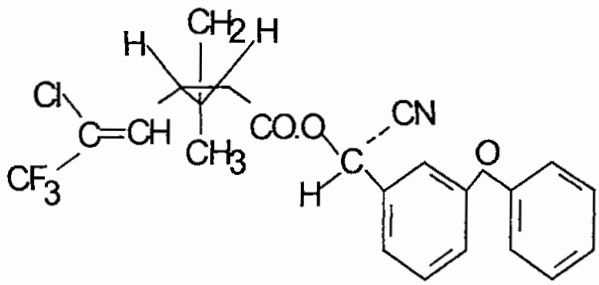
Chemical formulae

Empirical formula: $C_{23}H_{19}CLF_3NO_3$ (449.9)

Structural formula:

(Z)-(1R)-cis-





(Z)-(1S)-cis-

Chemical name: (IUPAC) (R+S)-alpha-Cyano-3-phenoxybenzyl (1S+1R)-cis-3-(Z-2-chloro-3,3,3-trifluoroprop-1-enyl)-2,2-dimethylcyclopropanecarboxylate

It is a colourless solid, solubility in purified water is 0.005 mg/l (ph 6.5) and buffered water is 0.004 mg/l (PA, 5.0 at 20°C. Again it is soluble in a range

of organic solvents stable >0.5 years on storage at 15-25°C. It is stable to light. Its melting point is 49.2°C; vapour pressure 200 npa at 20°C. It is a most effective insecticide against insect. The commercial grade is 2.5% pure (Hill 1983, Worthing and Walker 1987).

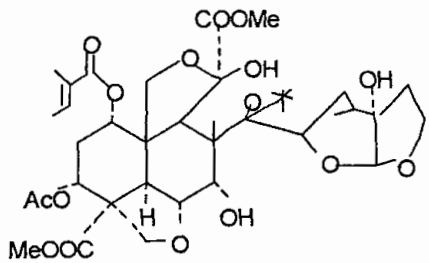
Lambda-cyhalothrin was procured as Karate of Syngenta Ltd. U K. Four serial doses were, 0.003105, 0.005500, 0.000776 and 0.000388 μg cm^{-2} in leaf disc method and 1.234, 0.617, 0.308 and 0.154 ng cm^{-2} in vial residue method.

Azadirachtin

Chemical formulae

Empirical formula: $C_{35}H_{44}O_{16}$

Structural formula:



Azadirachtin

Azadirachtin is structurally similar to insect hormones called "ecdysones", which control the process of metamorphosis as the insects pass from larva to pupa to adult. It affects the corpus cardiacum, an organ similar to the human pituitary, which controls the secretion of hormones. Metamorphosis requires the careful synchrony of many hormones and other physiological changes to be successful and azadirachtin seems to be an "ecdysone blocker". It blocks the insects production and release of these vital hormones. Insects then

will not moult, this of course breaks their life cycle (Nakanishi 1975, Kubo and Klocke 1982, Rembold *et al.* 1982).

Azadirachtin was procured as Nimbicidine 0.03 EC of ACI Crop Care. In the present study the four doses were 191.084, 95.552, 47.771 and 23.886 µg cm^{-2} in leaf disc method and 1168.80, 584.40, 292.20 and 146.10 ng cm^{-2} in vial residue method.

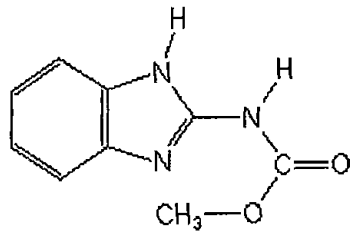
Three fungicides- carbendazim, mancozeb and sulphur were used in laboratory against *T. urticae*. A brief description of them are as:

Carbendazim

Chemical formulae

Empirical formula: $C_9H_9N_3O_2$

Structural formula :



Chemical name: (IUPAC) methyl benzimidazol – 2-yl carbamate

It is a systemic benzimidazole fungicide that plays a very important role in plant disease control (Quian 1996). It was first reported in 1973 and was developed by BASF, Hoeschst (now part of Bayer) and Dupont. It is used to control a broad range of diseases on arable crops (cereals, oilseed rape), fruits, vegetables and ornamentals (Hicks 1998).

Carbendazim was procured as Aimcozim 50 WP of Amco Pesticide Ltd., India. Four serial doses of 0.19745, 0.09873, 0.04936 and 0.02468 μg cm^{-2} in leaf disc method and 0.1250, 0.0625, 0.0313 and 0.0156 μg cm^{-2} in vial residue method were used.

Mancozeb

Chemical formulae

Empirical formula : (C4H6MnN2S4)x (Zn)y

Structural formula : $[- SCS.NHCH_2CH_2NHCS.S.Mn-]_x (Zn)_y$

Chemical name: manganese ethylenebis (dithiocarbamate) polymeric complex with zinc salt.

It molecular weight: (265.3) + (65.4). Its melting point: 192 - 194°C. It is soluble in water as 6 mg/L at 25°C and in ethanol : < 5 mg/L. (Kidd and James 1991). It hydrolyzes rapidly over a range of pHs; hydrolysis half-lives of 14C-Dithane at pH 5, 7 and 9 ranged from 1-1.5 days at 250C under sterile and dark conditions

It is a member of ethylenebisdiothiocarbamate (EBDC) fungicides. It has a negligible vapor pressure, therefore it has a low potential to volatilize into the air. In water, mancozeb can be quickly hydrolyzed with a half-life of less than 2 days. The identified hydrolysis degradates are ethylenethiourea (ETU), ethyleneurea (EU) and ethylene bisisothiocyanate sulfide (EBIS). Mancozeb is of low soil persistence with half-lives of less than 2 and 8 days in aerobic and anaerobic soils, respectively. The major metabolites are ETU and EU. Under aerobic conditions, the metabolites breakdown further to produce CO_2.

Mancozeb and its degradates moderately bind to soils with adsorption coefficient values (Kd) varied from 7 to 12 cm3/g.

Mancozeb was procured as Nemispore 80 WP of Isagro, Italy. Four serial doses of 12.74, 6.37, 3.18 and 1.59 μg cm^{-2} in leaf disc method and 0.08, 0.04, 0.02 and 0.01 μg cm^{-2} was used in vial residue method.

Sulphur

Chemical name : (IUPAC) sulphur (E-ISO); soufre (F-ISO); sulfur (II) ESA, JMAF)

It is a yellow solid and can exist as various allotropic forms. Rhombic sulphur is stable at normal temperatures but forms other allotropes on heating to between 94-119°C, the observed melting point depending on the rate of heating and extent of conversion. Rhombic sulphur has d 2.06; v.p. 0.527 mPa (30.4 °C). Solubility: Practically insoluble in water; the crystalline forms are soluble in carbon disulphide whereas the amorphous are not. It is incompatible with petroleum oils (Hill 1983, Worthing and Walker 1987).

Sulphur is the only ingredient in the mix that is toxic to pathogens. It is able to kill pathogens through direct contact or fumigation. The vapor action of sulphur allows the fungicide to be effective from a distance and is important in killing spores of powdery mildew.

Sulphur was procured as McSulfur 85 WP of Aco, B V, Netherland. Four serial doses of 4.2465, 2.1235, 1.0618 and 0.5309 μg cm^{-2} in leaf disc method and 0.67, 0.33, 0.17 and 0.08 μg cm^{-2} in vial residue method were used.

Toxicity test

Leaf disc method

This method is based on the surface film technique of Busvine (1971). For this purpose 2 cm diameter leaf discs were made from fresh bean leaf (Plate 6). The discs were checked under microscope to have no mites or any other insects. During preparation of the leaf discs it was kept in mind that the discs did not contain major veins to have the homogeneity of leaf surface. Then the discs were placed in petri dish having a water soaked cotton bed.

The insecticides/fungicides were serially diluted with acetone and a fixed volume (0.1ml) of insecticide solution was dropped on each leaf disc. Leaf discs were allowed to dry for five minutes at room temperature. Fifteen to thirty female adult TSSM were transferred to each disc with the help of a fine brush. Before actual experiment a set of ad-hoc experiments were done to find out the dose ranges between 10 – 90% mortality of the mites. The doses were calculated by having the actual quantity of insecticide / fungicide in 0.1ml of solution divided by the surface area of leaf disc. A separate control batch was maintained in which only acetone was dropped on leaf discs.

Vial residue method

Susceptibility of TSSM to the insecticides / fungicides was also evaluated by a vial residue method based on (Plate 7) Bynum *et al.* (1990). Glass vials (5ml) were used for this purpose. An appropriate concentration of

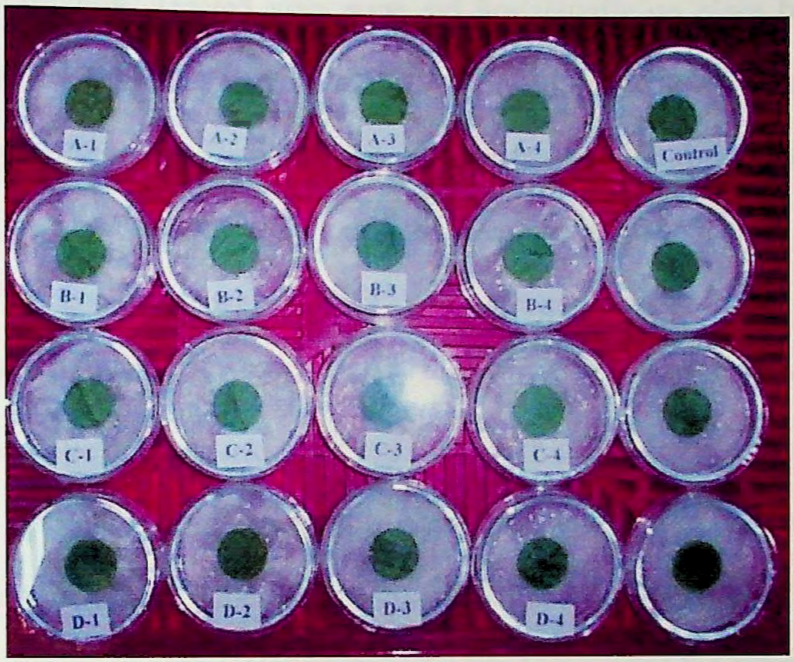


Plate 6. Toxicity test in leaf disc method.

Plate 7. Toxicity test in vial residue method.

each insecticide was dissolved in acetone. Each vial was coated with 0.1ml of insecticide solution. Treated vials were set horizontally on plain board then were rolled for 4 minutes to ensure uniform coverage of the inside surface as the acetone evaporated. The vials were then placed upright for an additional 2 minutes to permit further evaporation of acetone before capping. For each bioassay, four replicates with at least four concentrations of insecticide were tested. Vials treated only with acetone were used as controls. Twenty adult female TSSM were transferred into each vial with a fine brush and vials were then sealed with parafilm. Before actual experiment a set of ad-hoc experiments were also done to find out the dose ranges between 10 – 90% mortality of the mites. The doses were calculated by having the actual quantity of insecticide / fungicide in 0.10ml of solution divided by the inside surface area of the vial.

Mortality analysis

Mortality was assessed under a stereo binoculor Microscope after 24 hours. Mites were scored dead if they failed to make active movement after light tapping on the vials. Corrected mortality percentage was calculated using Abbott's formula (Abbott 1925).

$$Pt = \frac{Po - Pc}{100 - Pc} \times 100$$

where, Pt = corrected mortality percentage

Po = observed mortality percentage and

Pc = control mortality percentage

Probit regressions were estimated from mortality data according to the probit analysis of Finney (1947) and Busvine (1971) using a software developed in the Department of Agricultural and Environmental Science, University of Newcastle Upon Tyne, UK. The regression lines were fitted by MS Excel.

Results

The LC_{50} values for imidacloprid, dicofol, dimethoate, diazinon, chlorpyrifos, primiphosmethyl, malathion, carbaryl, carbosulfan, propoxur, cypermethrin, lambda-cyhalothrin, and azadirechtin on *T. urticae* along with 95% confidence limits are presented in Tables 14 and 15. The LC_{50} values for imidacloprid, dicofol, dimethoate, diazinon, chlorpyrifos, primiphosmethyl, malathion, carbaryl, carbosulfan, propoxur, cypermethrin, lambda-cyhalothrin and azadirechtin are 9.104343, 5.687062, 3.487464, 0.543986, 2.281443, 0.127215, 0.374751, 16.18107, 1.337664, 1.729300, 0.116357, 0.000704 and 25.38940 $\mu g\ cm^{-2}$ (Table 14) respectively in leaf disc method. But the LC_{50}

values for these chemicals in vial residue method are 126.032, 1.093905 128.062, 15.743, 104.076, 94.734, 30.712, 4452.00, 28.875, 974.613, 11.708, 0.1907 and 1471.266 ng cm^{-2} (Table 15). The regression equation for these chemicals were calculated and shown in Tables 14 and 15. The regression lines are fitted with logdose and probit mortality and are shown in Figures 24-49. Chi square (χ^2) values calculated at 2 degrees of freedom for these chemicals indicated that there were no heterogeneity on the tested population except imidacloprid, malathion and lambda-cyhalothrin in vial residue method. Among 13 tested chemicals the LC_{50} value for lambda-cyhalothrin was the minimum in both the method applied. The order toxicity of the used chemicals in leaf disc method is lambda-cyhalothrin > dicofol cypermethrin > primiphosmethyl > malathion > diazinon > carbosulfan> propoxur> chlorpyrifos > dimethoate ~~dicofol~~> imidacloprid> carbaryl> azadirechtin. In vial residue method the same was lambda-cyhalothrin > cypermethrin > diazinon > carbosulfan > malathion > primiphosmethyl > chlorpyrifos > imidacloprid > dimethoate > propoxur > dicofol > azadirechtin > carbaryl. It is obvious from the results that the lambda-cyhalothrin is the most effective against *T. urticae*.

Table-14. Dose mortality effect of different chemicals against *T. urticae* after 24 hours of exposure in leaf disc method.

Chemicals	LC_{50} value ($\mu g\ cm^{-2}$)	95% confidence limits ($\mu g\ cm^{-2}$)	Regression equation	Chi-square (at 2 df)
Imidacloprid	9.104343	6.504291 - 12.743744	Y = 3.974605 + 1.069478X	1.7835
Dicofol	5.687062	3.027731 - 10.682121	Y = 4.480243 + 0.688523X	0.4026
Dimethoate	3.487464	2.617232 - 4.647042	Y = 4.068519 + 1.716986X	0.2598
Diazinon	0.543986	0.249362 - 1.186712	Y = 3.975827 + 1.393678X	2.4836
Chlorpyrifos	2.281443	1.683614 - 3.09125	Y = 2.898033 + 1.547602X	2.8722
Primiphosmethyl	0.127215	0.090861 - 0.178114	Y = 3.399364 + 1.449143X	1.4699
Malathion	0.374751	0.273333 - 0.513642	Y = 4.439056 + 0.977793X	2.3198
Carbaryl	16.18107	12.85233 - 20.37194	Y = 3.030454+ 1.629061X	0.1361
Carbosulfan	1.337664	1.015365 - 1.762229	Y = 2.716185 + 2.027639X	0.6508
Propoxur	1.729300	1.307200 - .287200	Y = 2.776136 + 1.764658X	1.5682
Cypermethrin	0.116357	0.087481 - 0.196932	Y = 3.601400 + 1.312260X	2.6984
Lambda-cyhalothrin	0.000704	0.0975 - 0.3728	Y = 4.572324 + 0.504432X	1.9718
Azadirechtin	25.38940	14.94180 - 43.14210	Y = 4.856075 + 1.388925X	0.3448

Table-15. Dose mortality effect of different chemicals against *T. urticae* after 24 hours of exposure in vial residue method.

Chemicals	LC_{50} value (ng cm^{-2})	95% confidence limits (ng cm^{-2})	Regression equation	Chi-square (at 2 df)
Imidacloprid	126.032	65.324 -- 243.135	Y = 3.917007 + 0.984124X	7.2814
Dicofol	1092.905	0.947.621 -- 1596.92	Y = 3.366979 + 1.498222X	1.1981
Dimethoate	128.062	77.712 -- 210.734	Y = 4.863547 + 1.270278X	0.3865
Diazinon	15.743	11.198 -- 22.131	Y = 3.377050 + 1.258116X	0.0585
Chlorpyrifos	104.076	83.009 -- 130.489	Y = 0.609603 + 2.176310X	0.3034
Primiphosmethyl	94.734	77.083 -- 116.451	Y = 3.040239 + 2.007091X	0.9481
Malathion	30.712	17.852 -- 52.834	Y = 3.475603 + 1.025606X	7.1449
Carbaryl	4452.00	3695.8 - 5362.7	Y = 3.671055+ 2.049074X	0.7286
Carbosulfan	28.875	4.567 -- 182.556	Y = 3.929831 + 0.733106X	0.0634
Propoxur	974.613	684.481 -- 1387.714	Y = 3.568524 + 1.448644X	2.4111
Cypermethrin	11.708	4.859 -- 28.211	Y = 3.656969 + 1.255692X	0.0947
Lambda-cyhalothrin	0.1907	0.0975 -- 0.3728	Y = 4.606172 + 1.405001X	12.1067
Azadirechtin	1471.266	654.69 -- 3306.31	Y = 2.939933 + 1.218890X	2.4729

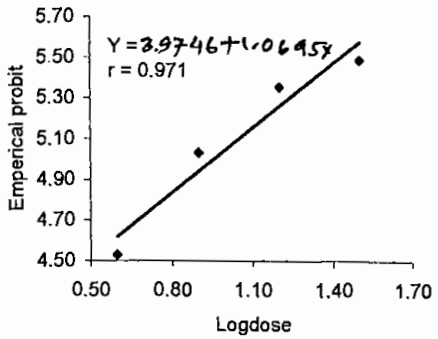


Figure 24. Regression line of probit mortality on logdose of imidacloprid applied on *T. urticae.*

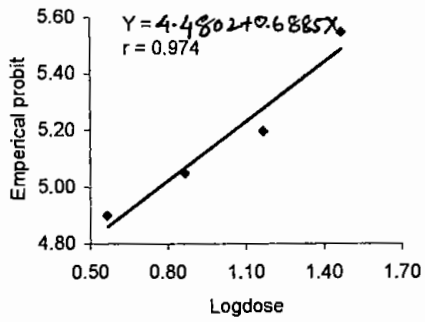


Figure 25. Regression line of probit mortality on logdose of dicofol applied on *T. urticae.*

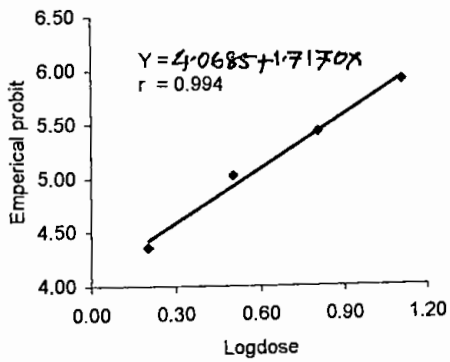


Figure 26. Regression line of probit mortality on logdose of dimethoate applied on *T. urticae.*

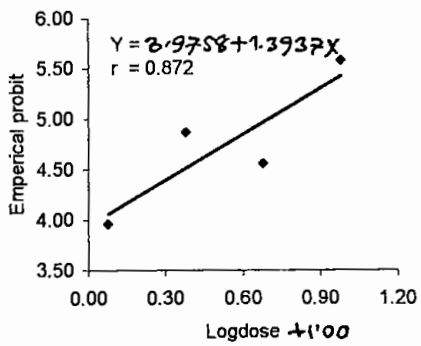


Figure 27. Regression line of probit mortality on logdose of diazinon applied on *T. urticae.*

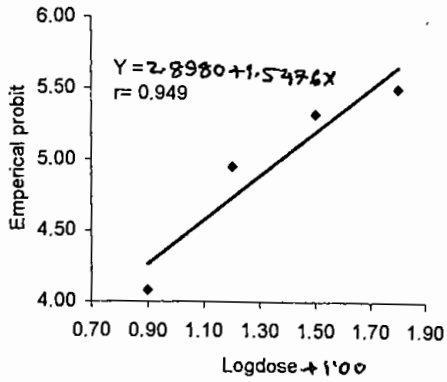


Figure 28. Regression line of probit mortality on logdose of chlorpyriphos applied on *T. urticae.*

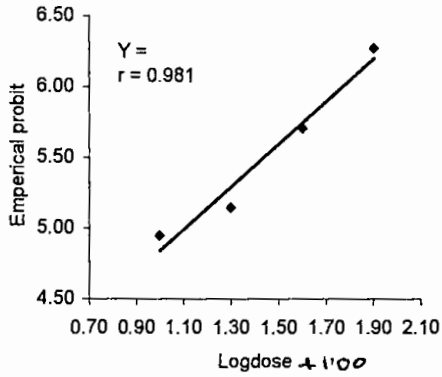


Figure 29. Regression line of probit mortality on logdose of primiphosmethyl applied on *T. urticae.*

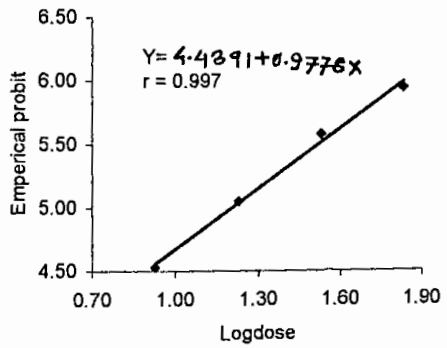


Figure 30. Regression line of probit mortality on logdose of carbaryl applied on *T. urticae.*

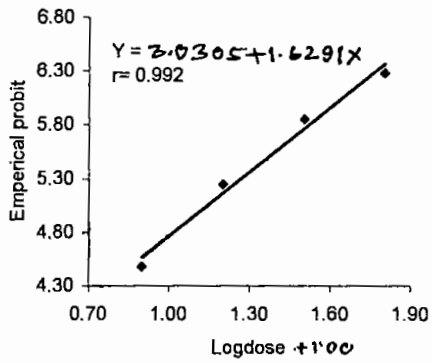


Figure 31. Regression line of probit mortality on logdose of carbosulfan applied on *T. urticae.*

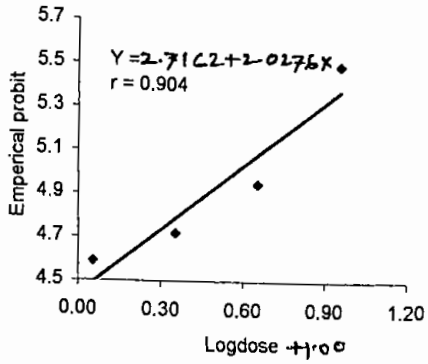


Figure 32. Regression line of probit mortality on logdose of malathion applied on *T. urticae.*

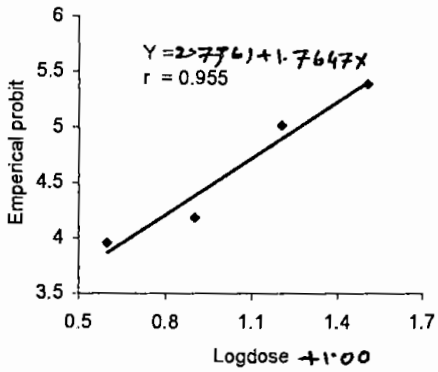


Figure 33. Regression line of probit mortality on logdose of propoxur applied on *T. urticae.*

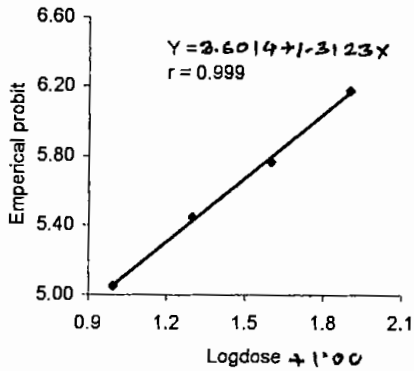


Figure 34. Regression line of probit mortality on logdose of cypermethrin applied on *T. urticae.*

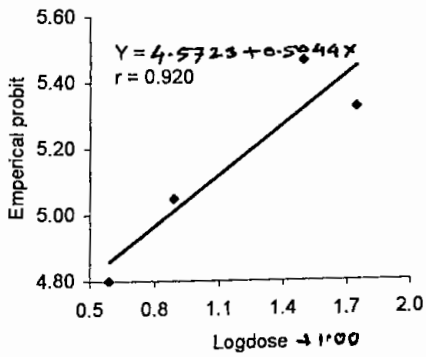


Figure 35. Regression line of probit mortality on logdose of lambda-cyhalothrin applied on *T. urticae.*

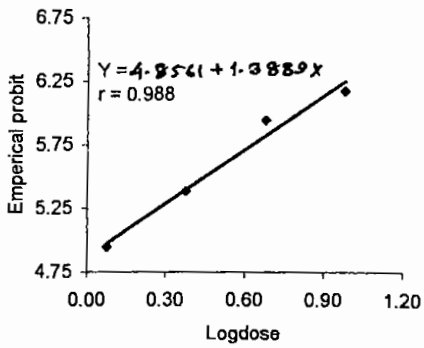


Figure 36. Regression line of probit mortality on logdose of azadirechtin applied on *T. urticae.*

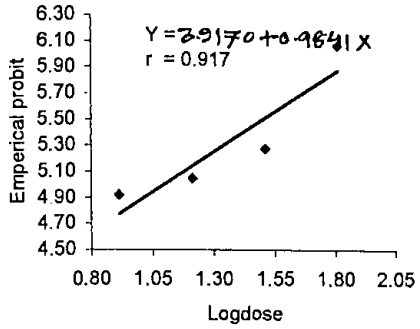


Figure 37. Regression line of probit mortality on logdose of imidacloprid applied on *T. urticae.*

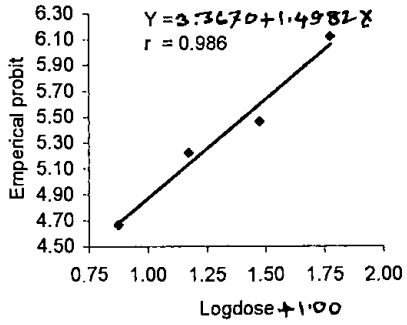


Figure 38. Regression line of probit mortality on logdose of dicofolo applied on *T. urticae.*

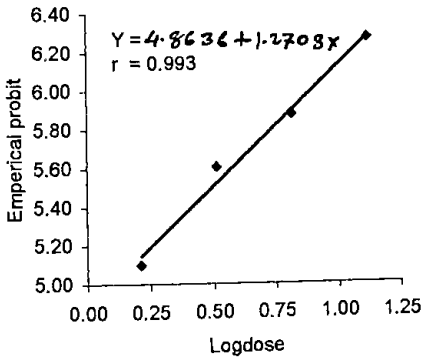


Figure 39. Regression line of probit mortality on logdose of dimethoate applied on *T. urticae.*

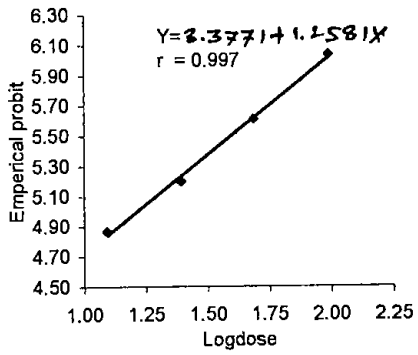


Figure 40. Regression line of probit mortality on logdose of diazinon applied on *T. urticae.*

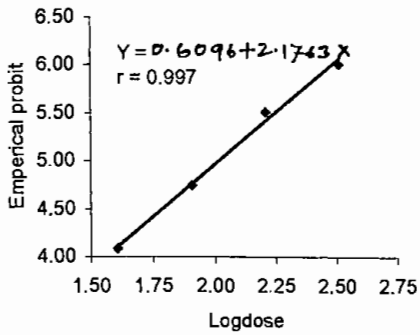


Figure 41. Regression line of probit mortality on logdose of chlorpyrifos applied on *T. urticae.*

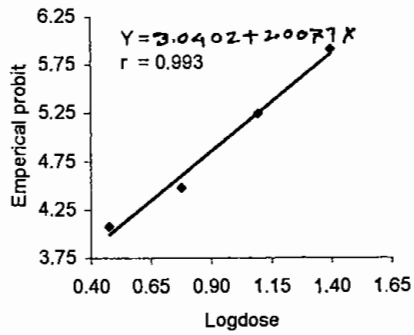


Figure 42. Regression line of probit mortality on logdose of primiphosmethyl applied on *T. urticae.*

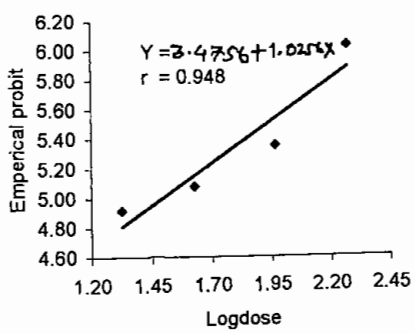


Figure 43. Regression line of probit mortality on logdose of malathion applied on *T. urticae.*

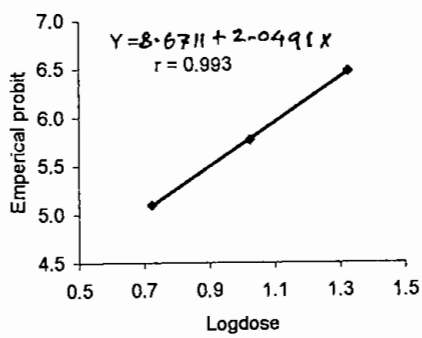


Figure 44. Regression line of probit mortality on logdose of carbaryl applied on *T. urticae.*

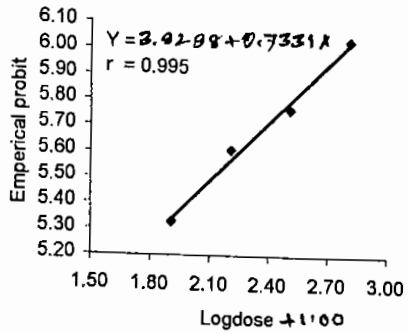


Figure 45. Regression line of probit mortality on logdose of carbosulfan applied on *T. urticae.*

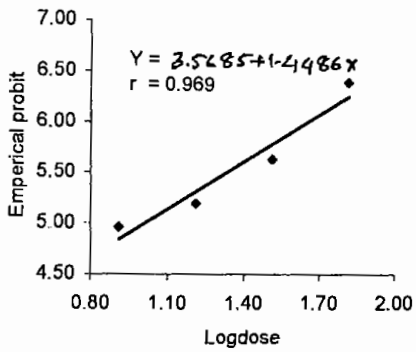


Figure 46. Regression line of probit mortality on logdose of propxur applied on *T. urticae.*

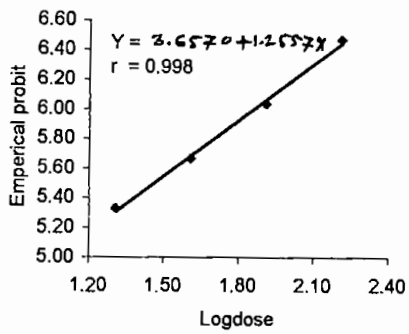


Figure 47. Regression line of probit mortality on logdose of cypermethrin applied on *T. urticae.*

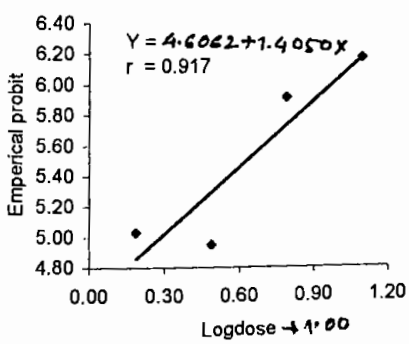


Figure 48. Regression line of probit mortality on logdose of lambda-cuhalothrin applied on *T. urticae.*

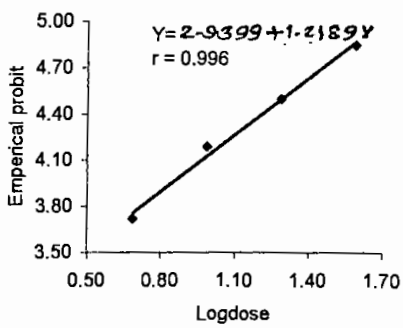


Figure 49. Regression line of probit mortality on logdose of azadirechtin applied on *T. urticae.*

The LC_{50} values for three fungicides viz. carbendazim, mancozeb and sulphur on *T. urticae* along with 95% confidence limits are presented in Table 16. The LC_{50} values of carbendazim, mancozeb and sulphur are 0.228532, 3.054463 and 1.398292 μg cm^{-2} respectively (Table 16) in leaf disc and 0.02741, 0.02209 and 0.15623 μg cm^{-2} respectively in vial residue method. The regression lines are fitted with logdose and probit mortality and are shown in Figures 50-55. Chi square (χ^2) values calculated at 2 degrees of freedom for these chemicals indicated that there was no heterogeneity on the tested population.

Among three tested fungicides the LC_{50} value for carbendazim was the lowest in the leaf disc method but that of mancozeb was the lowest in the vial residue method. The order of toxicity of the used chemicals in leaf disc method is carbendazim> sulphur> mancozeb. In the vial residue method the order of toxicity is found as mancozeb> carbendazim > sulphur.

Table-16. Dose mortality effect of different fungicides against *T. urticae* after 24 hours of exposure.

Test Method	Chemicals	LC_{50} value (μg cm^{-2})	95% confidence limits (μg cm^{-2})	Regression equation	Chi-square (2 df)
Leaf disc	Carbendazim	0.228532	0.11473 - 0.4551	Y = 3.785867 + 0.893476X	0.6464
	Mancozeb	3.054463	2.3323 - 4.0001	Y = 4.204741 + 1.639932X	4.7656
	Sulphur	1.398292	0.8565 - 2.2826	Y = 4.278414 + 0.629876X	0.4708
Vial residue	Carbendazim	0.02741	0.0203 - 0.0368	Y = 4.016109 + 2.246485X	7.0004
	Mancozeb	0.02209	0.0187 - 0.0259	Y = 4.514781 + 1.410987X	0.2467
	Sulphur	0.15623	0.0185 - 0.3397	Y = 3.668988 + 1.114981X	5.3678

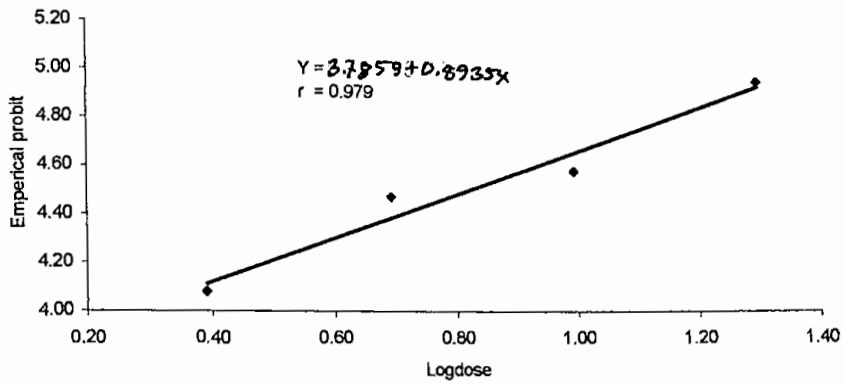


Figure 50. Regression line of probit mortality on logdose of carbendazim applied on *T. urticae* .

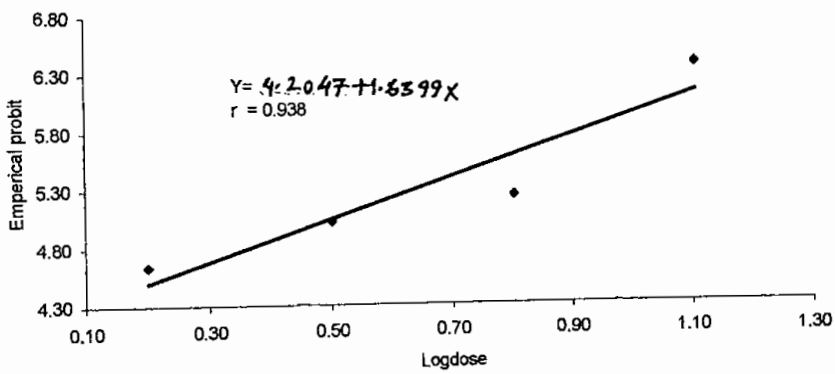


Figure 51. Regression line of probit mortality on logdose of mancozeb applied on *T. urticae* .

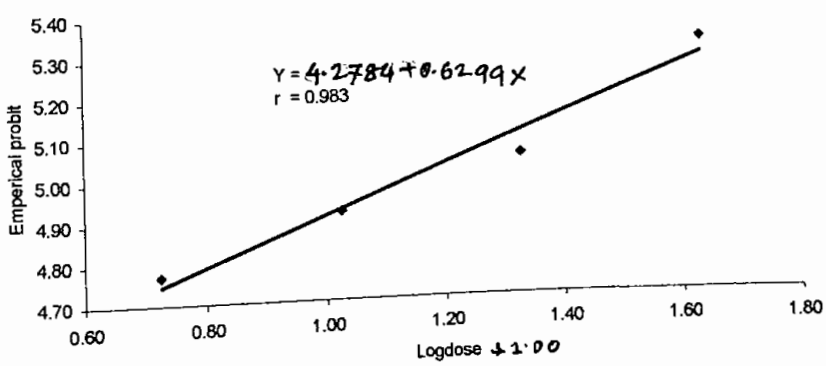


Figure 52. Regression line of probit mortality on logdose of sulphur applied on *T. urticae* .

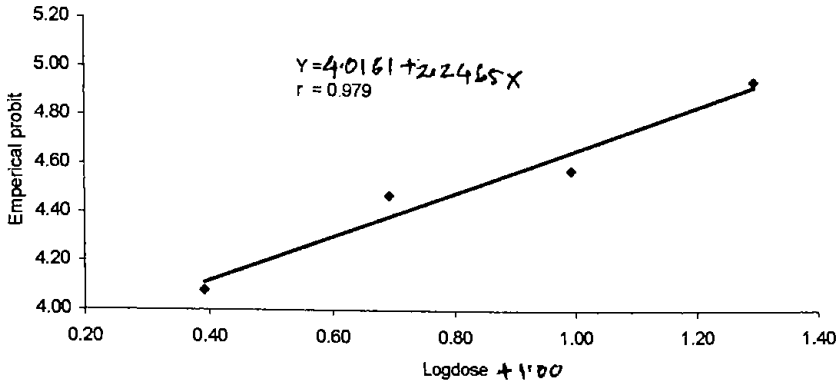


Figure 50. Regression line of probit mortality on logdose of carbendazim applied on *T. urticae*.

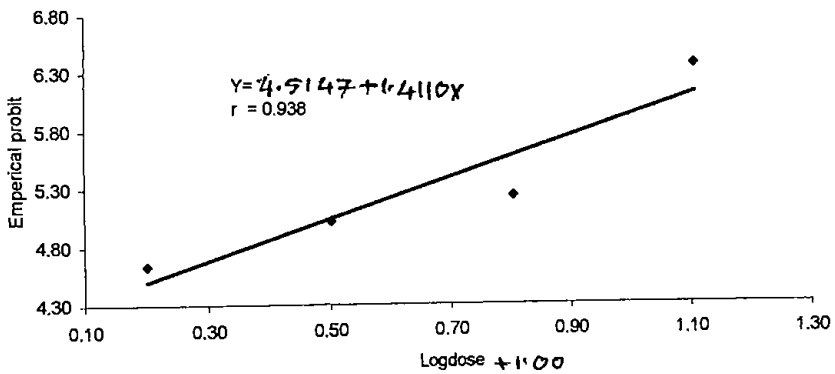


Figure 51. Regression line of probit mortality on logdose of mancozeb applied on *T. urticae*.

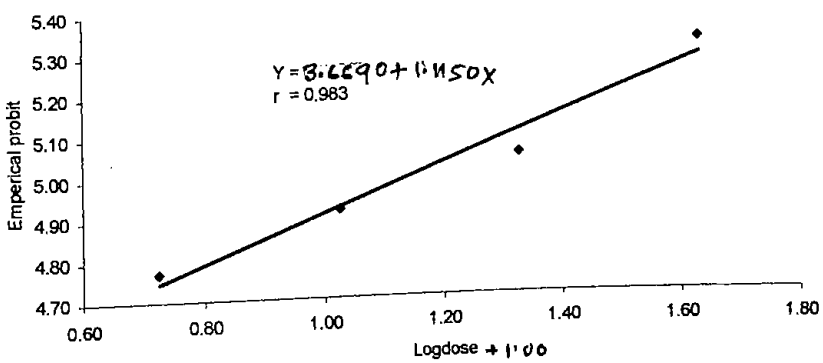


Figure 52. Regression line of probit mortality on logdose of sulphur applied on *T. urticae*.

Discussion

T. urticae suppression provided by chemicals varied greatly. Certain pyrethroids may suppress *T. urticae* populations while others may stimulate outbreaks by causing in increase in the density of *T. urticae* population. Bifenthrin is a pyrethroid, which provides excellent suppression of mites. Many pyrethroids stimulate mites by increasing respiration which can increase mite feeding and egg laying (Mckee and Knowles 1984).

Sharaf (1989) made trial with flubenzimine and methoate against mite on lemon and got the higher crop yield when applied at the economic threshold or at a lower infestation rate.

Labanowska (1990) evaluated the effectiveness of several preparations for the control of two-spotted spider mite on strawberry. The spray was applied before bloom and obtained satisfactory control with hexythiazox, a mixture of hexythiazox and dichlorvos, flufenoxuron, bromopropylate, lambda-cyhalothrin, biphenthrin, fenbutatin oxide, a mixture of hexythiazox and fenpropathrin and avamectin.

Labanowska and Tkaczuk (1991) conducted experiments with some new generation acaricides in the control of *T. urticae* on black currant and obtained excellent result with azocyclotin, fenbutatin oxide and bromopropylate. They also found the similar effectiveness with acrinathrine, bifenthrin, lambda-cyhalothrin and fenpropathrin having shorter residual effect.

Chahine *et al.* (1992) compared the effectiveness of two acaricides on *T. urticae* infesting bean and reported that acaricides reduced the mite population

effectively upto nine days of application. The spray of lambda-cyhalothrin effectively reduced the *T. urticae* population in apple (Li *et al.* 1992).

Pyridaben is also a mitochondrial toxicant that is a site 1 inhibitor on the electron transport system. However, it did not produce the positive results that chlorfenapyr did. Experiments conducted by Sekulic (1995) demonstrated that pyridaben has an LC_{50} of 0.33 ug/ml for larval *T. urticae* and an LC_{50} of 2.96 ug/ml for deutonymphs. This suggests that pyridaben can control younger stages of *T. urticae* more easily than older stages.

Bylemans and Goethem (1996) made a trial with neem extract azadirechtin and salts of dictylsulfo-succinate for the control of spider mite and reported their potential acaricidal activities. They also realized that when these compounds mixed with other acaricides did a very good control effect on *T. urticae*.

Chlorfenapyr provided excellent control of *T. urticae* infestations without short-term population resurgence (Allen and Kharboutli 1999). It provided quick and long term suppression of two-spotted spider mite populations. There was not any resurgence in the number of mites during the two weeks period of the trial. Other studies have found no short term resurgence in mite populations after application in the field. Chlorfenapyr is a mitochondrial toxicant that affects the production of ATP by acting as an uncoupler at the site of ATP synthase.

One of the first active ingredient isolated from neem azadirachtin has proved to be the trees main agent for battling insects. It appears to cause some 90 percent of the effect on most pests. It does not kill insects- at least not

immediately. Instead it both repels and disrupts their growth and reproduction. Research over the past 20 years has shown that it is one of the most potent growth regulators and feeding deterrents ever assayed. It will repel or reduce the feeding of many species of pest insects as well as some nematodes (Butterworth and Morgan 1968, Leuschner 1972, Ruscoe 1972, Zanno *et al.* 1975).

Direct application of a neem formulation containing 80% neem oil at a rate of 3% was highly toxic to *P. persimilis* and only moderately toxic to *T. urticae* (Papaioannou-Souliotis *et al.* 2000). Horticultural oil can control *T. urticae* eggs and mobile stages (Haitas *et al.* 1997) and reduce female fecundity (Osman 1997). Many neem products are known to have antifeedant effects on arthropod pests (Govindachari *et al.* 2000). Cote (2001) demonstrated different degrees of mite suppression by different products of neem.

Abamectin has been shown to cause significant mortality and reduction in the mobility and fecundity of *T. urticae* (Zhang and Sanderson 1990). Abamectin residues can kill *T. urticae* adults up to two weeks after application (Wright *et al.* 1984).

Cote (2001) found that abamectin, bifenthrin, chlorfenapyr and oil provided excellent suppression of *T. urticae* populations 7 days after application in laboratory trials but azadirachtin, pyridaben and spinosad had did not suppress populations of *T. urticae*.

Hexythiazox and neem oil did not provide good suppression of *T. urticae* populations 3 and 7 days after application, but populations began to

decline 14 days after application. It seemed to be slow acting. Populations were suppressed after a period of two weeks. The mode of action of hexythiazox is not completely understood. It is known to have ovicidal action, but provide poor control of adult forms of *T. urticae* (Chapman and Marris 1986). Hexythiazox causes female *T. urticae* to lay fewer viable eggs when treated .This effect combined with the long residual toxicity of hexythiazox may suppress mite populations over time.

The findings of the present experiment shows that lambda-cyhalothrin is the most toxic for TSSM. Many researchers like, Labanowska (1990) Labanowska and Tkaczuk (1991) and Li *et al.* (1992) also reported the excellent toxicity of this chemical on spider mites. The synthetic pyrithroid cypermethrin also proved as highly toxic to TSSM which is very similar to the reports of various researchers.

The present experiment revealed the toxicity of neem product azadirechtin on TSSM. Bylemans and Goethem (1996) made a trial with neem extract azadirechtin and reported its potential acaricidal activities on spider mite. They also realized that when these compounds mixed with other acaricides did a very good control effect on *T. urticae*. Osman (1997) found that many neem products have antifeedant effects on arthropod pests. Govindachari *et al.* (2000) also reported the antecedent effect of neem products on some arthropods. Cote (2001) demonstrated different degrees of mite suppression by different products of neem. But Papaioannou-Souliotis *et al.* (2000) found that direct application of a neem formulation containing 80%

neem oil at a rate of 3% was highly toxic to *P. persimilis* and only moderately toxic to *T. urticae.*

There are also few reports regarding the use of chemicals that demonstrated the adverse impact on the control of spider mite.

Kim *et al.* (1997) obtained the negative result with mancozeb for controlling tea mite *T. kanzawai.* They found that mancozeb killed the 100% of mite predator, *Amblyseius womersleyi.* But fenbutatin oxide is less toxic to *A. womersleyi* than to *T. kanzawai.*

Hill and Foster (1998) carried out an experiment with some insecticides on European red mite and its predator and found that mite outbreak occurred after few weeks of treatment as predators were killed due to insecticidal application.

Sclar *et al.* (1998) obtained the increase of spider mite population rather than control on ornamental plants treated with imidacloprid.

Stanyard *et al.* (1998) observed that the application of paramethrin drastically reduced natural enemies, allowed European red mite outbreaks to occur. They also reported that selective acaricides varied in their effects on *A. fallacis* and European red mite.

Summary and Conclusion

SUMMARY AND CONCLUSION

Two-spotted spider mite, *Tetranychus urticae* Koch causes serious damage to bean plant (*Lablab purpureus* L) resulting yield loss. The result of the present investigation reveals that the duration of developmental stages are greatly affected by temperature. The increase of temperature fastened the developmental rate and shortened the developmental duration. An egg developed to adult only in 4.22 days at 28.53°C whereas it took 28.33 days at temperature 13.78°C. A female *T. urticae* laid 82.46 eggs at average in autumn, which is higher than in winter and summer.

T. urticae population increase with the increase of temperature. Mite population differed significantly among different type of leaves and among different months. *T. urticae* population reached the peak in the month of April. The mature leaves contain the highest number of mite. Among total number the females are more than 65% percent on young and mature leaves. More than 75% of total number of *T. urticae* was immature on all type of leaves.

Scolothrips sexmaculatus Pergande *Phytoseiulus persimilis* Athias-Henriot and *Stethorus punctillum* Weise are the efficient predator of *T. urticae*. Adults as well as larvae of *S. punctillum* and *S. sexmaculatus* consumed eggs, immature stages and adults of *T. urticae*. But immature *P. persimilis* did not consume *T. urticae*. *S. punctillum* devoured more *T. urticae* than *S. sexmaculatus* and *P. persimilis*.

Among 13 insecticides of which one is botanical tested against *T. urticae*, lambda-cyhalothrin had the highest toxicity. The order of toxicity of these is lambda-cyhalothrin > cypermethrin > primiphosmethyl > malathion > diazinon > carbosulfan > propoxur > chlorpyrifos > dimethoate dicofol> imidacloprid> carbaryl> azadirechtin in leaf disc method and that in vial residue method is lambda-cyhalothrin > cypermethrin > diazinon > carbosulfan > malathion > primiphosmethyl > chlorpyrifos > imidacloprid > dimethoate > propoxur > dicofol > azadirechtin > carbaryl. The fungicides carbendazim, mancozeb and sulphur also had the toxic effect on *T. urticae*.

It is necessary to control the mite, *T. urticae* for better yield of bean in quantity and quality. Use of biological agents like *S. punctillum* can check the mite population. But before recommending it to the farmers, some experiments are required in the field level. The use of chemicals for the management of this pest is also recommended if the infestation reached higher. This experiment also suggest to carryout some experiment particularly effective on the immature stages of *T. urticae* but not or less harmful to predator and human health.

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Appendices

Appendix Table 1. Duration of egg stage of *T. urti*cae in different months.

Month / Repl	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	5	1	1	2	2	2	2	3	4	12	12
2	4	1	1	1	2	2	2	3	3	11	11
3	4	1	1	1	2	2	2	2	5	11	11
4	5	1	1		2	2	2	2	4	11	11
5	5	1	1	2	2	2	2	2	5	10	10
6	3	1	1	2	2	3	2	3	6	12	12
7	2	1	1	1	1	3	2	2	4	11	11
8	3	1	1	3	1	3	2	3	5	14	14
9	2	1	1	2	2	3	2	3	6	12	13
10	4	1	1	1	2	3	2	2	4	13	13
11	5	1	2	2	2	3	2	2	5	12	17
12	4	1	2	1	2	2	2	3	6	6	6
13	4	1	2	2	2	2	2	3	5	8	8
14	4	1			2	2	2	2	5	18	18
15	4	1	2	2	1	2	3	4	6	11	11
16	3	1	2	1	1	2	3	3	5	12	12
17	4	2	2	2	2	3	2	3	5	11	11
18	2	1	1	2	1	3	3	4		11	11
19	4	1	2	2	2	3	2	2	4	10	10
20	2	1	2	2	2	3	1	2	5	13	11
21	3	1	2	2	2	4	1	2	5	13	14
22	4	1	2	1	3	4	3	4	6	13	13
23	3	1	2	1	3	4	2	2	5	9	9
24	4	2	2	1	3	2	2	2	4	10	10
25	2	1	2	1	3	2	2		4	12	12
26	2	1	2	2	2	2	2	2	5	12	15
27	4	1	2	1	3	3	2	3	6	11	11
28	3	1	2		3	3	3		5	11	11
29			2		3	3	2			11	11
30			2		3		1			11	11
Aver	3.50	1.07	1.62	1.60	2.10	2.66	2.07	2.62	4.89	11.40	11.67

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	2440.90	9	271.21	331.07	0.00	1.91
Within groups	222.82	272	0.82			
Total	2663.72	281				

Appendix Table 2. Duration of larval stage of *T. urticae* in different months.

Month / Replication	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	2	1	1	1	1	1	1	2	2	2	2
2	3	1	1	1	1	1	1	1	2	4	4
3	4	1	1	1	1	1	1	1	2	4	4
4	3	1	1		1	1	1	2	2	4	4
5	2	1	1	1	1		1	1	2	3	3
6	3	1	1	1	1	1	1	0	2	2	2
7	2	1	1	1	1	1	1	2	3	2	2
8	3	1	1	1	1	1	1	2	3	2	2
9	2	1	1	1		1	1	1	2	4	3
10	1	1	1	1	1	1	1	1	3	4	4
11	2	1	0	1	1	1	1	2		5	3
12	2	1	0	1	2	1	1	1	2	2	2
13	1	1	0	1	2	1	1	1	3	2	2
14	1	2			1	1		2	3	2	2
15	2	2	1	1	1	1	0	2	3	2	3
16	2	2	0	1	1	1	1	1	2	2	2
17	2	1	0	1		1	1	2	3	3	3
18	2	2	1	1	1	1	0			3	3
19	2	2	1	1	2	1	1	2	2	2	2
20	1	1	0	1	2	1	1	2	2	3	3
21	1	1	0	1	1	1	1	3	3		
22	1	1	0	1	1	1	1		3	4	4
23	2	2	1	1	1	1	1	2	3	4	2
24	2	1	0		1	1	1	2	3	1	1
25	2	1	0	1	1	1	1		2	5	5
26	2	1	1	1	1	1	1	2	2	3	0
27	2	1	0	1	1	1	1	2	3	2	2
28	2	1	1		1	1	1		2	2	2
29			0		1	1	1			4	4
30			0		1		1			3	3
Average	2.00	1.21	0.55	1.00	1.14	1.00	0.93	1.63	2.46	2.93	2.69

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	183.19	10	18.32	47.88	1.02E-55	1.86
Within groups	111.33	291	0.38			
Total	294.52	301				

Appendix Table 3. Duration of protonymph stage of *T. urticae* in different months.

Month / Repl	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	2	1	1	1	1	1	1	1	2	3	3
2	1	2	1		1	2	1	2	2	8	8
3	2	2	1	1	1	1	1	2	2	2	2
4	2		1		1	1	1	2	2	3	3
5	2	2	1	1	1		1	2		4	4
6	2	2	1	1	1	1	1	2	3	2	2
7	1	2	1	1	1	1	1	1	2	4	4
8	1	2	1	1	1	1	1	1	2	2	2
9	2	2	1	1		1		2	2	5	6
10	1	2		1	1	1	1	2	2	1	2
11	2	1	1	1	1	1	1	1		5	3
12	2	1	1	1	1		1		3	3	3
13	2	2	1	1	1	1	1	2	2	6	6
14	2	2			1	1		2	3	4	4
15		2	0	1	2	1	1	2	2	2	2
16	2	2	1	1	2	1	1	2	3	4	4
17	2	2	1	1		1	1	2	2	3	3
18	2	1	1	1	2	1	1			4	4
19	2	2	1		1	1	1	2	2	5	5
20	2		1	2	1	1	1	2	2	2	2
21	2	2	1	1	1	1	1	2	2		
22	2	2	0	1	1	1	1		2	2	3
23	2	2		1	2	1	1	2	2		
24	2	2	1		1	1	1	2	2	5	5
25	3	2	1	1	1	1	1		2	3	3
26	2	2	0	1	1	1	1	1	2	3	3
27	2	1	1	2	1	1	1	2	2	3	3
28	2	2	1		1	1	1			10	9
29			1		1	1	1			2	2
30			1		1		1			4	4
Aver	1.89	1.81	0.89	1.09	1.14	1.04	1.00	1.78	2.17	3.71	3.71

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	286.91	10	28.69	37.44	6.72E-46	1.86
Within groups	212.26	277	0.77			
Total	499.16	287				

Appendix Table 4. Duration of deutonymphal stage of *T. urti*cae in different months.

Month / Rep	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	3	2	1	1	2		1	1	2	10	10
2	2	1	2		2		1	2			
3	2	1	1	1	1	2	2	2	3	9	9
4	3		1		1	1	2	2	3	9	9
5		1	1	1	2		2	2		11	11
6	2	2	1	2	2	1	1	2	3	10	11
7	2	2	1	1	2	1	1		3	11	
8	2	1	1	1	2	1	1	2	3	10	12
9	2	2	1	1		1		2	3		
10	2	2		1	2	1	2	2	3	9	8
11	3		1	1		1	1	2			
12	2	2	2	1	1		2		2	9	9
13	2	2	2	1		1	2	2	2	11	11
14	2	2			2	1		3	2		
15		2	1	1	2	1	2	2	3		13
16	2	1	1	1	2	1	1	3	3	3	8
17	2	2	1	2		1	1	2	3	9	9
18	2	2	1	2	2	1	2				
19	3	2	1		1	1	1	2	3	10	10
20	3		1	1	2		2	2	3		13
21	2	1	1	1	2	0	1	3	3		
22	2	2	1	1	2	0	2		3		
23	2	2		1	2	0	1	2	3		
24		1	1		1	1	2	2	2	5	10
25	2	2	1	1	1	1			2		10
26	2	1	1	2	1	1	1	2	2	7	12
27	3	2	2	1	1	1	1	2	3	10	
28	2	2			1	1	2				9
29			1			1	1			9	
30			1		3		1			8	11
Aver	2.24	1.68	1.15	1.18	1.68	0.92	1.44	2.09	2.70	8.89	10.26

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	2070.25	10	207.03	319.51	2.1E-134	1.87
Within groups	158.75	245	0.65			
Total	2229.00	255				

Appendix Table 5. Duration of egg to adult *T. urticae* in different months.

Month / Rep	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	12	5	4	5	6		5	7	10	27	27
2	10	5	5		6		5	8			
3	12	5	4	4	5	6	6	7	12	26	26
4	13		4		5	5	6	8	11	27	27
5		5	4	5	6		6	7		28	28
6	10	6	4	6	6	6	5	7	14	26	27
7	7	6	4	4	5	6	5		12	28	
8	9	5	4	6	5	6	5	8	13	28	30
9	8	6	4	5		6		8	13		
10	8	6		4	6	6	6	7	12	27	27
11	12		4	5		6	5	7			
12	10	5	5	4	6		6		13	20	20
13	9	6	5	5	5	5	6	8	12	27	27
14	9	7			6	5		9	13		
15		7	4	5	6	5	6	10	14		29
16	9	6	4	4	6	5	6	9	13	21	26
17	10	7	4	6		6	5	9	13	26	26
18	8	6	4	6	6	6	6				
19	11	7	5		6	6	5	8	11	27	27
20	8		4	6	7		5	8	12		29
21	8	5	4	5	6	6	4	10	13		
22	9	6	3	4	7	6	7		14		
23	9	7		4	8	6	5	8	13		
24		6	4		6	5	6	8	11	21	26
25	9	6	4	4	6	5			10		30
26	8	5	4	6	5	5	5	7	11	25	30
27	11	5	5	5	6	6	5	9	14	26	
28	9	6			6	6	7				31
29			4			6	5			26	
30			4		8		4			26	29
Aver	9.52	5.84	4.15	4.91	6.00	5.67	5.44	8.05	12.35	25.67	27.47

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	13725.51	10	1372.55	875.39	4.82E-19	1.87
Within groups	385.71	246	1.57			
Total	14111.22	256				

Appendix Table 6. Developmental success of different developmental stages of *T. urticae* in different months.

Months	Egg	Larva	Protonymph	Deutonymph	Adult
Mar	0.966	1.000	1.000	0.929	0.897
Apr	1.000	1.000	0.929	0.962	0.893
May	0.967	1.000	0.931	0.963	0.867
Jun	0.926	0.960	0.917	1.000	0.815
Jul	1.000	0.933	1.000	0.893	0.833
Aug	1.000	0.966	0.964	0.889	0.828
Sep	1.000	0.967	0.966	0.964	0.900
Oct	0.929	0.923	0.958	0.957	0.786
Nov	0.964	0.963	0.923	0.958	0.821
Dec	1.000	0.967	0.966	0.643	0.600
Jan	1.000	0.967	0.966	0.679	0.633
Average	0.977	0.968	0.956	0.894	0.807

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	0.088	10	0.009	0.954	0.495	2.054
Within groups	0.406	44	0.009			
Total	0.494	54				

Appendix Table 7. Daily fecundity of *T. urticae* in different seasons.

Day	Winter	Autumn	Summer
1st day	2.32	1.63	0.60
2nd day	2.53	2.17	2.20
3rd day	2.42	3.79	4.44
4th day	1.89	4.88	10.00
5th day	3.37	6.54	14.64
6th day	2.79	6.88	8.28
7th day	2.63	6.17	4.56
8th day	1.47	7.33	2.79
9th day	2.89	7.92	2.12
10th day	2.21	7.50	1.92
11th day	2.16	4.38	1.00
12th day	2.79	4.58	
13th day	2.95	3.83	
14th day	1.84	3.50	
15th day	1.00	3.25	
16th day	1.53	3.83	
17th day	0.47	2.46	
18th day	0.95	1.30	
19th day	1.05	0.38	
20th day	0.53	0.20	
21st day	0.39		
22nd day	0.63		
23rd day	0.47		
24th day	0.37		
25th day	0.37		
26th day	0.26		
27th day	0.35		
28th day	0.21		
29th day	0.23		
30th day	0.11		
31st day	0.00		
32nd day	0.00		
Average	1.35	4.13	4.78

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	279.58	31	9.02	1.38	0.19	1.82
Within roups	202.70	31	6.54			
Total	482.27	62				

Appendix Table 8. Reproductive period of *T. urticae* in different seasons.

Seasons / Replication	Winter	Autumn	Summer
1	30	19	11
2	32	18	8
3	29	19	10
4	26	20	10
5	32	20	10
6	29	19	10
7	26	19	9
8	27	17	10
9	27	21	10
10	27	18	7
11	30	19	11
12	31	20	8
13	30	17	8
14	28	20	9
15	30	19	9
16	30	19	8
17	29	17	8
18	29	19	8
19	31	19	11
20		18	8
21			11
22			9
23			10
24			9
25			10
Average	29.11	18.85	9.28

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between groups	4257.06	2	2,128.53	1106.158	1.19E-48	3.15
Within groups	117.38	61	1.92			
Total	4374.44	63				

Appendix Table 9. Total egg laid by a female *T. urticae* in different seasons.

Seasons / Replication	Winter	Autumn	Summer
1	53	81	54
2	62	79	46
3	55	85	49
4	29	82	54
5	34	87	58
6	59	85	47
7	59	81	46
8	45	81	59
9	26	88	75
10	50	81	67
11	55	83	79
12	60	81	59
13	65	76	59
14	52	89	58
15	58	76	54
16	60	77	56
17	68	90	52
18	62	83	62
19	54	81	85
20		82	78
21		89	88
22		76	71
23		82	71
24		84	72
25			71
Average	52.95	82.46	62.80

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	*F crit*
Between groups	4257.06	2	2128.53	1106.16	1.19E-48	3.15
Within groups	117.38	61	1.92			
Total	4374.44	63				

Appendix Table 10. Number of *T. urticae* on different type of leaves in three areas of Rajshahi City Corporation from January 2002 to April 2002.

Month	Week	Motihar area			Paba area			Boalia area		
		Young	Mature	Old	Young	Mature	Old	Young	Mature	Old
Jan. 02	1	0.00	0.00	6.00	4.00	5.33	1.33	2.00	4.00	1.33
	2	24.00	20.67	21.00	0.00	0.00	2.33	9.33	9.00	10.67
	3	1.00	1.67	1.33	0.33	2.33	2.00	0.00	1.67	1.33
	4	0.67	1.33	1.33	0.00	0.00	0.67	21.67	23.00	30.33
	5	3.67	3.67	5.67	2.67	4.33	3.33	0.33	7.67	4.67
Feb. 02	1	1.33	3.67	3.33	1.33	4.67	2.67	0.00	0.67	0.00
	2	21.00	35.17	38.67	0.00	0.67	0.00	3.67	3.00	5.67
	3	0.33	4.00	3.67	1.33	1.33	1.00	0.00	0.00	0.00
	4	1.67	1.33	2.33	0.00	2.33	1.00	0.00	0.00	0.00
Mar. 02	1	5.00	4.00	3.67	0.00	7.67	2.67	0.67	0.67	0.00
	2	5.67	31.67	27.67	2.00	6.67	6.00	0.00	3.33	7.00
	3	0.33	4.33	7.00	0.67	2.33	2.67	1.00	3.00	2.33
	4	1.67	7.00	4.67	2.00	2.67	1.67	0.00	0.00	0.00
Apr. 02	1	1.00	19.00	36.67	43.33	91.33	57.33	200.00	282.33	130.33
	2	99.33	160.33	141.33	56.00	112.00	32.00	37.33	57.00	16.00
	3	53.00	57.00	14.67	91.00	179.67	89.00	3.00	3.33	2.67
	4	6.33	24.33	5.67	7.67	7.00	9.33	6.33	7.33	8.67

Appendix Table 11. Number of *T. urticae* on different type of leaves in three areas of Rajshahi city corporation from May 2002 to August 2002.

Month	Week	Motihar area			Paba area			Boalia area		
		Young	Mature	Old	Young	Mature	Old	Young	Mature	Old
May 02	2	9.67	10.33	16.67	42.33	21.33	45.67	4.33	17.67	7.67
	3	0.00	0.00	0.00	3.33	5.67	5.33	2.00	4.33	5.67
	4	18.00	28.00	26.33	0.00	0.00	0.00	0.33	1.67	2.00
Jun. 02	1	4.33	24.33	22.00	25.00	45.33	16.33	4.33	22.67	44.00
	2	34.67	47.00	44.33	0.00	1.00	5.67	0.00	0.00	0.00
	3	5.33	11.33	9.67	9.00	9.00	7.33	22.00	70.33	12.00
	4	97.33	95.00	29.00	2.67	7.67	3.67	1.67	4.00	2.67
Jul. 02	1	28.33	41.67	13.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	21.33	109.00	45.33	29.33	4.00	0.00	0.33	22.00	25.67
	3	0.00	8.00	2.00	1.00	2.67	1.33	0.00	0.00	0.00
Aug. 02	1	75.33	131.00	13.33	5.67	11.00	22.67	302.67	413.67	218.67
	2	58.67	33.67	14.00	59.33	241.67	69.33	97.33	250.67	115.67
	3	0.67	0.33	0.33	0.00	2.00	1.67	0.00	0.67	0.00
	4	1.33	8.33	1.67	0.00	0.33	0.00	5.00	0.67	0.00

Appendix Table 12. Number of *T. urticae* on different type of leaves in three areas of Rajshahi city corporation from September 2002 to December 2002.

Month	Week	Motihar area			Paba area			Boalia area		
		Young	Mature	Old	Young	Mature	Old	Young	Mature	Old
Sep. 02	1	33.67	32.33	72.33	30.33	37.67	69.00	0.00	2.00	48.00
	2	1.33	7.67	9.67	3.33	13.00	9.00	30.00	43.33	76.00
	3	2.00	4.00	7.67	3.67	3.00	0.00	0.00	2.33	0.00
	4	11.67	0.00	0.00	0.67	0.00	0.00	56.33	99.67	104.67
	5	24.00	40.67	56.00	75.67	131.00	115.67	9.00	34.67	54.67
Oct 02	1	12.00	29.33	18.33	8.33	22.33	25.33	44.33	63.00	21.67
	2	5.33	8.67	17.67	16.00	66.00	10.00	8.00	17.67	16.67
	3	16.33	1.33	26.67	44.67	80.00	69.00	13.00	33.67	21.00
	4	1.33	11.33	4.33	0.67	46.00	37.33	13.00	28.33	31.33
	5	13.33	38.00	31.67	9.67	12.00	27.67	67.67	108.33	97.33
Nov. 02	1	19.00	35.67	13.67	0.67	5.67	5.33	7.67	19.00	20.00
	2	0.00	0.00	0.00	12.67	20.33	5.67	4.67	6.33	7.67
	3	42.00	83.33	109.00	46.00	107.33	84.33	16.67	24.00	4.00
	4	9.33	43.67	47.33	2.00	4.00	2.00	0.00	0.00	0.00
	5	2.00	3.67	3.33	1.67	5.67	7.67	2.00	5.00	3.33
Dec. 02	1	2.33	3.00	2.33	29.00	44.67	32.67	4.00	10.00	0.67
	2	2.67	10.00	9.67	2.00	0.00	4.00	1.33	1.33	3.67
	3	0.00	5.67	4.00	1.00	1.33	0.00	2.33	2.67	11.67
	4	5.00	22.33	16.67	9.33	16.00	21.67	0.00	8.33	15.33
	5	14.00	10.33	5.67	0.67	2.33	0.33	4.00	7.67	7.67

Appendix Table 13. Number of mites per leaf on different type of leaves in different months.

Months	Motihar			Paba			Boalia		
	Young	Mature	Old	Young	Mature	Old	Young	Mature	Old
Jan. 02	5.67	5.47	7.07	1.40	2.39	1.51	6.53	9.07	9.57
Feb. 02	7.46	10.63	12.00	0.67	2.25	1.17	0.92	0.92	1.42
Mar. 02	3.17	11.75	10.75	1.17	4.84	3.25	0.42	1.75	2.33
Apr. 02	39.92	65.17	49.59	49.50	97.50	46.92	61.67	87.50	39.42
May. 02	9.22	12.78	14.33	15.22	9.00	17.00	2.22	7.89	5.11
Jun. 02	35.42	44.42	26.25	9.17	15.75	8.25	7.00	24.25	14.67
Jul. 02	16.55	52.89	20.11	10.11	2.22	0.44	0.11	7.33	8.56
Aug. 02	34.00	43.33	7.33	16.25	63.75	23.42	41.00	62.33	41.33
Sep. 02	14.53	16.93	29.13	22.73	36.93	38.73	19.07	37.00	56.67
Oct. 02	9.66	17.73	19.73	15.47	45.27	33.87	29.20	50.20	37.60
Nov. 02	14.47	33.27	34.67	12.60	28.60	21.00	6.13	10.87	7.00
Dec. 02	4.80	10.27	7.67	8.40	12.87	11.73	2.33	6.00	7.80

Analysis of variance (ANOVA)

Source of Variation	SS	df	MS	F	P-value	F crit
Between months	27378.15	11	2488.92	16.43***	2.24E-12	1.89
Within months	14545.44	96	151.51			
Total	41923.59	107				

*** = P<0.001

Appendix Table 14. Number of mites per leaf in different months.

Months	Motihar	Paba	Boalia	Mean
Jan. 02	6.07	3.62	8.39	6.03
Feb. 02	10.03	4.97	1.09	5.36
Mar. 02	8.56	5.59	1.50	5.22
Apr. 02	51.56	65.53	62.86	59.98
May. 02	12.11	12.85	5.07	10.01
Jun. 02	35.36	17.06	15.31	22.58
Jul. 02	29.85	10.81	5.33	15.33
Aug. 02	28.22	29.11	48.22	35.18
Sep. 02	20.20	29.60	37.58	29.13
Oct. 02	15.71	26.82	39.00	27.18
Nov. 02	27.47	25.29	8.00	20.25
Dec. 02	7.58	9.65	5.38	7.54
Average	21.06	19.20	25.55	

Analysis of variance (ANOVA)

Source of Variation	SS	df	MS	F	P-value	F crit
Between areas	9.95	2	4.47	0.02	0.80	3.28
Within areas	10337.17	33	313.25			
Total	10247.12	35				

Appendix Table 15. Average number of *T. urticae* per leaf in three areas in different variety of leaves.

Areas	Young	Mature	Old	Mean
Motihar	16.12	27.09	19.89	21.03
Paba	13.56	26.78	17.27	19.20
Boalia	14.72	25.43	19.29	19.81
Aver	14.80	26.43	18.82	

Analysis of variance (ANOVA)

Source of Variation	SS	df	MS	F	P-value	F crit
Between leaf varieties	209.48	2	104.74	72.47***	0.01	5.14
Within leaf varieties	8.61	6	1.44			
Total	218.09	8				

*** = P>0.001

Appendix Table 16. Number of adult mites per leaf in different months.

Months	Young leaf	Mature leaf	Old leaf
Sept 02	21.63	20.36	9.10
Oct. 02	12.51	13.80	7.77
Nov. 02	13.70	26.70	24.44
Dec. 02	1.99	8.29	2.74
Jan. 03	2.97	6.26	7.26
Feb. 03	20.71	38.07	26.79
Mar. 03	28.13	37.98	24.58
Apr. 03	60.07	78.99	62.87
May. 03	89.48	83.55	97.30
Jun. 03	46.06	58.39	42.70
Jul. 03	7.03	5.68	5.15
Aug. 03	44.87	49.29	25.58

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between months	23645.40	11	2149.58	41.04***	7.55E-13	2.22
Within months	1257.12	24	52.38			
Total	24902.53	35				

*** = P>0.001

Appendix Table 17. Number of adult mites per leaf in different varieties of leaves.

Months	Young leaf	Mature leaf	Old leaf
Sept 02	21.63	20.36	9.10
Oct. 02	12.51	13.80	7.77
Nov. 02	13.70	26.70	24.44
Dec. 02	1.99	8.29	2.74
Jan. 03	2.97	6.26	7.26
Feb. 03	20.71	38.07	26.79
Mar. 03	28.13	37.98	24.58
Apr. 03	60.07	78.99	62.87
May. 03	89.48	83.55	97.30
Jun. 03	46.06	58.39	42.70
Jul. 03	7.03	5.68	5.15
Aug. 03	44.87	49.29	25.58

Analysis of variance (ANOVA)

Source of variation	SS	df	MS	F	P-value	F crit
Between leaf varieties	404.94	2	202.47	0.27	0.76	3.28
Within leaf varieties	24497.58	33	742.35			
Total	24902.53	35				

Appendix Table 18. Probit mortality of *T. urticae* by imidacloprid by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
31.847	1.5030	73	52	71.23	69	5.50	5.590	5.472	42.41	5.5815
15.924	1.2020	69	46	66.67	64	5.36	5.267	5.384	43.26	5.2596
7.962	0.9010	65	35	53.84	51	5.03	4.943	5.015	41.21	4.9377
3.981	0.5999	71	26	36.61	32	4.53	4.619	4.524	42.67	4.6157
Control		18	1							

Regression equation: Y = 3.974605+1.069478X

χ^2.= 1.7835 with 2 df; no significant heterogeneity

LC_{-50} = 9.104343 $\mu g\ cm^{-2}$

95% confidence limits

6.504291 - 12.743744 $\mu g\ cm^{-2}$

Log LC_{-50} = 0.9592487

Appendix Table 19. Probit mortality of *T. urticae* by dicofol by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
29.4586	1.4691	90	64	71.11	71	5.55	5.489	5.537	54.09	5.4918
14.7293	1.1681	85	49	57.64	58	5.20	5.280	5.228	53.29	5.2845
7.3645	0.8671	75	39	52.00	52	5.05	5.069	5.000	47.77	5.0772
3.6823	0.5661	65	30	46.05	46	4.90	4.860	4.916	40.75	4.8700
Control		30	0							

Regression equation : Y = 4.480243+0.688523X

χ^2.= 0.4026 with 2 df; no significant heterogeneity

LC_{-50} = 5.687062 $\mu g\ cm^{-2}$

95% confidence limits

3.027731 - 10.682121 $\mu g\ cm^{-2}$

Log LC_{-50} = 0.[illegible]

Appendix Table 20. Probit mortality of *T. urticae* by dimethoate by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
12.7389	1.1051	40	33	82.50	82	5.92	5.951	5.946	18.84	5.9659
6.3694	0.8040	40	27	67.50	67	5.44	5.441	5.429	24.04	5.4491
3.1847	0.5030	40	21	52.50	51	5.03	4.932	5.015	25.36	4.9322
1.5924	0.2020	40	11	27.50	26	4.36	4.424	4.360	22.32	4.4154
Control		10	0							

Regression equation ; Y = 4.068519+1.716986X

χ^2. = 0.2598 with 2 df; no significant heterogeneity

LC_{-50} = 3.487464 $\mu g\ cm^{-2}$

95% confidence limits

2.617232 - 4.647042 $\mu g\ cm^{-2}$

Log LC_{-50} = 0.54250

Appendix Table 21. Probit mortality of *T. urticae* by diazinon by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.955414	0.980191	109	83	76.14	72	5.58	5.425	5.564	65.50	5.3408
0.477107	0.678619	150	65	43.33	33	4.56	4.969	4.565	95.10	4.9206
0.238854	0.378139	108	58	53.71	45	4.87	4.515	4.880	62.74	4.5018
0.119427	0.077112	81	23	28.40	15	3.96	4.059	3.955	35.55	4.0822
Control		19	3							

Regression equation : Y = 3.975827+1.393678X

χ^2.= 2.483 with 2 df; no significant heterogeneity

LC_{-50} = 0.543986 $\mu g\ cm^{-2}$

95% confidence limits

0.249362 - 1.186712 $\mu g\ cm^{-2}$

Log LC_{-50} = 0.735588

Appendix Table 22. Probit mortality of *T. urticae* by chlorpyrifos by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
6.3694	1.80409	40	28	70.00	70	5.52	5.675	5.52	22.32	5.6900
3.1847	1.50306	40	25	62.50	63	5.33	5.204	5.35	25.08	5.2241
1.5924	1.20205	40	29	47.50	48	4.95	4.735	4.94	24.64	4.7583
0.7962	0.90102	40	7	17.50	18	4.08	4.265	4.08	20.12	4.2924
Control		10	0							

Regression equation : Y = 2.898033+1.547602X

χ^2.= 2.8722 with 2 df; no significant heterogeneity

LC_{-50} = 2.281443 $\mu g\ cm^{-2}$

95% confidence limits

1.683614 -- 3.09125 $\mu g\ cm^{-2}$

Log LC_{-50} =0.358209

Appendix Table 23. Probit mortality of *T. urticae* by primiphosmethyl by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.79618	1.9010	97	87	89.69	90	6.28	6.204	6.23	35.89	6.1542
0.39809	1.5999	98	74	75.51	76	5.71	5.750	5.70	52.13	5.7179
0.19904	1.2989	98	55	56.12	56	5.15	5.294	5.17	61.44	5.2817
0.09952	0.9979	60	29	48.33	48	4.95	4.840	4.96	37.62	4.8454
Control		15	0							

Regression equation : Y = 3.399364+1.449143X

χ^2.= 1.4699 with 2 df; no significant heterogeneity

LC_{-50} = 0.127215 $\mu g\ cm^{-2}$

95% confidence limits

0.090861 -- 0.178114 $\mu g\ cm^{-2}$

Log LC_{-50} =0.10454

Appendix Table 24. Probit mortality of *T. urticae* by malathion by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.9076	0.95789	97	68	70.10	69	5.50	5.384	5.47	59.75	5.3756
0.4535	0.65658	79	40	50.63	48	4.95	5.087	4.95	50.32	5.0810
0.2267	0.35564	99	41	41.41	39	4.72	4.791	4.71	60.98	4.7868
0.1134	0.05462	86	32	37.21	34	4.59	4.496	4.60	47.98	4.4924
Control		22	1							

Regression equation : Y = 4.439056+0.977793X

χ^2.= 2.3198 with 2 df; no significant heterogeneity

LC_{-50} = 0.374751 $\mu g\ cm^{-2}$

95% confidence limits

0.273333 -- 0.513642 $\mu g\ cm^{-2}$

Log LC_{-50} =0.425267

Appendix Table 25. Probit mortality of *T. urticae* by carbaryl by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
67.675	1.8304	101	84	83.17	83	5.95	5.99	5.984	47.57	6.0123
33.838	1.5293	80	58	72.50	72	5.58	5.51	5.556	46.48	5.5219
16.919	1.2283	74	39	52.70	52	5.05	5.03	5.050	47.13	5.0315
8.459	0.9273	76	25	32.89	32	4.53	4.55	4.516	44.15	4.5410
Control	---	22	0		---	---	---	---	---	---

Regression equation Y = 3.030 454+ 1.629061X

χ^2.= 0.1361 with 2 df, no significant heterogeneity

LC_{-50} 16.18107 $\mu g\ cm^{-2}$

95% confidence limits

12.8523 - 20.3719 $\mu g\ cm^{-2}$

Log LC_{-50} 1.209007

Appendix Table 26. Probit mortality of *T. urticae* by carbosulfan by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
6.36943	1.804092	40	36	90.00	90	6.28	6.365	6.25	13.44	6.374
3.18471	1.503065	40	32	80.00	80	5.85	5.764	5.83	21.28	5.763
1.59236	1.202039	40	24	60.00	60	5.25	5.164	5.24	25.36	5.153
0.79619	0.901017	40	12	30.00	30	4.48	4.565	4.46	23.24	4.543
Control		10	0							

Regression equation : $Y = 2.716185 + 2.027639\ X$ $\chi^2 = 0.6508$ with 2 df; no significant heterogeneity

$LC_{50} = 1.337664\ \mu g\ cm^{-2}$ 95% confidence limits 1.0154 - 1.7622s $\mu g\ cm^{-2}$

Log LC_{50} = [illegible].1263

Appendix Table 27 Probit mortality of *T. urticae* by propoxur by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
3.18471	1.5030	52	35	67.30	66	5.41	5.425	5.402	31.25	5.4285
1.59236	1.2020	50	26	52.00	51	5.03	4.907	5.015	31.70	4.8973
0.79618	0.9010	57	13	22.80	21	4.19	4.388	4.202	30.32	4.3660
0.39809	0.5999	40	7	17.50	15	3.96	3.869	3.975	14.80	3.8348
Control		11	0							

Regression equation: $Y = 2.776136 + 1.764658X$ $\chi^2 = 1.5682$ with 2 df; no significant heterogeneity

$LC_{50} = 1.7293\ \mu g\ cm^{-2}$ 95% confidence limits 1.3072 - 2.2872 $\mu g\ cm^{-2}$

Log LC_{50} = 0.237870

Appendix Table 28. Probit mortality of *T. urticae* by cypermethrin by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.79617	1.901012	40	35	87.50	88	6.18	6.128	6.178	16.20	6.0960
0.39808	1.599984	40	31	77.50	78	5.77	5.717	5.766	21.28	5.7009
0.19904	1.298959	40	27	67.50	68	5.45	5.307	5.212	24.64	5.3059
0.09952	0.997929	40	21	52.50	52	5.05	4.895	5.072	25.08	4.9109
Control		10	0							

Regression equation : Y = 3.601400+1.312260X

χ^2.= 2.6984 with 2 df; no significant heterogeneity

LC_{-50} = 0.116357 $\mu g\ cm^{-2}$

95% confidence limits

0.087481 -- 0.196932 $\mu g\ cm^{-2}$

Log LC_{-50} = -0.934207

Appendix Table 29. Probit mortality of *T. urticae* by lmbda-cyhalothrin by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.003105	1.4920	99	67	67.68	68	5.47	5.324	5.44	60.98	5.3249
0.005500	1.7403	82	52	63.42	63	5.33	5.453	5.32	49.28	5.4502
0.000776	0.8898	101	53	52.48	52	5.05	5.013	5.05	64.33	5.0212
0.000388	0.5888	83	35	42.17	42	4.80	4.858	4.81	52.04	4.8693
Control		26	0							

Regression equation ; Y = 4.572324+0.504432X

χ^2.= 1.9718 with 2 df; no significant heterogeneity

LC_{-50} = 0.000704 $\mu g\ cm^{-2}$

95% confidence limits

0.000338 - 0.001464 $\mu g\ cm^{-2}$

Log LC_{-50} = -3.152427

Appendix Table 30. Probit mortality of *T. urticae* by azadirechtin by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
191.084	0.980206	40	35	87.50	88	6.18	6.254	6.128	14.80	6.217
95..542	0.679179	40	33	82.50	83	5.95	5.829	5.902	20.12	5.799
47.771	0.378243	40	26	65.00	65	5.39	5.405	5.375	24.04	5.381
23.886	0.077034	40	19	47.50	48	4.95	4.979	4.940	25.36	4.963
Control	---	10	00	00.00	---	---	---	---	---	---

Regression equation Y = 4.856075+1.388925X

χ^2.= 0.3448 with 2 df, no significant heterogeneity.

LC_{-50} = 25.3894 $\mu g\ cm^{-2}$

95% confidence limits

14.9418 – 43.1421 $\mu g\ cm^{-2}$

Log LC_{-50} = 1.4046

Appendix Table 31. Probit mortality of *T. urticae* by imidacloprid by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
650.00	1.8125	74	64	86.48	86	6.08	5.68	6.00	41.29	5.7011
325.00	1.5118	191	119	62.30	61	5.28	5.38	5.26	117.65	5.4048
162.50	1.2126	116	62	53.44	52	5.05	5.09	5.05	73.89	5.1099
81.25	0.9138	107	52	48.59	47	4.92	4.80	4.94	67.08	4.8163
Control		24	1							

Regression equation : Y = 3.917007+0.984124X

χ^2.= 7.2814 with 2 df; [illegible] heterogeneity was adjusted

LC-$_{50}$ = 126.032 ng cm^{-2}

95% confidence limits

65.324 -- 243.135 ng cm^{-2}

Log LC-$_{50}$ = 2.1002480

Appendix Table 32 Probit mortality of *T. urticae* by dicofol by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose +1.00	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
6.006	1.778	96	84	87.50	87	6.13	6.07	6.08	42.14	6.0316
3.003	1.477	84	58	69.05	68	5.47	5.61	5.46	46.87	5.5806
1.502	1.176	80	49	61.25	59	5.23	5.14	5.22	50.72	5.1298
0.751	0.876	83	33	39.76	37	4.67	4.68	4.66	49.88	4.6788
Control		21	0							

Regression equation : Y = 3.366979+1.498222X

χ^2.= 1.1981 with 2 df; no significant heterogeneity

LC-$_{50}$ =1.093905ng cm^{-2}

95% confidence limits

8-947.621 -- 1596.92 ng cm^{-2}

Log LC-$_{50}$ = 0.038898

Appendix Table 33. Probit mortality of *T. urticae* by dimethoate by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
1300.00	1.1139	74	67	90.54	90	6.28	6.29	6.23	27.38	6.2785
650.00	0.8129	77	63	81.82	81	5.88	5.91	5.90	36.26	5.8961
325.00	0.5118	77	57	74.03	73	5.61	5.53	5.58	44.73	5.5137
162.50	0.2121	82	46	56.10	54	5.10	5.15	5.09	51.98	5.1330
Control		24	2							

Regression equation : Y = 4.863547+1.270278X

χ^2.= 0.3865 with 2 df; no significant heterogeneity

LC-$_{50}$ = 128.062 ng cm^{-2}

95% confidence limits

77.712 -- 210.734 ng cm^{-2}

Log LC-$_{50}$ = 2.107420

Appendix Table 34. Probit mortality of *T. urticae* by diazinon by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
97.40	1.988	104	89	85.58	85	6.04	6.018	6.01	45.65	5.9902
48.70	1.687	156	116	74.36	73	5.61	5.622	5.61	87.04	5.6135
24.35	1.394	117	70	59.83	58	5.20	5.237	5.21	73.35	5.2469
12.18	1.093	83	39	46.99	45	4.87	4.841	4.89	52.04	4.8702
Control		21	0							

Regression equation : Y = 3.377050+ 1.258116X

χ^2.= 0.0585 with 2 df; no significant heterogeneity

LC-$_{50}$ = 15.743 ng cm^{-2}

95% confidence limits

11.198 - 22.131 ng cm^{-2}

Log LC-$_{50}$ = 1.1972087

Appendix Table 35. Probit mortality of *T. urticae* by chlorpyrifos by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
324.70	2.5114	40	34	85.00	85	6.04	6.095	6.00	17.56	6.0753
162.30	2.2102	40	28	70.00	70	5.52	5.429	5.51	24.04	5.4199
81.20	1.9095	40	16	40.00	40	4.75	4.765	4.74	24.64	4.7653
40.60	1.6085	40	7	17.50	18	4.09	4.100	4.09	18.84	4.1102
Control		10	0							

Regression equation : Y = 0.609603+ 2.176310X

χ^2.= 0.3034 with 2 df; no significant heterogeneity

LC_{-50} = 104.076 ng cm^{-2}

95% confidence limits

83.009 -- 130.489 ng cm^{-2}

Log LC_{-50} = 2.0173

Appendix Table 36. Probit mortality of *T. urticae* by primiphosmethyl by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
250.00	1.3979	58	48	82.76	82	5.92	5.87	5.86	29.17	5.8457
125.00	1.0969	51	32	62.75	60	5.25	5.26	5.28	31.97	5.2415
62.50	0.7781	57	20	35.09	30	4.48	4.61	4.48	34.25	4.6018
31.25	0.4771	59	14	23.73	18	4.08	3.99	4.12	23.89	3.9976
Control		15	0							

Regression equation : Y = 3.040239+2.007091X

χ^2.= 0.9481 with 2 df; no significant heterogeneity

LC_{-50} = 94.734 ng cm^{-2}

95% confidence limits

\77.083 -- 116.451 ng cm^{-2}

Log LC_{-50} = 1.9764565

Appendix Table 37. Probit mortality of *T. urticae* by malathion by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
185.00	2.2672	145	124	85.51	85	6.04	5.78	5.99	77.14	5.79980
92.50	1.9661	208	134	64.42	64	5.36	5.48	4.35	125.00	5.49106
46.25	1.6263	160	86	53.75	53	5.08	5.14	5.07	101.44	5.14257
23.13	1.3263	165	80	48.48	47	4.92	4.84	4.94	103.45	4.83488
Control		26	0							

Regression equation : Y = 3.475603+1.025606X

χ^2.= 7.1449 with 2 df; [illegible]ficant heterogeneity was adjusted.

LC-$_{50}$ = 30.712 ng cm^{-2}

95% confidence limits

17.852 - 52.834 ng cm^{-2}

Log LC-$_{50}$ = 1.4873

Appendix Table 38. Probit mortality of *T. urticae* by carbaryl by leaf disc method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
21240	1.327	79	74	93.67	93	6.48	6.43	6.49	23.85	6.3904
10620	1.026	87	69	79.31	78	5.77	5.80	5.73	43.76	5.7736
5310	0.725	84	47	55.95	54	5.10	5.17	5.09	53.25	5.1568
2665	0.424	88	33	37.50	35	4.61	4.54	4.60	51.12	4.5416
Control	---	26	1		---	---	---	---	---	---

Regression equation Y = 3.671055+2.049 074X

χ^2.= 0.7286 with 2 df, no significant heterogeneity

LC-$_{50}$ 4452.00 ng cm^{-2}

95% confidence limits

3695.8 - 5362. ng cm^{-2}

Log LC-$_{50}$ 3.6485

Appendix Table 39. Probit mortality of *T. urticae* by carbosulfan by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
649.00	2.8122	40	34	85.00	85	6.04	6.031	6.005	17.56	5.9909
324.50	2.5111	40	31	77.50	78	5.77	5.801	5.732	20.12	5.7702
162.25	2.2102	40	29	72.50	73	5.61	5.572	5.584	23.24	5.5496
81.13	1.9095	40	25	62.50	63	5.33	5.344	5.318	24.64	5.3291
Control		10	0							

Regression equation : Y = 3.929831+0.733106X

χ^2.= 0.0634 with 2 df; no significant heterogeneity

LC_{-50} = 28.875 ng cm^{-2}

95% confidence limits

4.567 -- 182.556 ng cm^{-2}

Log LC_{-50} = 1.460522

Appendix Table 40. Probit mortality of *T. urticae* by propoxur by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
6500	3.8128	62	57	91.94	92	6.41	6.17	6.36	25.11	6.1929
3250	3.5118	57	42	73.68	74	5.64	5.74	5.64	30.32	5.7571
1630	3.2121	66	38	57.58	58	5.20	5.32	5.17	40.65	5.3233
815	2.9611	73	36	49.32	49	4.97	4.89	4.99	45.77	4.8875
Control		12	0							

Regression equation : Y = 3.568524+1.448644X

χ^2.= 2.4111with 2 df; no significant heterogeneity

LC_{-50} = 974.61 ng cm^{-2}

95% confidence limits

684.481 - 1387.714 ng cm^{-2}

Log LC_{-50} =2.9888

Appendix Table 41. Probit mortality of *T. urticae* by cypermethrin by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
162.30	2.2102	40	37	92.50	93	6.48	6.452	6.49	12.08	6.4351
81.15	1.9095	40	34	85.00	85	6.04	6.071	6.00	17.56	6.0570
40.63	1.6085	40	30	75.00	75	5.67	5.689	5.67	22.32	5.6787
20.32	1.3074	40	25	62.50	63	5.33	5.306	5.31	24.64	5.3003
Control		10	0							

Regression equation : Y = 3.656969+1.255692X

χ^2.= 0.0947 with 2 df; no significant heterogeneity

LC-$_{50}$ = 11.708 ng cm^{-2}

95% confidence limits

4.859 -- 28.211 ng cm^{-2}

Log LC-$_{50}$ = 1.0684

Appendix Table 42. Probit mortality of *T. urticae* by lambda-cyhalothrin by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose +1.00	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
1.234	1.0913	125	110	88.00	88	6.18	6.18	6.18	50.62	6.1394
0.617	0.7881	98	81	82.65	82	5.92	5.74	5.89	52.13	5.7135
0.308	0.4885	121	60	49.59	48	4.95	5.30	4.97	75.87	5.2925
0.154	0.1875	120	63	52.50	51	5.03	4.86	5.05	75.24	4.8696
Control		31	2							

Regression equation : Y = 4.606172+1.405001X

χ^2.= 12.1067 with 2 df; variation has been adjusted.

LC-$_{50}$ = 0.1907 ng cm^{-2}

95% confidence limits

0.0975 -- 0.3728 ng cm^{-2}

Log LC-$_{50}$ = -0.719649

Appendix Table 43. Probit mortality of *T. urticae* by azadirechtin by vial residue method after 24 hours of exposure.

Dose (ng cm^{-2})	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
1168.80	1.5906	40	18	45.00	44	4.85	4.86	4.86	25.08	4.8787
584.40	1.2895	40	13	32.50	31	4.50	4.50	4.51	22.32	4.5118
292.20	0.9885	40	9	22.50	21	4.19	4.13	4.21	18.84	4.1448
146.10	0.6875	40	5	12.50	10	3.72	3.76	3.72	13.44	3.7779
Control		10	1							

Regression equation : Y = 2.939933+1.218890X

χ^2.= 2.4729.1257 with 2 df; no significant heterogeneity

LC-$_{50}$ = 1471.266 ng cm^{-2}

95% confidence limits

654.6959 - 3306.309 ng cm^{-2}

Log LC-$_{50}$ =2.1681

Appendix Table 44. Probit mortality of *T. urticae* by carbendazim by leaf disc method after 24 hours of exposure.

Dose (µg cm^{-2})	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.19745	1.2954	51	40	49.38	49	4.97	4.95	4.97	51.35	4.9433
0.09873	0.9944	56	19	33.92	34	4.59	4.67	4.58	33.65	4.6743
0.04936	0.6933	70	21	30.00	30	4.48	4.39	4.40	37.24	4.4053
0.02468	0.3923	51	9	17.64	18	4.08	4.11	4.09	24.02	4.1364
Control		15	0							

Regression equation : Y = 3.785867+0.893476X

χ^2.= 0.6464 with 2 df; no significant heterogeneity

LC-$_{50}$ 0.2285 µg cm^{-2}

95% confidence limits

0.1147 TO 0.4551 µg cm^{-2}

Log LC-$_{50}$ -0.641113

Appendix Table 45. Probit mortality of *T. urticae* by mancozeb by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
12.74	1.1051	51	47	92.17	92	6.41	6.05	6.29	22.39	6.0171
6.37	0.8041	52	52	59.62	60	5.25	5.54	5.22	30.21	5.5234
3.18	0.5024	51	26	50.98	51	5.03	5.04	5.03	32.49	5.0286
1.59	0.2013	58	21	36.21	36	4.64	4.53	4.63	33.70	4.5350
Control		16	0							

Regression equation : Y = 4.204741+1.639932X

χ^2.= 4.7656 with 2 df; no significant heterogeneity

LC_{-50} 3.054463 $\mu g\ cm^{-2}$

95% confidence limits

2.3323 TO 4.0000 $\mu g\ cm^{-2}$

Log LC_{-50}=0.4849348 $\mu g\ cm^{-2}$

Appendix Table 46. Probit mortality of *T. urticae* by sulphur by leaf disc method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
4.2465	1.628	78	50	64.10	63	5.33	5.20	5.35	48.91	5.3038
2.1235	1.327	78	42	53.84	52	5.05	5.10	5.04	49.45	5.1142
1.0618	1.025	100	49	49.00	47	4.92	4.92	4.91	63.40	4.9243
0.5309	0.724	85	37	43.53	41	4.77	4.74	4.76	52.36	4.7350
Control		31	1							

Regression equation : Y = 4.278414+0.629876X

χ^2.= 0.470851 with 2 df; no significant heterogeneity

LC_{-50} 1.39829 $\mu g\ cm^{-2}$

95% confidence limits

0.85656 TO 2.28263 $\mu g\ cm^{-2}$

Log LC_{-50} = 0.145599

Appendix Table 47. Probit mortality of *T. urticae* by carbendazim by vial residue method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.1250	1.0969	146	143	97.94	98	7.05	6.49	6.82	44.09	6.4803
0.0625	0.7958	195	145	74.35	74	5.64	5.82	5.59	98.08	5.8040
0.0313	0.4913	142	76	53.52	53	5.08	5.14	5.06	90.02	5.1199
0.0156	0.1931	151	52	34.44	33	4.56	4.46	4.57	84.26	4.4499
Control		49	0							

Regression equation : Y = 4.016109+2.246485X

χ^2.= 7.0004 with 2 df; no significant heterogeneity

LC_{-50} 0.027414 $\mu g\ cm^{-2}$

95% confidence limits

0.0203 TO 0.0368 $\mu g\ cm^{-2}$

Log LC_{-50} −1.562027

Appendix Table 48. Probit mortality of *T. urticae* by mancozeb by vial residue method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose + 1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.08	0.9031	180	141	78.33	78	5.77	5.78	5.76	95.76	5.7880
0.04	0.6020	218	144	66.05	66	5.41	5.36	5.39	134.28	5.3636
0.02	0.3010	154	73	47.40	47	4.92	4.94	4.91	97.63	4.9392
0.01	0.0206	184	59	52.06	32	4.53	4.52	4.51	106.90	4.5148
Control		38	0							

Regression equation : Y = 4.514781+ 1.410987 X

χ^2.= 0.2467 with 2 df; no significant heterogeneity

LC_{-50} 0.02209 $\mu g\ cm^{-2}$

95% confidence limits

0.0187 - 0.0259 $\mu g\ cm^{-2}$

Log LC_{-50} −1.655804

Appendix Table 49. Probit mortality of *T. urticae* by sulphur by vial residue method after 24 hours of exposure.

Dose ($\mu g\ cm^{-2}$)	Logdose +1	MT	MK	Kill (%)	CM (%)	Emp pro	Exp pro	Wrk pro	Weight	Final pro
0.67	1.526	100	79	79.00	79	5.81	5.75	5.79	53.20	5.7050
0.33	1.518	112	62	55.35	55	5.13	5.39	5.11	68.99	5.3621
0.17	1.230	82	54	65.85	66	5.41	5.06	5.40	52.23	5.0409
0.08	0.903	84	28	33.33	33	4.56	4.69	4.55	50.48	4.6759
Control		21	0							

Regression equation : Y = 3.668988+1.114981 X

χ^2.= 5.3678 with 2 df; no significant heterogeneity

LC_{-50} 0.1562 $\mu g\ cm^{-2}$

95% confidence limits

0.0185 TO 0.3397 $\mu g\ cm^{-2}$

Log LC_{-50} = − 0.806318

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