OVIPOSITION AND DISPERSAL RESPONSES OF
THE TWO SPOTTED SPIDER MITE
Tetranychus urticae Koch (Acari : Tetranychidae)
TO FENVALERATE AND PERMETHRIN RESIDUES IN SOYBEANS
Glycine max (L.) Merrill

By

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Laboratory experiments were conducted to evaluate *Tetranychus* *urticae* Koch dispersal response to fenvalerate and permethrin. A petri dish spider mite trap which allows the partitioning of the dispersal response into spindown and walkoff categories was developed. Fenvalerate induced the more severe dispersal response.

A greenhouse experiment was conducted to evaluate *Tetranychus* *urticae* oviposition site selection in response to residues of fenvalerate and permethrin, at two levels of residue deposition. When pyrethroid-free leaf surface was available, nearly all eggs were found on the untreated surface, away from the pyrethroid residues. When pyrethroid-free leaf surface was not available, a substantial number of eggs were found suspended by silk threads above the treated surface. The results were found to be in agreement with the general pyrethroid avoidance hypothesis.

A series of greenhouse experiments were conducted to evaluate *Tetranychus urticae* oviposition response following impingement, and contact with residues of fenvalerate and permethrin. In all instances the pyrethroids were found to reduce the number of eggs oviposited. Mites recovered after several days, and oviposition returned to normal. The results did not lend support to the hormoligosis hypothesis of insecticide induced mite outbreaks.

Field and greenhouse experiments were conducted to evaluate *Tetranychus urticae* oviposition response, over time, to soybeans which have received an application of fenvalerate of permethrin. The pyrethroids did not alter the soybeans in a way which improved the quality of the plant as a resource for increased levels of spider mite oviposition.

DEDICATION

This work is dedicated to my parents, and with love and appreciation for their support and understanding during my college career.

This work is also dedicated to , who introduced me to entomology; a superb teacher and talented researcher who possesses the kind of vision needed in the world today.

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CHAPTER I

INTRODUCTION

Soybean Production in Virginia

Soybean production in the Commonwealth of Virginia has increased in recent decades. With temperature and soil requirements similar to those of corn, soybeans can easily be integrated into common corn rotations. The crop can be processed into edible oils and flour, high protein animal feed supplements, and even harvested as a high protein animal forage.

650,000 acres of soybeans were planted in Virginia in 1983, an increase of 73.8% over that planted in 1978 (Anon. 1984). Four systems are used for growing soybeans in Virginia (Ferguson 1983). These are: No-till double crop soybeans following barley, no-till double crop soybeans following wheat, full season drill (or broadcast) planted soybeans, and full season conventionally planted soybeans. Although the species of insect pests attacking soybeans do not vary widely from system to system, the relative and total abundance of populations are dependant upon the system used for production (Ferguson 1983).

Arthropod Pests and Their Control in Virginia Soybeans

Four species of insects are annual pests in Virginia soybeans (Greene et al. 1985). These include a leaf feeder, the mexican bean beetle *Epilachna varivestis* Mulsant (Coleoptera : Coccinellidae); a leaf and pod feeder, the corn earworm *Heliothis zea* (Boddie) (Lepidoptera : Noctuidae); and two related species of seed/pod feeders, the green stink bug *Arcosternum hilare* (Say) and the brown stink bug *Euchistus servus* (Say) (Hemiptera : Pentatomidae). Several species of arthropods occur sporadically and may occasionally damage soybeans (McPherson et al. 1981). These include two species of spider mites, the two spotted spider mite *Tetranychus urticae* Koch, and the atlantic spider mite *Tetranychus turkistani* Ugarov and Nikolski (Acari : Tetranychidae). Three insect species which are occasional pests are the green cloverworm *Plathypena scabra* (Fab.) (Lepidoptera : Noctuidae); the bean leaf beetle *Cerotoma trifurcata* (Forster) (Coleoptera : Chrysomelidae); and the japanese beetle *Papillia japonica* Newman (Coleoptera : Scarabaeidae).

Control of destructive insects in Virginia soybeans is achieved by following an integrated pest management strategy developed by V.P.I. and S.U. extension entomologists (McPherson et al. 1981). The Virginia soybean pest management program is based on the integration of cultural, biological, and chemical controls, in conjunction with extensive field scouting, all designed to maintain pest populations below an economic threshold (Allen and McPherson 1982). Greene et al. (1985) recently demonstrated the economic benefits of an integrated approach to insect pest population management.

Spider Mites in Virginia Soybeans

Baker and Connell (1961) noted an increase in the importance of spider mites as pests of soybeans in Delaware, paralleling the increases in soybean acreage since the 1940's. Severe infestations were observed in the middle 1950's, with some fields suffering as much as 50 percent defoliation. Spider mites reached pest status in California soybean fields five of the seven years from 1973 to 1979 (Carlson et al. 1979). Spider mites occur sporadically as a pest of soybeans in Virginia (McPherson et al. 1981). Extensive acaricide applications were made for control during 1977, 1980, and 1983. Acaricides were used on 42,400 acres of Virginia soybeans in 1983 (R.M. McPherson, V.P.I. and S.U., Personal Communication). The atlantic spider mite, T. turkestani, was the most common species in Delaware soybean fields (Baker and Connell 1963). The two spotted spider mite, T. urticae was the most common species in Virginia (Smith and McPherson 1984).

Infestations of spider mites in soybeans are associated with hot and dry periods (Baker and Connell 1961, Smith and McPherson 1984), especially when soybeans are in the pod-fill stages (R3-R6) (Poe 1980). Infestations are often first observed near field borders (Smith and McPherson 1984), from where the infestation slowly expands into the field. Spider mites tend to feed from the underside of the leaflet surface, piercing the pallisade and spongy mesophyll cells with their stylet mouthparts. The feeding mite pumps out the cellular contents, and proceeds to the next cell (Baker and Connell 1963). Feeding damage results in speckling and bronzing of the leaf tissue (Baker and Connell 1963). Dense infestations of spider mites in soybeans can result in premature leaf drop (Smith and

McPherson 1984). The economic threshold level for spider mite damage in soybeans is not well established and only vaguely defined. Current Virginia recommendations for control call for acaricide applications when leaf damage is observed, and live spider mites are present in the fields (McPherson et al. 1981).

Historically, spider mite control in agroecosystems has been achieved through the use of acaricides such as chlorobenzilate, dicofol, and DMC (Huffaker et al. 1969). Concern was expressed in the 1950's and 1960's over the economics of acaricide use in soybeans (Baker and Connell 1963). The per-acre value of the soybean crop has increased since that time, so acaricides are usually cost effective and justified if spider mite population reach damaging levels. Currently, carbophenothion (Trithion ®) and dimethoate (Cygon ® 400) are recommended for spider mite control in Virginia soybeans (Smith et al. 1984).

Pyrethroid Insecticides and Outbreaks of Spider Mites

The pyrethroids fenvalerate (Pydrin® 2.4 EC) and permethrin (Pounce® 3.2 EC or Ambush® 3.2 EC) are effective insecticides recommended for insect control in Virginia soybeans (Smith et al. 1984). The pyrethroids are a relatively new class of synthetic organic insecticides which offer advantages such as low mammalian toxicity, low dosage rates, and broad spectrum insecticidal activity. However, they have the drawback of frequently inciting spider mite outbreaks in crops where they are used. Workers since 1978 have documented the problem of spider mite outbreaks in orchard agroecosystems which are seemingly induced by the application of pyrethroid insecticides (Hoyt et al. 1978, Hall 1979, Riedl and Hoying 1980, Hislop et al. 1981, Penman et al. 1981, Riedl et al. 1981, Hull and Starner 1983, Iftner and Hall 1983b, Penman and Chapman 1983, Iftner and Hall 1984, Hull et al. 1985). At this time, little has been done beyond observation to assess the impact of pyrethroid insecticides on Tetranychus urticae Koch, individuals and populations, in soybean fields.

Historically, several mechanisms have been hypothesized as contributing to agrochemically-induced outbreaks of spider mites. The most common hypothesis concerns the destruction of mite predators, leading to a breakdown in natural control (Huffaker et al. 1969). A second mechanism involves the hormoligosis hypothesis (Luckey 1968), that is, sublethal quantities of an agricultural chemical (in this case a pyrethroid insecticide) can stimulate a female spider mite to increased levels of fecundity (Riedl and Hoying 1980, Maggi and Leigh 1983). A third hypothesis is that pesticides in general (van de Vrie et al. 1972) and pyrethroids in particular (Hoyt et al. 1978, Riedl and Hoying 1980, Iftner and Hall 1983b, Maggi and Leigh 1983) may induce a physiological change in the host plant foliage which then makes the treated plant more suitable for mite reproductive development. A fourth hypothesis is that pesticide residues (van de Vrie et al. 1972), and pyrethroid residues in particular (Penman and Chapman 1983) act as repellents, forcing spider mite populations to disperse to untreated foliage. This induced dispersal releases the spider mite population from certain inter- and intraspecific density-dependent population regulating factors, resulting in a rapid increase in population size.

Research Objectives

The objectives of this research were to:

1. Investigate certain behavioral responses of the two spotted spider mite, *Tetranychus urticae* Koch to residues of fenvalerate and permethrin on soybean foliage.

2. Evaluate *Tetranychus urticae* Koch egg production after direct treatment, and after contact with fenvalerate and permethrin residues on soybean foliage.

3. Determine *Tetranychus urticae* egg production on soybeans treated with fenvalerate and permethrin.

CHAPTER II

LITERATURE REVIEW

Tetranychid Biology

Extensive studies of tetranychid biology were undertaken through the 1950's and 60's. Prior to World War II, the tetranychid mites were of only minor importance as agricultural pests. Post World War II, and following the introduction of synthetic organic pesticides, spider mites were elevated to primary importance as agricultural pests (Huffaker et al. 1969). Interest in tetranychid biology paralleled the increasing economic importance of spider mites. Major reviews by Boudreaux (1963), Huffaker et al. (1969), van de Vrie et al. (1972), and Helle and Overmeer (1973) cover the pre-1970 body of literature pertaining to tetranychid biology, ecology, pest status, and genetics, spanning three decades of research. This section will briefly review the older literature, while concentrating on the more recent additions to our knowledge of tetranychid biology, with the emphasis on the two spotted spider mite, *Tetranychus urticae* Koch.

Life Cycle

Tetranychus urticae develops from an egg, through the larval, protonymphal and deutonymphal stages, prior to reaching the adult stage. The larval form has three pairs of legs, while all other motile stages have four. Transformation to the next higher form occurs during quiescent periods between the motile stages (Boudreaux 1963). The quiescent deutonymph, just prior to ecdysis, is called a teliochrysalid (Shih et al. 1976).

Tetranychus urticae rate of development is strongly dependent on ambient temperature (Boudreaux 1963). A growth budget for T. urticae was constructed by Mitchell (1973), life tables were constructed by Laing (1969) and Shih (et al. 1976). Rate of development data from these studies are presented in Table II-1.

The life cycle is very short, with a mean generation time of 24.0 days at 20.3°C (Laing 1969), and 13.6 days at 27.0°C (Shih et al. 1976). The intrinsic rate of population increase (rm) varies with environmental conditions and experimental technique, but was found to be 0.208 (Watson 1964), 0.143 (Laing 1969), and 0.336 (Shih et al. 1976). Laing considered the relatively low rm value (0.143)

Table II-1. _Tetranychus_ _urticae_ Koch. Data on rate of development from selected life table studies.

Stage	Duration (Days)			
	Laing (1969)		Shih et al.(1976)	
	M	F	M	F
Egg	6.7	6.7	2.3	2.3
Larva	3.6	3.6	0.6	0.6
Protonymph	2.7	3.0	0.4	0.4
Deutonymph (includes Teliochrysalid)	3.1	3.5	2.3	4.3
Teliochrysalid	1.5	1.5	0.4	2.4
Mean Temperature	20.3°C		27.0°C	

and long generation (24.0 days) to be a reflection of the sub-optimum mean temperature of 20.3°C. Overall, males develop faster than females (Laing 1969, Shih et al. 1976).

Fertilization

Fertilization of the females occurs immediately following the transformation to the adult stage (Boudreaux 1963). Multiple matings are possible, but one successful mating will generally service a female through the duration of oviposition (Helle 1967). In contrast, a male will mate many times over its adult life (Helle 1967). As a result, the "functional" sex ratio of a population is skewed strongly toward the males, with intense competition among the males for mating opportunities (Murtaugh and Wrensch 1978). Helle (1967) calculated the probability of a female being fertilized by one class of sperm to be 93.8%. The sperm supply of one male is sufficient to fertilize several dozen females, contributing to a high probability of mating success (Helle and Overmeer 1973). The high probability of fertilization occuring early in the adult female's life improves the population dispersal potential (Mitchell 1970). Fertilized females will produce both sexes, while unfertilized females will produce only males (van de Vrie et al. 1972).

Oviposition

Tetranychus urticae teneral females undergo a short pre-oviposition period, the duration depending on temperature (Laing 1969). The pre-oviposition period lasts approximately one day in the temperature range of 22-27°C (van de Vrie et al. 1972). Total egg production over the life of the female can exceed 100 eggs (van de Vrie et al. 1972). Shih et al. (1976) reported a mean lifetime egg production of 143.9 eggs per female. Laing (1969) reported a mean lifetime egg production of 37.9 eggs per female, with a range from 12 to 125. van de Vrie (et al. 1972) considered egg production in the range of 40 to 80 eggs per female to be the most common. Oviposition was found by Laing (1969) to continue for 15.7 days, and by Shih (et al. 1976); 19 days. Daily egg production varies, with peak production (Wrensch and Young 1975, Shih et al. 1976).

Sex Ratio

The true sex ratio for *T. urticae* is variable and apparently skewed toward the production of females, but to varying degrees (Boudreaux 1963). Laing (1969) reported a ratio of 2.9 females per male. Mitchell (1972) was able to select strains on the basis of sex ratio, concluding that the sex ratio was independent of sperm load and individual response to environmental conditions. The basis for the sex ratio is thought to be polygenic, with inheritance involving a maternal factor (Helle and Overmeer 1973). Wrensch and Young (1978) found the sex ratio of *Tetranychus cinnabarinus* (Boisduval), a sib-species, was reduced in a population maintained under high density conditions. Host plant quality was not found to influence sex ratio.

Diapause

Tetranychus urticae diapauses as an adult female. A color change from green to yellow-orange-red is characteristic (Boudreaux 1963, van de Vrie et al. 1972), and fall fertilization is possible (Boudreaux 1963). Dorsal striations often vary between diapausing and nondiapausing forms (van de Vrie et al. 1972). Diapause is induced by a gradually shortening photoperiod, with the effect modified by temperature and host plant nutritional quality (van de Vrie et al. 1972). Diapause can be broken with a period of chilling (Boudreaux 1963).

Water Conservation

Early workers thought water loss to be a serious problem for spider mites. More recently, research has shown the mite cuticle to be relatively impermeable to water (Boudreaux 1963, Huffaker et al. 1969). Water loss is further reduced through the retraction of the stylophore, which closes the peritremes and spiracular openings (McEnroe 1961a). Water conservation is further enhanced through the excretion of nitrogen in the form of guanine, which is insoluable in water (McEnroe 1961b).

Mineral Nutrition

The mineral nutrition of *T. urticae* has been the subject of continuous study since the 1950's. Research on this topic was fueled by the increasing pest status of spider mites, possibly the result of improved plant cultural practices (i.e. increased fertilizer use) (Huffaker et al. 1969). Rodriguez (1951) found tomato leaf nitrogen to be negatively correlated with <u>Tetranychus bimaculatus</u> Harvey population increases. Phosphorus, up to a certain leaf concentration, was positively correlated with mite population increases. Studies on the metabolism of labeled phosphorous (Rodriguez 1954) confirmed the importance of phosphorus to egg production; as eggs were found to have three times the concentration of phosphorus as that in the mite body. Watson (1964) found that macronutrient deficiencies in lima beans decreased adult longevity and female fecundity. Nitrogen deficiency had the most detrimental effect on adult longevity, phosphorous deficiency had the least effect. Phosphorus deficiency was found to be the most detrimental to female fecundity. Cannon and Connell (1965) found the number of <u>Tetranychus atlanticus</u> McGregor progeny positively correlated with leaf nitrogen and phosphorus in soybeans. Mellors and Propts (1983) recently concluded that the ratio of nitrogen to potassium and phosphorous was more important than the total concentration of all combined. High nitrogen concentration relative to potassium and phosphorous in radish plants appears to promote spider mite infestations.

Host Plant Quality and Population Density

The relative quality of the host plant resource can have a profound effect on certain spider mite fitness traits. Of the four fitness traits evaluated by Wrensch and Young (1975), *T. cinnabarinus* fecundity was found to be most sensitive to host plant resource quality, compared to adult longevity, duration of oviposition, and hatchability. Overall, the developmental rate was considered to be the most important single parameter affecting the intrinsic rate of population increase. Further studies have shown host plant quality during the development of the F_1 generation, and population density, to have effects on *T. cinnabarinus* rate of development (Wrensch and Young 1978). The relative density of the F_1 generation had the most severe effect, reducing the developmental rate, survivorship, and sex ratio of those mites developing under high density conditions. These results support the more general observations of Davis (1952a) of a reduction of *Tetranychus multisetis* McGregor population development under crowded conditions.

Leaf age can have an influence on spider mite population development. Henneberry (1962) reported that two spotted spider mite populations developed more rapidly on younger lima bean foliage than on other foliage. Watson (1964) produced similar results with _T. telarius_, demonstrating reduced fecundity on older lima beans compared to younger. These results differ somewhat from those of Larson and Berry (1984), who found newly expanded peppermint leaves to be only marginally suitable for _T. urticae_ population development. Even so, field studies of _T. urticae_ population ecology in peppermint have shown population to most frequently colonize the upper strata of the peppermint canopy (Hollinsworth and Berry 1982).

Genetics

Early studies on the genetics of the tetranychid mites were extensively reviewed by Helle and Overmeer (1973). _T. urticae_ females have arrhenotokous reproduction. Fertilized (diploid) eggs produce females, while unfertilized (haploid) eggs produce only males. The ultimate mechanism for sex determination in the tetranychid mites is presently unknown (Helle and Overmeer 1973).

Arrhenotokous genetics predisposes tetranychids to acaricide resistance development (Huffaker et al. 1969). Haploidy in males results in the rapid and severe selection of mutations in tetranychid populations. Intra-population variability is relatively low, while variability between populations can be quite high (Helle and Overmeer 1973).

Pheromones and Reproductive Behavior

Adult males are often observed "standing guard" over quiescent female deutonymphs. The guarding male will then proceed to mate with the teneral female, soon after ecdysis. The observations of male attraction to quiescent female deutonymphs led to the hypothesized existance of a local sex pheromone, emitted by the female (Cone et al. 1971a). The existence of the pheromone was confirmed by demonstrating male affinity for clumps of inert plastic treated with the extract of female deutonymphs (Cone et al. 1971a). Additional studies found that female attractiveness increased as ecdysis approached, and that male response to the sex pheromone was occasionally erratic. Some males were observed not to respond to the pheromone at all, while other males would leave the "guarding" position, presumably to feed, for varying lengths of time (Cone et al. 1971b).

Male searching behavior for the quiescent female deutonymph is influenced by at least two factors; the local sex pheromone, and the deutonymphal web (Penman and Cone 1972). Webbing initiates the trend towards linearity in mite searching movements, while the sex pheromone increases the intensity of the response (Penman and Cone 1972). Once a male has located a quiescent female deutonymph, he will assume the guarding position, and attempt to establish dominance over other competing males. Male behavior toward competing males can be very aggressive, often resulting in severe injury. First discovery and establishment of dominance are competitive advantages. The biological sex ratio is skewed toward males because of multiple matings, and active search for females. The aggressive male behavior becomes very important in the successful transmission of an individual's genes to the next generation (Potter et al. 1976). Males of a sibling species, *T. cinnabarinus*, also respond to the *T. urticae* sex pheromone, and are able to compete equally with *T. urticae* females. The progeny of such matings show a reduced sex ratio, but normal fecundity (Murtaugh and Wrensch 1978).

Silk Production

All motile stages of *T. urticae* produce silk, with the amount produced increasing from stage to stage (Saito 1977). The silk is a protein, possibly with moisture absorbing capabilities (Hazan et al. 1975). Low humidities induce the production of large amounts of silk, into which eggs are intertwined (Hazan et al. 1974). White fecal pellets are commonly deposited in the webbing and are suspected of having hygroscopic activity (Hazan et al. 1974). Further study has shown that the hatchability of eggs is reduced under low humidity conditions, following the removal of silk, leading to the hypothesis that silk webbing combined with fecal pellet deposition serve as a humidity regulating mechanism for eggs under low humidity conditions (Hazan et al. 1975).

Spatial Distribution and Dispersal

Tetranychid mite populations are contagiously (aggregated) distributed on the host plant (Boudreaux 1963). Hussey and Parr (1963) noted that *T. urticae* populations in the greenhouse remained in the same location from year to year. In addition, resistant strains commonly appeared in localized populations within the greenhouse, suggesting low levels of population immigration / emigration even within the confines of the greenhouse. Mitchell (1973) observed _T_. _urticae_ females to circumscribe a "territory" using silk, and then restrict feeding and oviposition to within the confines of the territory. Progeny of a female rarely venture outside the confines of the mother's territory. This behavior may serve to ease the task of mate searching by the male. Such behavior would also tend to reduce dispersal under conditions of adequate resources. Mollet and Sevacherian (1984), in an attempt to develop a reliable sampling plan for spider mites in cotton, found that mites could be most reliably found on mainstem node #5, which is usually found in the upper 1/3 of the cotton canopy. Hollingsworth and Berry (1982) noted a similar distribution of spider mites in peppermint fields. Early infestation of spider mites in soybeans are frequently observed on older foliage (Poe 1980).

Light has been shown to influence spider mite dispersal (Huffaker et al. 1969). McEnroe and Dronka (1971) demonstrated that under high density conditions, dispersal from damaged plant tissue is tied to a shift in photobehavioral response. The shift from green (-) class (non-dispersing) to the green (+) class (dispersing) may be due to water stress and low relative humidity. These workers showed that the response class was not heritable. Overall, the trend is to disperse from an exhausted food supply to a new resource (Huffaker et al. 1969). McEnroe and Dronka (1971) noted that teneral females belonged to the green (+) class up to the point of first feeding (approximately 24 hours), after which they switched to the green (-) class, returning to the green (+) only under conditions of water stress (resource depletion). This supports the observations (Hussey and Parr 1963) of teneral females dispersing away from the leaf upon which they developed, even when the original resource was still in good condition.

The unclear taxonomic status of the tetranychid mites as outlined by van de Bund and Helle (1960) and Boudreaux (1956) has complicated the interpretation of some of the early literature on tetranychid dispersal. The most significant mode of T. urticae dispersal was thought to be walking, augmented by the "roping" phenomenon (Hussey and Parr 1963). To initiate roping, mites will gradually drop from the plant surface on silken threads 7-10 mm long, one after the other until a silk rope of up to several millimeters in length is formed. Hundreds of dispersing mites of all age classes could be found on, or trapped within the silk rope. The rope will eventually reach the ground, or sway in air currents until it contacts a neighboring plant, forming a "bridge" for the dispersing population (Hussey and Parr 1963).

Some species of tetranychids have been observed to "balloon", or air drift, in air currents by virtue of their ability to spin a long silken thread, or a "parachute". Wind dispersal of Metatetranychus citri (McGregor), Oligonychus punicae (Hirst) and Eotetranychus sexmaculatus (Riley) has been observed (Fleschner et al. 1956). Tetranychus telarius (thought to be T. urticae by Boykin and Campbell (1984)) was not observed to air drift (Fleschner et al. 1956). This idea was supported by Hussey and Parr (1963), with T. urticae. In another report, T. telarius (actually T. cinnabarinus) was observed to wind disperse from bean plants, although the mites were more likely to perish on the depleted resource (Boyle 1957). More recently, Brandenburg and Kennedy (1982) observed wind dispersal of *T. cinnabarinus* from heavily infested field corn. The findings of another recent study on wind dispersal of *T. urticae* in peanut fields (Boykin and Campbell 1984) contradicts earlier work, concluding that wind dispersal is an important component of *T. urticae* ecology in peanut fields. Phoresy may contribute to spider mite dispersal (Boudreaux 1963, Poe 1980), although there are some doubts of its importance (Mitchell 1973).

General Insecticide / Spider Mite Interactions

Phytophagous mite interactions with agricultural pesticides have been of interest to researchers since the late 1940's. An early review by Ripper (1956) listed 216 papers on the general topic of pesticides and their effect on arthropod populations. In the short span of only ten years following World War II, 50 insect and mite species had demonstrated resurgence following pesticide applications. Three general hypotheses were suggested by Ripper as possible explanations for this phenomenon:

1. The reduction of natural enemy populations following pesticide use.

2. Favorable influences of pesticides on phytophagous arthropods.
3. The removal of competitive species.

DDT, a chlorinated hydrocarbon, was the major insecticide in use at that time.

Moriarty (1969) reviewed the literature on sublethal effects of insecticides on insect species. Spider mite research was not included in the review, but the subtle effects of DDT on insect physiology and behavior was discussed. Moriarty emphasized the difficulties inherent in uncovering subtle physiological and behavioral responses in arthropods. Huffaker et al. (1969), in a discussion of general tetranychid ecology and natural control, briefly reviewed some of the literature on pesticide induced spider mite outbreaks. The authors acknowledge the "explosion" of spider mite populations which usually followed the introduction of new pesticides. Only scant and contradictory evidence for the direct reproductive stimulation of tetranychid mites was found. The potential for pesticide stimulation of plants by such insecticides as DDT, carbaryl, parathion, and diazinon as contributing factors to tetranychid resurgence was noted.

van de Vrie et al. (1972) published an extensive review of the pre-1970 literature on tetranychid interactions with agricultural chemicals. The authors reiterated Ripper's (1956) hypotheses on insect population resurgence, and added that pesticide formulations may be a contributing factor.

Luckey (1968) proposed the term hormoligosis to describe the phenomenon of arthropod reproductive stimulation by sublethal dosages of agricultural pesticides. The hormoligosis hypothesis predicts that:

"Subharmful quantities of any stressing agent will be stimulatory to the organism by providing it with increased sensitivity to respond to changes in its environment and increased efficiency to develop new or better systems to fit a sub-optimal environment." (Luckey 1968)

Hormoligosis is observed when dietary antibiotics are fed to immature poultry, stimulating growth (Luckey 1968). Although not explicitly stated, hormoligosis was the working hypothesis for much of the research on pesticide / spider mite interactions over the previous three decades. In a brief review of the literature on spider mite outbreaks following insecticide applications, Bartlett (1968) noted that neither natural enemy destruction or pest fecundity stimulation adequately explained spider mite population increases in all cases. Of the 59 pesticides reviewed, 25 were reported as upsetting the normal balance of spider mite population. The remainder of this section will be devoted to the physiological and behavioral responses of tetranychid mites to DDT, organophosphates, carbamates, and formamidine insecticides / acaricides.

DDT : Physiological Responses

The literature on reproductive and developmental rate responses of tetranychid mites to DDT has been throughly reviewed by others (Bartlett 1968, Huffaker et al. 1969, van de Vrie et al. 1972). A summary of the pertinent literature in presented in tables II-2 and II-3. In conclusion, the sum total of the research on hormoligosis as a contributor to phytophagous mite outbreaks following DDT applications is inconclusive, and often contradictory.

Table II-2. Tetranychidae. Reports of observed phytophagous mite outbreaks following DDT applications.

Date	Author(s)	Location	Crop
1950	Huffaker & Spitzer	California	Pears
1952	Clancy & Pollard	Virginia	Apples
1952	Michelbacher & Bacon	California	Walnut
1959	Klostermeyer	Washington	Alfalfa
1959	Putman & Herne	Ontario	Peaches

Table II-3. Tetranychidae. Compilation of common mite responses to DDT.

		Responses Observed			
		Stimulated Reproduction		Natural Enemy Demise	Stimulated Rate of Development
		Generation			
Date	Author(s)	P	F		
1948	Wingo & Thomas	N	N	-	N
1950	Huffaker & Spitzer	Y*	-	N*	-
1952	Clancy & Pollard	-	-	Y	-
1952	Davis	-	-	-	N
1952	Hueck et al.	Y	-	-	-
1958	Locher	Y	-	-	-
1960	Pielou	N	-	-	-
1961	Seifert	-	Y	-	-
1963	Putman	N	-	-	-
1964	Attiah & Boudreaux	N	N	-	-
1966	Saini & Cutkomp	N	-	-	Y**
1966	Sanford & Herbert	-	-	Y	-
1974	Dittrich et al.	Y	Y	-	-

* Authors expressed some reservation

** F_1 females only, Y = Yes, N = No

DDT : Behavioral Responses

The body of literature on tetranychid behavioral responses to DDT residues is much less extensive, but no less controversial than the hormoligosis literature. Davis (1952b) observed *Tetranychus multisetis* McGregor to disperse away form DDT residues. DDT was considered to be an irritant (for lack of a better term) which appeared to increase mite locomotor activity. Pielou (1960) confirmed this observation, as *Panonychus ulmi* (Koch) females were more likely to spend time, and oviposit, on untreated surface. DDT was considered to be an irritant which repels mites.

Putman (1963) did not observe any change in *P. ulmi* distribution on peach trees following DDT treatment. Attiah and Boudreaux (1964b) did not consider DDT induced dispersal of spider mites to be direct contributor to mite outbreaks. These workers postulated that the destruction of natural enemies following DDT treatment would allow for relatively unrestricted dispersal of spider mites from crowded colonies, possibly resulting in a mite outbreak. In this scenario, DDT would be an indirect influence on spider mite dispersal.

Organophosphates: Physiological Responses

Wolfenbarger (1948) noted increases in potato yields following treatment with three phosphatic insecticides and phosphoric acid. The yield response could not be explained by adequate insect control alone. Mathys et al. (1968) noted a general increase in mite populations on parathion treated pears, while no such increase was observed on gusathion treated plants. Overall, the mite reproductive response was highly variable, with some replicates showing increased populations. Changes in leaf nitrogen, phosphorus, potassium, calcium, and magnesium could not explain the changes in mite population densities.

Penman et al. (1981) showed azinphos-methyl to slightly reduce *T. urticae* oviposition. Leigh and Wynholds (1980) found more eggs and immature mites on cotton plants treated with methyl parathion. Dimethoate and methyl parathion had no effect on *T. urticae* rate of development or egg hatch. Maggi and Leigh (1983) found increased levels of oviposition in the first four days of *T. urticae* adult life on parathion treated cotton plants. Mites on parathion treated plants exhibited a greater population growth potential compared to those on phosphoric acid treated plants. Results form the field experiments were more consistent than results from the greenhouse experiments.

Organophosphates: Behavioral Responses

Minimal research has been done on this topic, but organophosphates such as azinphos-methyl (Penman et al. 1981) and phosmet (Iftner and Hall 1983b) do not appear to be irritants.

Carbamates: Physiological Responses

Carbaryl has been recognized for its potential to induce spider mite outbreaks in orchards (Putman and Herne 1960) and peanuts (Campbell 1978). Putman and Herne (1960) noted several effects on phytoseiid predators, while carbaryl was relatively innocuous to tetranchids. Dittrich et al. (1974) found hormoligosis effects in *T. urticae* following carbaryl treatment. The responses included a shift towards females in the F_1 generation following treatment of the parents, and higher egg production by the P and F_1 generations. Chang and Knowles (1978) showed that aldicarb metabolism reactions in *T. urticae* were similar to those observed in insect species. Aldicarb has a degree of acaricidal activity against tetranychids. Penman et al. (1981) could not demonstrate a hormoligosis effect by carbaryl on *T. urticae*, disagreeing with the findings of Dittrich et al. (1974).

Formamidines: Behavioral Responses

Formamidines differ from the previously discussed insecticide groups by having excellent acaricidal properties. Chlordimeform is the most well known member of this class of insecticides / acaricides. Distinct behavioral responses by tetranychids to formamidine residues have been observed. *T. urticae* and *T. cinnabarinus* have been observed to disperse away from residues through conventional locomotion, or "walkoff", and by dropping from the leaf surface on a silk thread, or "spindown" (Gemrich et al. 1976, Gerson and Aronowitz 1981, Franklin and Knowles 1984). The choice of dispersal response may be related to the specific structure of the formamidine compound Gemrich et al. (1976).

Tetranychid Responses To Pyrethroid Insecticides

Elliot et al. (1978) reviewed the progress made with photostable pyrethroids for insect control. Low use rates, broad spectrum activity, and favorable toxicological properties were considered to be major advantages of pyrethroid use. A disadvantage was the recognized potential for the development of resistance, especially cross resistance to DDT. These authors did not foresee the spider mite problems. At that point in time, the potential for pyrethroid induced outbreaks of spider mites was not documented or recognized.

Croft and Hoyt (1978) noted the early reports of spider mite outbreaks in orchard systems, and cautioned against the rapid integration of pyrethroid insecticides into IPM programs traditionally based on organophosphate insecticides. Since these early reports of spider mite outbreaks, research worldwide on the pyrethroid-spider mite problem has blossomed in much the same manner as did the research on the DDT-spider mite problem two decades earlier. In this final section the literature on pyrethroid-spider mite interactions will be reviewed. Reports are categorized as observational, toxicological, physiological, or behavioral based on the nature of the reported responses.

Observational Reports

A number of papers since 1977 have documented the pyrethroid-spider mite problem. Hall (1977) noted outbreaks of spider mites in Ohio and Michigan apple orchards following pyrethroid applications. Outbreaks of *Tetranychus urticae*, *Tetranychus mcdanieli* McGregor, and *Panonychus ulmi* followed the use of fenvalerate and permethrin in Northwestern U.S.A. apple and pear orchards. Both materials showed initial, but short lived, acaricidal activity. Both insecticides were highly toxic to an important mite predator *Metaseiulus occidentalis* (Nesbit) (Acari: Phytoseiidae) (Hoyt et al. 1978).

Hoy et al. (1979) recorded dramatic increases in populations of *Tetranychus pacificus* McGregor following applications of permethrin in vineyards. *M. occidentalis* is an important mite predator in the vineyard system, and was found to be very susceptible to the insecticide. *Tetranychus pacificus*, in contrast, was tolerant of low to moderate rates of permethrin. Hall (1979) evaluated several pyrethroid insecticides in apples. The pyrethroids were effective insecticides, but their use led to a general resurgence of P. ulmi populations.

Fenvalerate induced outbreaks of T. urticae in Northern California pear orchards, but provided good control of the pear psylla. Higher dosages of fenvalerate initially appeared to be acaricidal. A correlation was observed between the amount of foliage present at the time of the fenvalerate application and the peak summer populations of T. urticae. As pyrethroid applications were made later in the season T. urticae populations showed corresponding increases.

Pyrethroid induced disruption of orchard systems has been observed in parts of the world other than North America. Bower and Kaldor (1980), working in Australia, did not observe undue increases in T. urticae populations following applications of permethrin, but did note an absence of phytoseiid predators on the treated trees. Permethrin was observed to have acaricidal activity on spider mites. Aliniazee and Cranham (1980) reported on outbreaks of P. ulmi in Southeast England apple orchards following applications of permethrin, cypermethrin, fenvalerate, and decamethrin. All were highly toxic to *T. pyri*, but showed no activity on *P. ulmi*.

Hislop et al. (1981) suggested the use of pyrethroid treated protein hydrolysate bait for the control of the walnut husk fly in walnut. Partial treatment of the tree resulted in good fly control, and restricted the spider mite buildup to the treated portions of the tree canopy. Reidl et al. (1981) summarized the California work on pyrethroid use in pear orchards for psylla control, suggested that pyrethroid be restricted to use during the pre-bloom period. Pre-bloom applications were found to be less disruptive than the foliar applications later in the season.

Hull and Starner (1983), found from six seasons of field data in Pennsylvania apple orchards, that fenvalerate and permethrin were highly toxic to the predatory mites *Amblyseius fallacis* (German) (Acari : Phytoseiidae) and *Zetzellia mali* (Ewing) (Acari : Stigmaeidae). A more general predator *Hyaliodes vitripennis* (Say) (Hemiptera : Miridae), and an important coccinellid predator of spider mites *Stethorus punctum* (LeConte) (Coleoptera : Coccinellidae) appeared less affected by the pyrethroids. None-the-less, spider mite outbreaks were observed, and caution was recommended in the use of pyrethroids for insect control in orchard systems. In a later paper, Hull et al.(1985) showed that season-long control of insect pests of apple with fenvalerate was economically competitive with traditional spray programs, but resulted in outbreaks of _P_. _ulmi_. Moreover, a dose response was observed, since larger mite populations were found on trees sprayed with the higher dosages. _Stethorus punctum_ never successfully established in the fenvalerate treated block, although it did establish in the conventional, organophosphate treated block.

Comparative Toxicology : Phytophagous Versus Predatory Mites

Numerous observations of predator mite destruction following pyrethroid applications led to studies by several workers on the comparative toxicity of pyrethroid insecticides to pest and predatory species of mites. All studies, with the exception of Penman et al. (1981), were based on the slide dip technique. Roush and Hoy (1978) found _T_. _urticae_ to be 20 to 40 times more tolerant of permethrin than the phytoseiid predator _M_.

occidentalis. The authors suggested that only very low use rates of permethrin could spare the predators in field systems. Wong and Chapman (1979) found fenvalerate and cypermethrin to be highly toxic to the phytoseiid predators *T. pyri*, *M. occidentalis*, and *T. urticae*. Azinphos-methyl, an organophosphate insecticide used for many years in apple orchards, was much less toxic to the phytoseiids. Rock (1979) also found fenvalerate and permethrin to be highly toxic to *A. fallacis*. Both insecticides were relatively innocuous to *T. urticae*, although fenvalerate was about three times more toxic to *T. urticae* than permethrin. Iftner and Hall (1983a) found fenvalerate to be approximately 10 times more toxic to *P. ulmi* and *T.urticae* than permethrin, with *P. ulmi* being the most susceptible to both materials. In a study using a treated leaf disk bioassay, Penman et al (1981) found fenvalerate residues to be only slightly toxic to *T. urticae*.

Pyrethroids : Physiological Responses

Penman et al. (1981) found that fenvalerate, residues and direct treatment, reduces *T. urticae* egg production. The effect was not permanent, as egg production returned to normal after the mites were removed from contact with the pyrethroid. Fecal pellet production was not diminished by fenvalerate treatment, suggesting that the reduced level of oviposition was not due to and inhibition of feeding. Iftner and Hall (1984) confirmed that fenvalerate treatment reduced T. urticae oviposition, but not permethrin. T. urticae reared 15 generations on permethrin and fenvalerate treated lima bean foliage showed a slight increase in total egg production, combined with a shift towards earlier oviposition. These workers also reported a one to two day shortening of the immature rate of development period for mites exposed to permethrin and fenvalerate residues, Minimal data were presented to support this claim. The authors concluded that the slight increase in egg production, combined with the shift toward an earlier fecundity schedule and a shorter developmental time, could help explain the phenomenon of pyrethroid induced spider mite outbreaks. McKee and Knowles (1984) reported on the results of laboratory studies which suggest that some pyrethroid insecticides can stimulate T. urticae respiration. The authors suggested that just such a stimulation could contribute to hormoligosis.

However, their data actually show a decrease in mite respiration following treatment with fenvalerate and permethrin.

Pyrethroids : Behavioral Responses

Hall (1979) noted a change in *T. urticae* behavior on foliage treated with fenvalerate. *T. urticae* females oviposited and fed to a greater degree on the untreated surface, when presented with a choice of treated versus untreated surface. Penman et al. (1981), noted an increase in *T. urticae* walkoff from fenvalerate treated lima bean leaf disks, the degree of which was positively correlated with the treatment rate. Penman and Chapman (1983), using whole lima bean plants, noted that *T. urticae* individuals dispersed away from fenvalerate treated portions (leaves) to untreated portions of the plant. Mites would not colonize treated foliage. When the entire plant was treated with fenvalerate, *T. urticae* populations were significantly reduced. Spindown from fenvalerate treated foliage was observed, and suspected of being a significant component of *T. urticae* dispersal from fenvalerate residues.

Iftner and Hall (1983b) found that *T. urticae* females were repelled by fenvalerate and permethrin residues on soybean, and what appeared to be disruptions in feeding behavior. Fenvalerate showed a more severe and longer lasting effect than did permethrin. Spindown from pyrethroid treated foliage was also observed. In another study designed to evaluate _T_. _urticae_ physiological response to fenvalerate and permethrin, Iftner and Hall 1984 observed _T_. _urticae_ eggs suspended on silk threads above the pyrethroid treated foliage, a condition rarely observed with the host plant still undamaged. Although the previously mentioned studies show pyrethroids to disperse spider mites, Mollet and Sevacherian (1984) did not observe any alteration in the distribution of spider mites in cotton fields following the application of pyrethroid insecticides.

Chapter III

DISPERSAL RESPONSE OF *Tetranychus* *urticae* Koch (Acari: Tetranychidae) TO FENVALERATE AND PERMETHRIN RESIDUES ON SOYBEANS, *Glycine* *max* (L.) Merrill

INTRODUCTION

Concern regarding pyrethroid induced outbreaks of spider mites has increased in recent years. The commonly hypothesized cause, predator reduction, fails to adequately explain the occurrence of spider mite outbreaks following pyrethroid applications in agroecosystems where natural enemies are of limited value in regulating mite populations (Hall 1979, Reidl and Hoying 1980). Pyrethroid induced dispersal of spider mites has been observed (Hall 1979, Penman et al. 1981, Penman and Chapman 1983, Iftner and Hall 1983b), and postulated as a mechanism contributing to mite outbreaks (Penman and Chapman 1983, Iftner and Hall 1983b). Dispersed mites relocate sufficiently far from the original infestation so as to be released from limiting factors such as intra-specific competition for nutrients and predation by natural enemies. Survivability and fecundity of colonizing mites and their progeny is increased, as is the effective rate of population development.

DDT contributed to spider mite outbreaks through the indirect influence of spider mite dispersal (Attiah and Boudreaux 1964b). Formamidine compounds, such as chlordimeform, have been shown to cause a hyperactive response in ticks resulting in detachment from the host, and random, rapid walking behavior (Atkinson and Knowles 1974). However, organophosphate insecticides such as azinphos-methyl (Penman et al. 1981) and phosmet (Iftner and Hall 1983) did not induce a dispersal response in the two spotted spider mite *Tetranychus urticae* Koch.

The two methods by which spider mites have been observed escaping pesticide residues have been termed "walkoff" and "spindown" (Gemrich et al. 1976, Gerson and Aronowitz 1981). Mites which escape from pesticide residues by dropping from the leaf on a fine silk thread apparently do not return to the leaf surface. These mites remain suspended several millimeters under the leaf (Gerson and Aronowitz 1981). Results from experiments by Penman and Chapman (1983) with *T. urticae* infesting beans showed spindown to be the most significant component of the total spider mite dispersal from fenvalerate treated leaf tissue. Their results also suggested, but could not prove, that the spindown response to permethrin may be less severe than the response to fenvalerate. Iftner and Hall (1983b) evaluated T. urticae dispersal response to fenvalerate and permethrin on soybeans, but did not attempt to partition the walkoff from the spindown dispersal. Whole plants were used in both of their studies.

The objectives of my study were to :

1. Evaluate T. urticae dispersal response to fenvalerate and permethrin on soybeans.
2. Partition the dispersal response into walkoff and spindown components, so that the relative significance of each could be evalutated.
3. Develop an assay of spider mite dispersal response to pesticides which would be easy to use, and avoided the use of whole plants.

Materials and Methods

The two spotted spider mites used in these experiments were drawn from a laboratory colony maintained on "Essex" soybeans held at 20-30°C, 30-60% r.h., and 16 hour photoperiod. Water emulsions (120 ppm) of formulated fenvalerate (Pydrin ® 2.4 EC) and permethrin (Pounce ® 3.2 EC) were prepared for each experiment. Experiments were run under controlled temperature and continuous lighting regimes in a plant growth chamber. The first set of experiments involved individual mites held inside small leaf cages attached to the undersides of unifoliate soybean leaves. The second set of experiments were designed to place a more precise value on walkoff dispersal in the controls, and eliminate the necessity for whole plants.

Experiment I. "Essex" soybeans were grown under greenhouse conditions, in Metro-Mix® 500 potting medium. Four plants were raised in individual 10 cm x 10 cm plastic pots until the unifoliate leaves were fully expanded. Small leaf cages were constructed from a 6 mm x 55 mm strip of lightweight, clear plastic sheeting, formed into a 15 mm diameter ring, and glued to a 20 mm diameter disk of 55 x 55 meshes per cm nylon screen.

free on leaf surface, trapped in Tanglefoot (walkoff), or free on leaf cage plastic/netting (spindown). The data from the four repetitions were pooled. The pooled data was considered to be discontinuous, requiring the use of a chi-square analysis with 4 degrees of freedom on a 3X3 contingency table.

Experiment II. "Essex" soybeans were seeded in a 30 cm x 61 cm plastic flat containing Pro-Mix potting medium. Plants were maintained outdoors until the leaflets of the second trifoliates were fully expanded. The flat was divided into three sections of equal size, the sections separated, and moved to individual flats. Treatments were applied to run-off with a hand-held pump sprayer. The control section was sprayed to run-off with distilled water. All treatments were allowed to dry.

Traps were constructed from 100 mm x 10 mm plastic petri dishes. Each dish was separated into upper (cover) and lower halves. A 30 cm^3 plastic syringe was used to apply a bead of Tanglefoot circumscribing the inside bottom of the dish. A piece of double-sided sticky tape was used to suspend an excised soybean leaflet inside the dish cover, abaxial surface down. The lower half of the dish served as a trap for mites which descended from the leaf surface. The point of attachment of the adaxial leaflet surface to the dish cover allowed mites to "walkoff" the leaflet and onto the dish surface.

Ten leaflets were sampled randomly from each of the treatments. A 3/0 camel's-hair brush was used to place three adult female spider mites near the center of the abaxial leaflet surface. Each cage was assembled and placed inside a plant growth chamber.

Experiments were allowed to run four hours at 25±0.5°C, 45-60% r.h., under continuous light. After four hours the cages were opened and the location of the mites determined with the assistance of a 20X stereo microscope. Spider mites found within the Tanglefoot ring around the bottom of the petri dish were recorded as having "spun-down". Spider mites which had not "spun-down", but were not found on the leaflet surface, were recorded as having "walked-off". Spider mites found on the leaflet surface were recorded as not dispersed, and their location (adaxial or abaxial) was recorded. Spider mites which had become entrapped in the Tanglefoot barrier were classified according to their orientation in the barrier. The experiment was repeated three times. Data from the three repetitions were pooled and analyzed in a manner similar to experiment I.

Results

Experiment I. This experiment was designed to partition the mite dispersal response into walkoff and spindown components. The results were consistent for the four repetitions of the experiment (Table III-1). comparing the relative size of the dispersing cohorts, fenvalerate (88%) proved more likely to induce dispersal than permethrin (58%). However, 36% of the control cohort also dispersed.

Out of 31 total observations, only one mite spun down in the control. The incidence of spindown was increased by pyrethroid treatment of the foliage, with more spindown observed in the fenvalerate treatment (9 of 31) compared to the permethrin treatment (6 of 31). Walkoff dispersal in the control (10 of 31) and permethrin treatments (12 of 31) were similar, although less than the walkoff observed in the fenvalerate treatment (19 of 31). Several of the dispersing mites were observed suspended by silk threads. Mortality attributable to pyrethroid poisoning was not observed, although mites were occasionally lost due to cage failure. The small leaf cage/whole plant technique was awkward to use. The proximity of the Tanglefoot

Table III-1. *Tetranychus urticae* Koch. Locations of female mites 12 hours after placement on treated foliage.

Treatment	Not Dispersed	Dispersed Walk off	Dispersed Spindown	Total[1] Dispersed
Water/Control n=31	20	10	1	(11)[3] 36%[4]
Permethrin n=31	13	12	6	(18) 58%
Fenvalerate n=32	4	19	9	(28) 88%

X^2 value[2] = 19.7 p = 0.001

[1] Not included in the Chi-Square analysis.

[2] 3 X 3 Contingency Table.

[3] Actual number observed.

[4] Percent of total observations.

barrier to the mite feeding on the leaflet surface may have led to accidental entrapment, inflating the extent of true walkoff dispersal in the control. Because of this, another experimental approach was used in experiment II.

Experiment II. This experiment was designed to more precisely evaluate walkoff dispersal, and to eliminate the use of whole plants. Results were consistent for the three repetitions of the experiment (Table III-2). Dispersal in the controls (15%) were substantiallly reduced from the level observed in experiment I (36%). Dispersal in the permethrin (56%) and fenvalerate (81%) treatments were reduced only slightly compared to the results of experiment I.

Walkoff dispersal in the pyrethroid treatments was markedly increased over that observed in the controls (7 of 88), with little difference between the permethrin (19 of 84) and fenvalerate (21 of 90). Spindown dispersal was also greatly increased in the permethrin (28 of 84) and fenvalerate (52 of 90) treatments, while spindown in the control remained a relatively rare event (6 of 88). An almost 5-fold increase in spindown was observed in the permethrin treatment, along with a nearly 9-fold increase in the

Table III-2. _Tetranychus urticae_ Koch. Locations of female mites four hours after placement on treated foliage.

Treatment	Not Dispersed	Dispersed		Total[1] Dispersed	
		Walkoff	Spindown		
Water/Control n=88	75	7	6	(13)[3]	15%[4]
Permethrin n=84	37	19	28	(47)	56%
Fenvalerate n=90	17	21	52	(73)	81%

X^2 value[2] = 81.9   p = 0.001

[1] Not included in the Chi-Square analysis.

[2] 3 X 3 Contingency Table.

[3] Actual numbers observed.

[4] Percent of total observations.

fenvalerate treatment. A portion of the spider mite cohort in each treatment which had been classified as "not dispersed" in Table III-2, had in fact, dispersed from the abaxial (lower) leaf surface, the original point of placement, to the adaxial (upper) leaf surface (Table III-3). In the table it can be seen that fenvalerate induced a more severe dispersal response (35%), than did permethrin (19%) and the control (4%). Mortality attributable to pyrethroid poisoning was not observed.

The petri dish trap/excised soybean leaflet technique was a marked improvement over the use of whole plants. Large numbers of leaflets could be treated rapidly, and in a manner which approximates field spray applications. The ease of setup, transfer, and recording of mite locations afforded by the use of small units instead of whole plants, allowed for the observation of a larger number of mites.

Table III-3. *Tetranychus* *urticae* Koch. Distribution of "not-dispersed" female mites between upper and lower leaf surfaces 4 hours after placement on treated foliage.

Treatment	Observations	Upper Surface (%)	Lower[1] Surface (%)
Control	75	4	96
Permethrin	37	19	81
Fenvalerate	17	35	65

X^2 value[2] = 14.6 $p = 0.005$

[1] All mites originally released on the lower surface.

[2] 3 X 2 Contingency Table

Discussion

The proportion of the control cohort in experiment I found entrapped in the Tanglefoot barrier was higher than expected. This result was most likely an artifact of the small leaf cage technique. Numerous observations of T. urticae encounters with Tanglefoot suggest that the mites are slightly repelled when the presence of the material is detected by contact with the forelegs. Excessive contact with the sticky barrier may cause the mite to fall from the leaf surface and into the Tanglefoot. The petri dish trap used in experiment II apparently alleviated this problem because exposure to the Tanglefoot was limited until after dispersal had occurred. Since there can be differences in chemical adsorption to the leaf surface between leaf dip and spray application techniques, spray treatment used in experiment II should more closely duplicate field conditions.

The techniques used did not allow for direct observation of spider mite dispersal. Saito (1977) observed T. urticae frequently falling off the leaf surface, but the falls always resulted in mid-air suspension. I have made similar observations of T.urticae adult females traversing the undersides of soybean leaflets. The mites frequently fall several millimeters, but are suspended by a silk thread. Continuous silk production while walking has been postulated by Saito (1977) as an explanation for this phenomenon, and I observed nothing to discredit this idea. *Tetranychus urticae* females can quickly return to the leaf surface via the thread following an "accidental" fall. Gerson and Aronowitz (1981) did not observe *Tetranychus cinnabarinus* (Boisduval) returning to the leaf surface following spindown in response to certain acaricide treatments. The choice not to return to the leaf surface may be due to some factors influencing mite behavior, not the physical limitations of the mite.

Both sets of experiments show that fenvalerate induces a more severe dispersal response than permethrin, results which are in agreement with those of Iftner and Hall (1983b). These workers evaluated *T. urticae* dispersal after a 24 hour period. My results conclude that much, if not all, of the dispersal will occur within four hours after treatment. Penman and Chapman (1983) suggested that fenvalerate may induce a more severe spindown response than permethrin. Data from experiment II are clear in showing fenvalerate to induce a more severe spindown response than to permethrin.

Data in Table III-3 provide additional confirmation of pyrethroid induced dispersal of *T. urticae*, and the variation in individual response to the pyrethroids. These mites had not dispersed from the leaf, but some were induced to move to the upper leaf surface. Again, fenvalerate invoked the most severe response.

The petri dish trap technique proved to be a reliable method for quickly assessing mite dispersal response to pesticides. The units are inexpensive, easy to set up, and allow for the evaluation of a number of individuals. In a broad sense, the results obtained were similar to those obtained using whole plant (Penman and Chapman 1983, Iftner and Hall 1983b) and excised leaf disk (Penman et al. 1981) techniques. The trap is an improvement in that it allows the dispersal response to be broken down into two components, in a reliable manner, without the complication of using potted plants. The trap allows spindown to be evaluated, which is not possible when using leaf disks on wet cotton. The relationship between dispersal and spider mite outbreaks following pyrethroid applications was described by Iftner and Hall (1983b). Unfortunately, little information is available on pyrethroid induced dispersal in field situations. A recent study by Mollet and Sevacherian (1984) with several of the newer pyrethroids (not including permethrin and fenvalerate) showed no change in the within-plant distribution of *T. cinnabarinus* infesting field cotton. Spider mites suspended by fine silk threads would be exposed to air currents, therefore being likely candidates for wind dispersal. Boykin and Campbell (1984) found increased wind dispersal of spider mites from peanut plots treated with certain pesticides, none of which were pyrethroids. The increased incidence of wind dispersal was attributed to a large buildup of the mite populations in these plots. The differences in formulation chemistry may be a factor influencing the repellency phenomenon (Gould 1984).

In summary, my data support previous studies on pyrethroid induced spider mite dispersal in other crops. This study shows spindown to be the most important method of *T. urticae* dispersal from fenvalerate, but not as important from permethrin residues. In addition, the dispersal response will be manifest within four hours after treatment. The petri dish technique appears to be an improvement over previous whole plant and leaf disk techniques. This information on spider mite behavior should be useful to the soybean integrated pest management programs being developed throughout the country. Treatment decision guidelines for controlling arthropod pests should begin to incorporate information such as this so that pest resurgence or secondary pest outbreaks can be minimized.

Chapter IV

OVIPOSITION SITE SELECTION BY *Tetranychus urticae* Koch (Acari: Tetranychidae) IN RESPONSE TO FENVALERATE AND PERMETHRIN RESIDUES ON SOYBEANS, *Glycine max* (L.) Merrill

INTRODUCTION

Pyrethroid insecticides influence the dispersal behavior of the two spotted spider mite, *Tetranychus urticae* Koch (TSSM) (Iftner and Hall 1983b, Penman and Chapman 1983). Spider mites escape pyrethroid residues by walking to plant surfaces devoid of residue, or by descending from the treated surface on silk threads (Penman and Chapman 1983). Fenvalerate (Pydrin® 2.4 EC) elicits a more severe overall dispersal response, including a greater "spindown" response, than does permethrin (Pounce® 3.2 EC) (see chapter III). The dispersal of spider mites in response to pyrethroid treatment may contribute to pest resurgence (Penman and Chapman 1983, Iftner and Hall 1983b), through a reduction in intraspecific density-dependent population regulation, as well as predator escape. Hall (1979) observed more TSSM eggs on pyrethroid-free leaf surface than treated surface. The effects of pyrethroid insecticides on spider mite oviposition are not fully understood. Therefore, the objective of this study was to evaluate TSSM oviposition behavior on soybeans treated with fenvalerate and permethrin at two levels of residue deposition.

Materials and Methods

The TSSM used in these experiments were drawn from a laboratory colony maintained on "Essex" soybeans held at 20° - 30°C, 30 - 60% r.h., and 16 hour photoperiod. Plants were raised in 10 cm X 10 cm pots filled with Metro-Mix 500 ® potting medium, and held outdoors in the spring, 1984. Two plants were grown in each pot and utilized while in the early vegetative stage (second trifoliate expanding).

A leaf cage (designed according to Hughes et al. 1966) was centered over the midrib of the middle leaflet, first trifoliate, and attached to the abaxial surface. Each cage served as a replicate for one of the leaf treatment schemes. Seven leaf treatments were tested (Figure IV-1) plus a control. Water emulsions of fenvalerate (Pydrin ® 2.4 EC, 120 ppm) and permethrin (Pounce ® 3.2 EC, 120 ppm) were prepared. Insecticide was applied to the leaf surface enclosed by each cage (130 mm^2) using a 3/0 sable artists' brush. Leaf area to the right of the midrib was not treated in the half area treatments. Distilled water was applied to the controls. Treatments were allowed to dry (one hour). Insecticide treatment schemes were replicated four times, the control was replicated seven times.

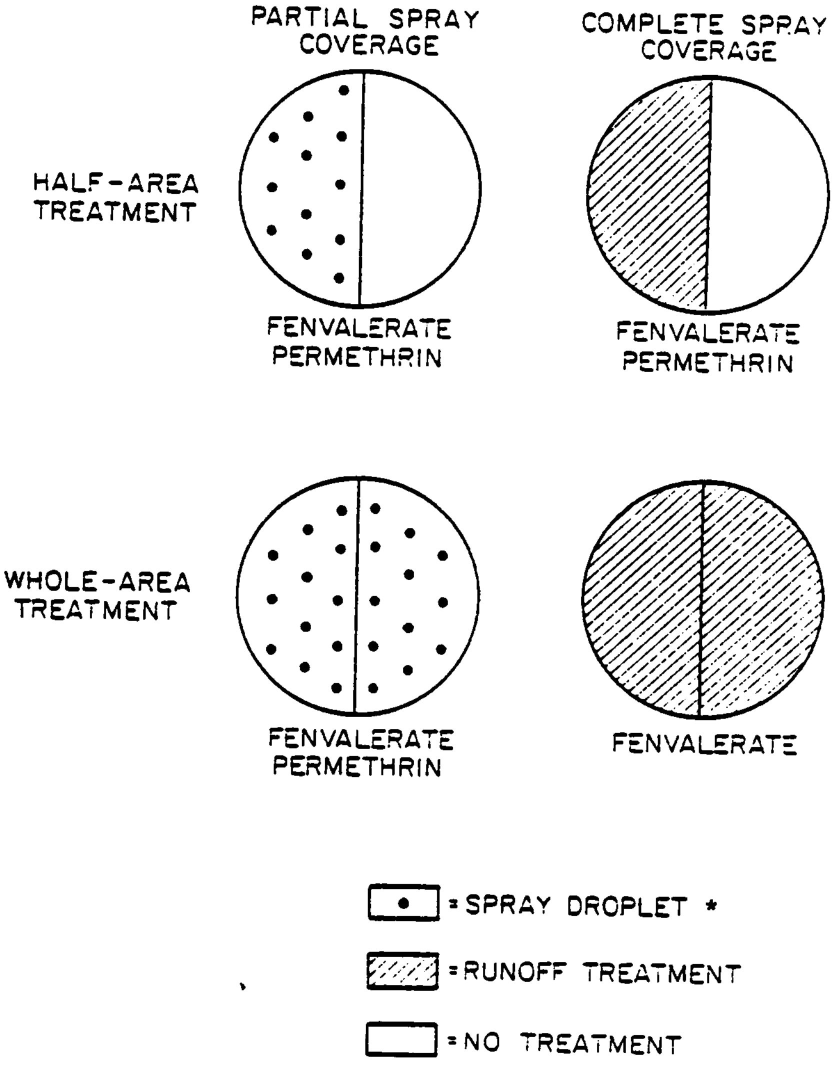

Figure IV-1. Diagramatic representation of pyrethroid insecticide treatments applied to soybean leaflets. Circles represent the leaf surface inside the leaf cages. Vertical lines represent the leaflet midribs.

* Droplets approx. 1 mm in dia.

The young soybeans were too weak to support the weight of the leaf cages, so leaf cage support brackets were constructed. A perpendicular cross brace 21 cm long was attached approximately midway on a 42 cm X 2 cm x 0.5 cm wooden stake upright. A small wire brad was inserted at each end of the crossbrace, facing downward. One support was placed in each pot, each brad gripping the cork portion of a leaf cage, securing the cage in an upright position.

A 3/0 camel's-hair brush was used to transfer three adult female TSSM into each cage, one mite to the left, one to the right, and one on the midrib. One control replicate received five TSSM, another received four, the remaining five control replicates received three mites each. The experimental units were placed in a plant growth chamber, and held for 72 hours at 25°C/19°C ± 0.5°C and a 16 hour photoperiod. experimental units were removed from the chamber, the cages opened, and the location of eggs determined using 20X magnification. Egg location was recorded as: Left half, surface; Left half, suspended; Right half, surface; Right half, suspended. Eggs oviposited on cage walls, attached to trichomes, or held off the surface by a network of silk threads, were classified as "suspended".

Egg distribution in the horizontal plane was analyzed by arcsine square root probability transformation of the replicate frequencies associated with eggs oviposited in the right half of the cage (surface and suspended). Transformed data were tested for homogeneity of variance using the Bartlett's Test (Sokal and Rohlf, 1981). Differences between treatments were analyzed using a one-way analysis of variance ($p = 0.01$), with means separated by Duncan's New Multiple Range Test (Duncan, 1955). Egg distribution in the vertical plane was analyzed by arcsine square root probability transformation of the replicate frequencies associated with eggs oviposited on the leaf surface. Transformed data were tested for homogeneity of variance using the Bartlett's Test (Sokal and Rohlf, 1981). Differences between treatments were analyzed using a one-way analysis of variance ($p = 0.01$), with means separated by Duncan's New Multiple Range Test (Duncan 1955).

Results

Relative humidity in the plant growth chamber ranged from 50 to 70%. The numbers of eggs oviposited in the pyrethroid treatments ranged from 112 to 382, with the 24 control mites ovipositing 550 eggs. For the purpose of orientation the terms horizontal and vertical plane will be used in this and the following chapters. The horizontal plane is defined as lying parallel to and in contact with the leaf surface proper (not including trichomes). The vertical plane lies perpendicular to but not contacting the leaf surface proper.

Eggs in the controls were distributed nearly equally between the right and left halves of the leaf cage. Egg distribution was significantly shifted toward the right (untreated) halves of the leaf cages in the permethrin (>95%) (Figure IV-2B,C) and fenvalerate (>95%) (Figure IV-3B,C) half-leaf treatments. No significant difference was observed between the two spray coverage schemes. The partial spray coverage treatments, with only 14% (est.) of the leaf surface are covered with pyrethroid, still produced an effect not statistically different from the 100% coverage treatments. No significant differences were found in

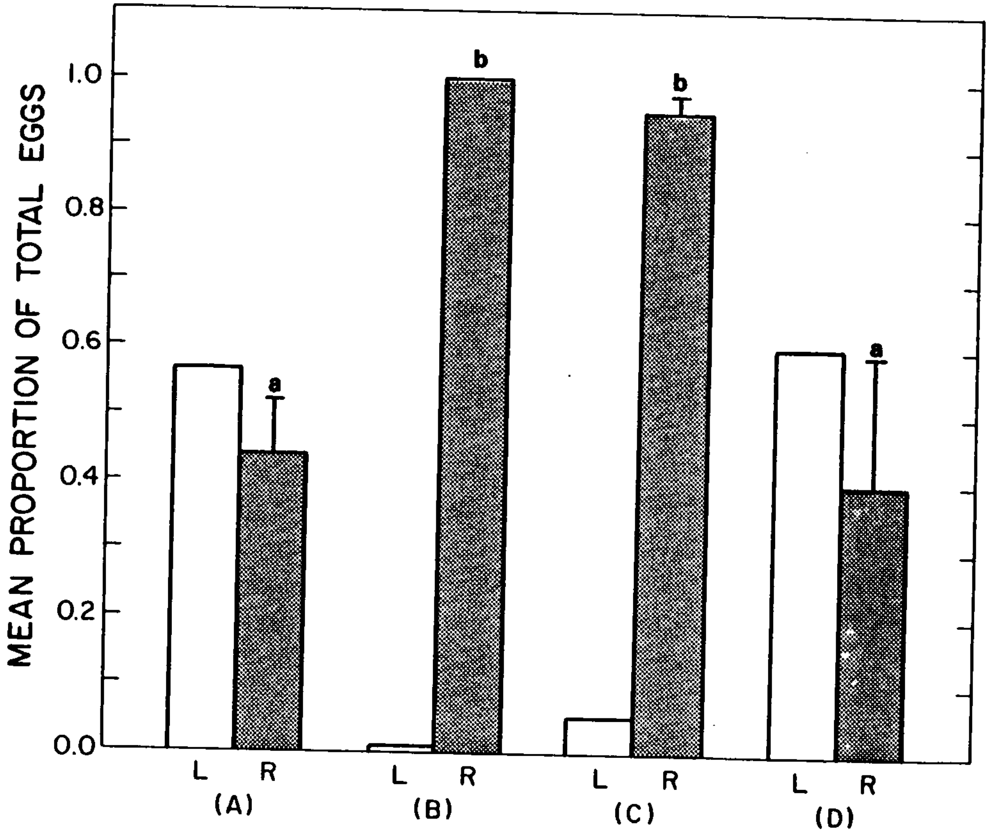

Figure IV-2. *Tetranychus urticae* Koch. Oviposition site selection in response to permethrin residues on soybean leaves. Mean proportion of total eggs distributed between the left (L) and right (R) halves of the leaf cages. Differences in lower case letter indicates significant difference, ANOVA, followed by Duncan's New Multiple Range Test, a = 0.01. Small bar represents the standard error of the mean.

(A) Control
(B) Partial spray coverage - left half of caged area treated.
(C) Complete spray coverage - left half of caged area treated.
(D) Partial spray coverage - whole area treated.

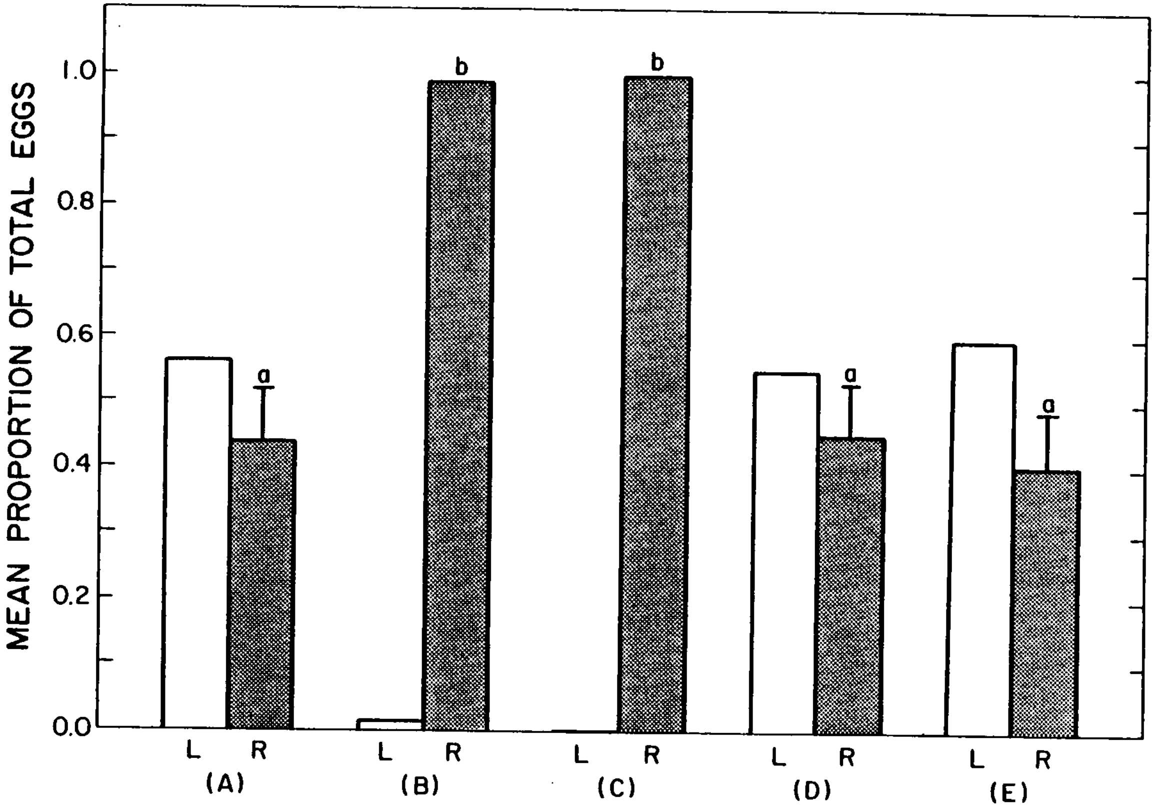

Figure IV-3. *Tetranychus urticae* Koch. Oviposition site selection in response to fenvalerate residues on soybean leaves. Mean proportion of total eggs distributed between the left (L) and right (R) halves of the leaf cages. Differences in lower case letter indicates significant difference, ANOVA, followed by Duncan's New Multiple Range Test, a = 0.01. Small bar represents the standard error of the mean.

(A) Control
(B) Partial spray coverage - left half of caged area treated.
(C) Complete spray coverage - left half of caged area treated.
(D) Partial spray coverage - whole area treated.
(E) complete spray coverage - whole area treated.

horizontal plane egg distribution between the control, whole-leaf permethrin (Figure IV-2 A, D) and fenvalerate (Figure IV-3 A, D, E) treatments, all approximated an equal distribution between halves.

Greater than 95% of the control eggs were found on the leaf surface. A significant proportion of eggs were oviposited off the leaf surface in the permethrin (49 %) (Figure IV-4 D) and fenvalerate (approx. 30%) (Figure IV-5 D, E) whole-leaf treatments. No signifciant differences were found in vertical plane egg distribution between the control, permethrin (Figure IV-4 A, B, C) and fenvalerate (Figure IV-5 A, B, C) half-leaf treatments, with greater than 95% of the total eggs oviposited on the leaf surface.

Spider mites demonstrated a clear preference for oviposition away from fenvalerate and permethrin residues. TSSM females were able to differentiate treated vs. untreated leaf surface, ovipositing almost exclusively (95%) on untreated surface. Once untreated surface was located, oviposition in the vertical plane reflected oviposition in the controls, i.e. > 90% of the eggs were oviposited directly on the leaf surface. If pyrethroid-free leaf surface was not available, a substantial proportion (> 30%) of the eggs were

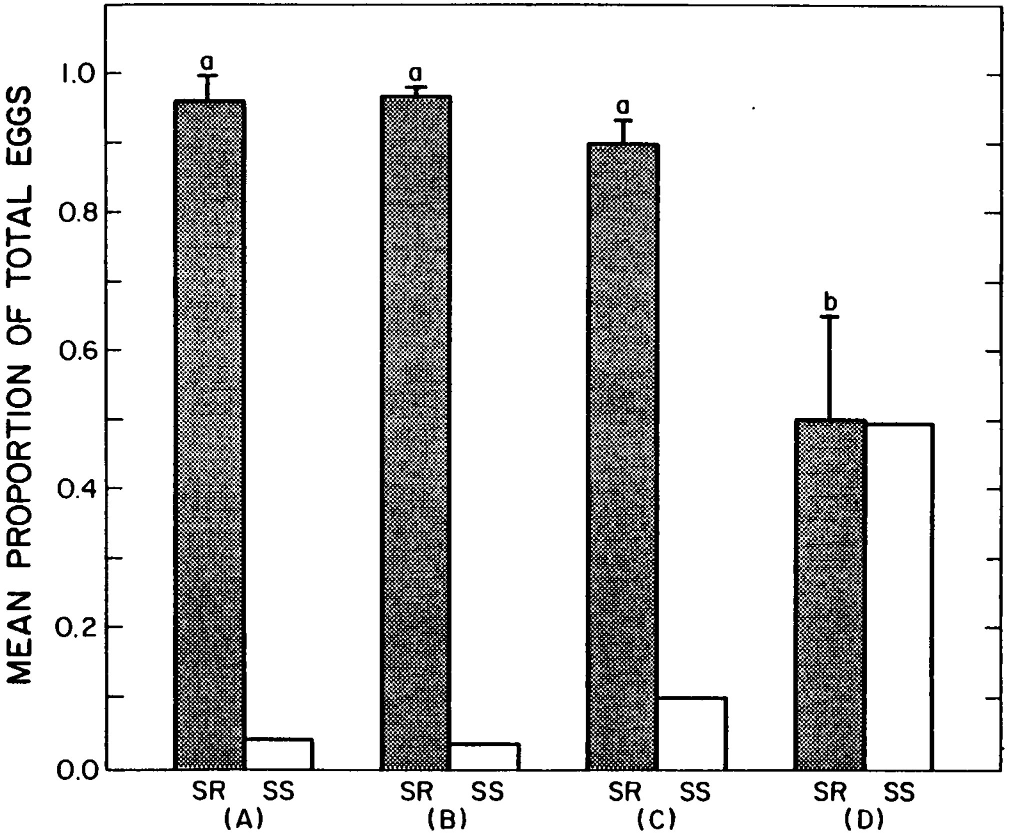

Figure IV-4. *Tetranychus urticae* Koch. Oviposition site selection in response to permethrin residues on soybean leaves. Mean proportion of total eggs; oviposited on the leaf surface (SR) vs. suspended above the leaf surface (SS). Differences in lower case letter indicates significant difference, ANOVA, followed by Duncan's New Multiple Range Test, a = 0.01. Small bar represents the standard error of the mean.

(A) Control
(B) Partial spray coverage - left half of caged area treated.
(C) Complete spray coverage - left half of caged area treated.
(D) Partial spray coverage - whole area treated.

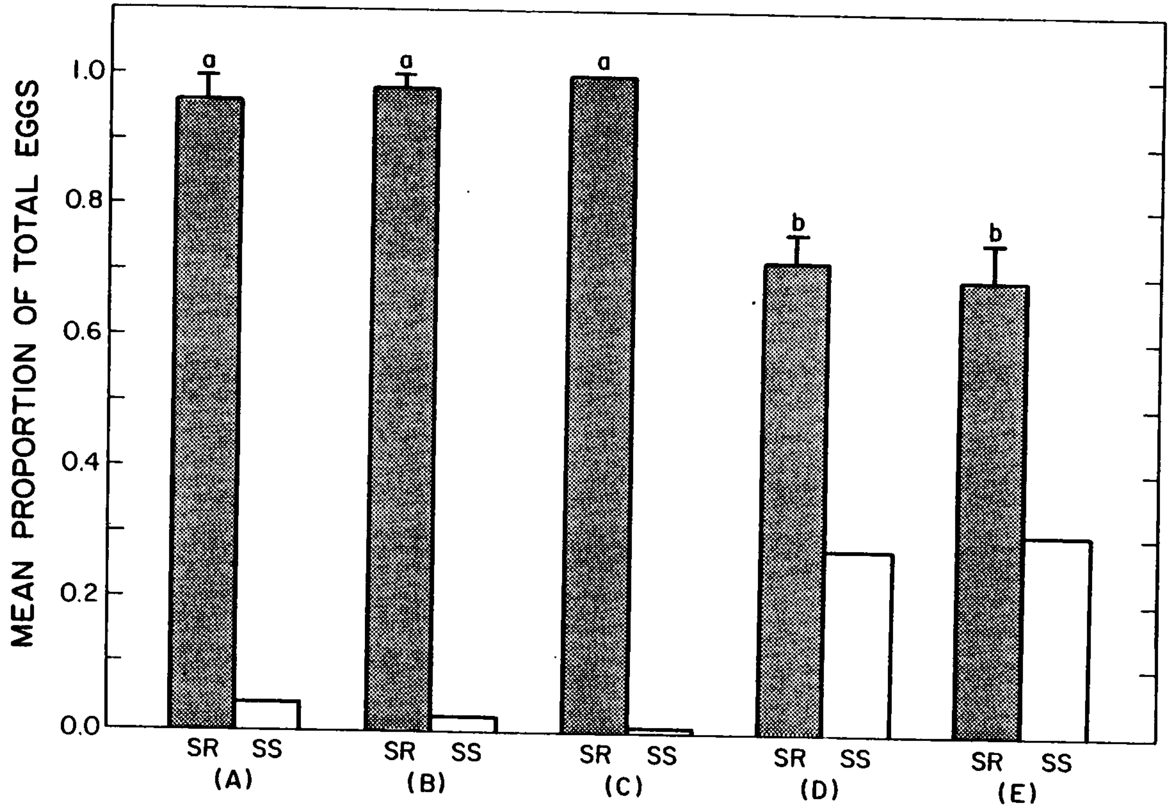

Figure IV-5. *Tetranychus urticae* Koch. Oviposition site selection in response to fenvalerate residues on soybean leaves. Mean proportion of total eggs; oviposited on the leaf surface (SR) vs. suspended above the leaf surface (SS). Differences in lower case letter indicates significant difference, ANOVA, followed by Duncan's New Multiple Range Test, a = 0.01. Small bar represents the standard error of the mean.

(A) Control
(B) Partial spray coverage - left half of caged area treated.
(C) Complete spray coverage - left half of caged area treated.
(D) Partial spray coverage - whole area treated.
(E) Complete spray coverage - whole area treated.

oviposited suspended off the leaf surface in a network of silk threads.

Discussion

These results suggest that pyrethroid residues directly influence TSSM oviposition site selection. This interpretation was offered by Iftner and Hall (1984) as an explanation for reduced TSSM oviposition in the presence of pyrethroid residues. The added energy and time required to oviposit away from the residues leads to a reduction in egg production. Behavior such as this implies active oviposition site selection by TSSM females.

An alternative explanation involves a more passive oviposition site selection response. Since TSSM females exhibit a general avoidance response in the presence of pyrethroid residues (Iftner and Hall 1983b, Penman and Chapman 1983), TSSM females might be expected to increase the amount of time spent off the leaf surface, traversing a network of silk threads, when pyrethroid-free leaf surface is unavailable. Boudreaux (1963) noted that tetranychid eggs are often observed in the vicinity of veins on the undersides of host plant leaves. Eggs in this location are considered to be in a favorable "protected" position. This observation implies some degree of oviposition site selection. However, in a more general interpretation, oviposition by phytophagous mites appears to be carried out in a "haphazard" manner (Jeppson et al. 1975). TSSM eggs can usually be found anywhere on the leaf surface (or off the leaf surface), suggesting that oviposition site selection is not an active response.

In the experimental treatments where pyrethroid-free leaf surface was available, a majority of the eggs were found on the leaf surface. These results suggest that TSSM female oviposition site selection behavior is not directly related to the presence (or absence) of pyrethroid residues. The location of TSSM eggs may be directly related to the location of the female at the time the egg is ready for oviposition. It is the location of the female that is influenced by the pyrethroid residues.

No significant differences were observed in egg distribution between the two levels of "spray" coverage, with either fenvalerate or permethrin. Discontinuous deposits of pyrethroid residue may present enough of an irritation to the mite so that the untreated leaf tissue in the vicinity of the deposits is not attractive. In a more practical sense, TSSM females in the field may be more likely to colonize untreated foliage, rather than partially treated foliage.

These findings help to better understand the relationship between mite behavior and pyrethroid induced outbreaks of spider mites in soybeans and other agricultural crops. Pyrethroid insecticides can alter the dispersal, and hence oviposition behavior of egg laying females, causing them to seek untreated areas, which resulted in a more rapid expansion of the infestation. This information should be incorporated into integrated pest management programs. In field situations where mite outbreaks are likely to occur (i.e. hot/dry conditions) the pyrethroid insecticides recommended for pest control should be replaced with classes of compounds less likely to induce secondary outbreaks of spider mites.

Chapter V

OVIPOSITION RESPONSE OF *Tetranychus urticae* Koch (Acari: Tetranychidae) TO FENVALERATE AND PERMETHRIN: DIRECT TREATMENT AND EXPOSURE TO RESIDUES ON SOYBEANS, *Glycine max* (L.) Merrill

INTRODUCTION

Concern regarding pyrethroid induced outbreaks of spider mites has increased in recent years. Natural enemy demise following pyrethroid applications has not adequately explained the phenomenon of spider mite outbreaks in crop systems where natural enemies appear to be of limited value in regulating mite populations (Hall 1979, Reidl and Hoying 1980). This suggests that additional factors are involved in the induction of mite outbreaks following pyrethroid applications. Alternative explanations include direct reproductive stimulation of the spider mite (McKee and Knowles 1984), pyrethroid induced improvement of the host plant as a nutritional resource (Hoyt et al. 1978), and pyrethroid induced dispersal leading to a reduction in intraspecific density-dependent population regulation (Iftner and Hall 1983b, Penman and Chapman 1983).

The hypothesis of pest reproductive stimulation by sublethal dosages of an insecticide was considered by Luckey (1968) to fit into the general pharmacological hypothesis of hormoligosis. Since the 1950's many workers have tested such an hypothesis in attempting to explain DDT induced outbreaks of spider mites with variable results (Locher 1958, Pielou 1960, Attiah and Boudreaux 1964a, Saini and Cutkomp 1966, Dittrich et al. 1974). Hormoligosis has again been proposed as a factor which could potentially contribute to spider mite outbreaks following pyrethroid applications (McKee and Knowles 1984). Short term observations of Tetranychus urticae Koch egg production following direct treatment and exposure to residues of fenvalerate have shown a depression of oviposition, followed by recovery when removed from the residues, and placed on untreated foliage (Penman et al. 1981).

The objective of this study was to evaluate two spotted spider mite, Tetranychus urticae Koch, (TSSM), oviposition response, and egg distribution under three conditions of pyrethroid exposure. The first condition involved direct exposure to fenvalerate and permethrin residues on soybean. The second involved removal of the mites from the first set of conditions and transferring them to untreated foliage. The third condition involved direct treatment of the mites with pyrethroids, followed by placement on untreated foliage for observation.

Materials and Methods

The two spotted spider mites (TSSM) used in these experiments were drawn from a laboratory colony maintained on soybeans, var. Essex, held at 20-30°C, 30-60% r.h., and 16 hour photoperiod. Plants were grown under greenhouse conditions in Metro-Mix 500® potting medium. Three plants were grown in each pot, then thinned to two at the unifoliate stage. Only plants in the early vegetative stages were utilized.

Small leaf cages (Hughes et al. 1966) were used to confine the TSSM to the leaves. The weight of the leaf cages was supported by brackets. A perpendicular crossbrace 21 cm long was attached approximately midway on a 42 cm X 2 cm X 0.5 cm wooden upright. A small wire brad was inserted at each end of the crossbrace, facing downward. One support was placed in each pot, each brad gripping the cork portion of a leaf cage, thus securing the cage in an upright position.

<u>Experiment</u> <u>I</u>. <u>Exposure of TSSM to pyrethroid residues</u>. Water emulsions of commercially formulated fenvalerate (Pydrin® 2.4 EC, 120 ppm) and permethrin (Pounce® 2.4 EC, 120 ppm) were prepared. Insecticides were applied to runoff on the first trifoliate of soybeans with only one trifoliate expanded, using a

hand-held pump sprayer. Distilled water was used to treat controls. Six plants were assigned to each treatment, and all plants allowed to dry (approx. 1 hour). A leaf cage was centered over the midrib, middle leaflet, of each treated trifoliate, and attached to the abaxial surface. Six cages (replications) were used in each test treatment.

Three freshly molted and fertilized TSSM adult females (1-72 hours old) were transferred to each cage using a 3/0 camel's hair brush, for a total of 18 TSSM per treatment. Experimental units were held in a plant growth chamber at 25°C/19°C ± 0.5°C and 16 hour photoperiod. Cages were examined every twelve hours for the numbers of mites present. Egg counts were made every 24 hours. Egg distribution, surface oviposited vs. suspended (eggs found attached to trichomes, cage walls, or intertwined in the silk webbing) was recorded daily. Eggs were removed daily from all cages using a 3/0 camel's hair brush.

After five days, new cages were affixed to the next newest trifoliate on each test plant as previously described. The new trifoliate leaves had not expanded at the time of the insecticide application, and therefore were free of residues. Surviving TSSM were transferred from the original cage to the new leaf site on each plant, where they were not directly exposed to any pyrethroid residues. TSSM presence and oviposition were monitored for an additional six days. From the raw data a value of eggs per mite-day oviposition (MDO) was calculated. Analysis of variance was used to detect differences between the treatment means within a particular time and the cumulative egg production per mite for the 0-5 day (on residues) and 6-11 days (removed from residues) time brackets. When statistical significance was found, treatment means were separated using Fisher's Protected Least Significant Difference procedure (Zar 1974). Egg distribution data was analyzed by arcsine square root probability transformation of the surface oviposition frequencies, with statistical significance determined using the Kruskal-Wallis non-parametric procedure (Zar 1974). Means from the 0-5 day test were separated using the non-parametric means separation procedure suggested by Zar (1974). Means from the 6-11 day test were separated on the basis of non-overlap of any treatment rank groupings.

Experiment II. Direct treatment of TSSM. Water emulsions of commercially formulated fenvalerate

(Pydrin 2.4 EC, 120 ppm) and permethrin (Pounce 3.2 EC, 120 ppm) were prepared. The experimental units were identical in design to those used in the 0-5 day experiment I, but with all plants left untreated. Six plants were assigned to each of the insecticide treatments and control.

Forty freshly molted and fertilized female TSSM (1-48 hours old) were selected for each treatment, and the control. Each of these cohorts was transferred with a 3/0 camel's-hair brush to an excised soybean leaflet maintained in a petri dish. Each leaflet was sprayed to runoff with the appropriate insecticide, or distilled water (control), using a hand-held pump sprayer. Treated leaflets/mites were placed in a plant growth chamber at 25°C ± 0.5°C and continuous light until dry (approx. one hour). Four TSSM females were placed in each leaf cage; 24 mites per treatment. Cages were monitored for mite survival and egg production as in experiment I. TSSM mortality was analyzed using chi-square, and egg production between the control and permethrin treatments was analyzed using one way analysis of variance.

This experiment was repeated with the pyrethroid concentration decreased one magnitude to 12 ppm. For this experiment leaf cages were moved up each plant to the middle leaflet of the second trifoliate, of the plants used in the 120 ppm direct application experiment. TSSM presence, egg production, and egg distribution was recorded and analyzed as in experiment I, with the exception of egg production and distribution being evaluated every 12 hours instead of every 24. The monitoring was continued for a total of seven days after treatment.

Results

Experiment I. This experiment was designed to evaluate *T. urticae* oviposition response over a five day period while in direct contact with permethrin and fenvalerate residues. Direct contact with pyrethroid residues significantly reduced the numbers of eggs oviposited in the first 72 hours (Table V-1, A) The degree of reduction observed after one day in the permethrin (2.1 ± 0.3) and fenvalerate (2.0 ± 0.7) treatments was comparable, but significantly less than the control (7.3 ± 0.1). The relationship between treatments observed after two days was similar, with permethrin (4.4 ± 0.9) comparable to fenvalerate (3.6 ± 0.5), but significantly less than the control (10.2 ± 0.3). The reduction in the number of eggs oviposited in the permethrin treatment after three days was more moderate (5.8 ± 0.8), significantly more than the fenvalerate treatment (4.8 ± 0.6) but still significantly less than the control (9.6 ± 0.4). No differences between treatments and controls were significant at the four and five day ratings. Oviposition dropped off sharply in the control after the third day (9.6 ± 0.4), falling to 6.0 ± 0.5 by the fifth day. Cumulative egg production calculated on a

Table V-1. Tetranychus urticae Koch. (TSSM). Mean numbers of eggs oviposited in response to pyrethroid insecticides, expressed as eggs per mite-day oviposition ± std. error of the mean.[1] Table includes data from experiments I and II.

A. Avg. no. of TSSM eggs oviposited on pyrethroid residues, 120 ppm.

Days post treatment =		1	2	3	4	5
Control	n=18	7.3a±0.1	10.2a±0.3	9.6a±0.4	8.2a±0.3	6.0a±0.5
Permethrin	n=18	2.1b±0.3	4.4b±0.9	5.8b±0.8	6.3a±1.4	5.9a±1.5
Fenvalerate	n=18	2.0b±0.7	3.6b±0.5	4.8b±0.6	5.9a±0.6	4.9a±0.5

B. Avg. no. of TSSM eggs oviposited on untreated soybeans following five days on pyrethroid residues, 120 ppm.

Days post treatment =		1	2	3	4	5	6
Control	n=14	5.2a±0.7	7.6a±0.4	7.2a±1.0	6.4a±0.9	5.7a±0.9	5.7a±0.9
Permethrin	n=13	4.9a±0.8	6.0a±0.6	8.0a±0.9	7.1a±0.8	6.3a±0.7	6.9a±0.4
Fenvalerate	n=12	3.3a±0.5	4.1b±1.1	4.3a±0.9	5.3a±1.1	5.1a±1.2	5.6a±1.4

C. Avg. no. of TSSM eggs oviposited on untreated soybeans following direct treatment with pyrethroids, 12 ppm.

Days post treatment =		1	2	3	4	5	6	7
Control	n=24	6.1a±0.4	6.4a±0.3	6.2a±0.5	5.4a±0.5	4.8a±1.0	5.4a±0.7	3.7a±0.6
Permethrin	n=24	4.3b±0.3	5.2b±0.2	5.4a±0.6	4.9a±0.4	4.4a±0.4	3.7a±0.4	3.3a±0.2
Fenvalerate	n=24	1.2c±0.5	2.5c±0.2	4.2a±0.2	5.3a±0.2	4.6a±1.0	4.7a±0.7	3.5a±0.7

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[1] Means followed by the same letter are not significantly different, analysis of variance followed by Fisher's Protected LSD procedure, $\alpha = 0.05$.

[2] TSSM at start of the experiment.

per mite basis (Table V-2) showed the pyrethroids to be comparable in significantly reducing the numbers of eggs oviposited (permethrin 24.5 ± 3.7, fenvalerate 21.1 ± 2.4) compared to oviposition in the controls (41.3 ± 0.9). Fenvalerate and permethrin altered the distribution of eggs in the leaf cages (Table V-3 "five days on residues"), with only 17% (fenvalerate) and 23% (permethrin) of the total eggs, oviposited directly on the leaf surface, over the five days. Egg distribution in the control cages was significantly different, with >99% of the eggs oviposited directly on the leaf surface.

After five days on residues, all mites were transferred to fresh, untreated foliage for an additional six days to monitor the continuation of oviposition. Relative humidity ranged from 30 to 70% over the period six to eleven days after first exposure to the residues in experiment I. No significant differences in numbers of eggs oviposited on day one (six days after treatment) in the fenvalerate (3.3 ± 0.5), permethrin (4.9 ± 0.8) and control (5.2 ± 0.7) treatments were observed (Table V-1, B). On day two, oviposition in the control (7.6 ± 0.4) and permethrin (6.0 ± 0.6) treatments increased and remained

Table V-2. _Tetranychus_ _urticae_ Koch (TSSM). Mean numbers of eggs oviposited over the duration of each experiment, expressed as eggs per mite over the duration specified, ± std. error of the mean.[1]

Treatment	Experiment 5 days on residues	 6 days on untreated[2]	 7 days direct[3]
Control	41.3a±0.9	37.8a±4.2	37.9a±2.7
Permethrin	24.5b±3.7	39.2a±3.2	31.0b±2.0
Fenvalerate	21.1b±2.4	29.3a±4.8	26.5b±2.3

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[1] Means in columns followed by the same letter are not significantly different, analysis of variance followed by Fisher's Protected LSD procedure, $\alpha = 0.05$.

[2] TSSM from the "5 days on residues" experiment, transferred to untreated soybean foliage for an additional 6 days.

[3] TSSM treated directly with 12 ppm concentration, and transferred to untreated soybean foliage for 7 days.

Table V-3. <u>Tetranychus urticae</u> Koch (TSSM). Vertical plane egg distribution, expressed as the percentage of egg totals oviposited on the soybean leaf surface ± std. error of the mean.[1]

	Experiment		
Treatment	5 days on residues	6 days on untreated[2]	7 days direct[3]
Control	99.5a±0.1	97.4a±1.0	97.5a±0.7
Permethrin	22.5b±12.0	63.0b±8.7	96.0a±1.5
Fenvalerate	17.2b±6.0	15.2c±7.7	84.3a±9.4

---

[1] Means in columns followed by the same letter are not significantly different, Kruskal-Wallis non-parametric procedure, followed by non-parametric means separation procedure described by Zar (1974).

[2] TSSM from "5 days on residues" experiment, transferred to untreated soybean foliage for an additional 6 days. Treatment means separated on the basis of distinct grouping of rank values.

[3] TSSM treated directly with 12 ppm concentration, and transferred to untreated soybean foliage for 7 days.

comparable, while oviposition in the fenvalerate treatment was significantly reduced (4.1 ± 1.1). A similar relationship was observed on day three with the control (7.2 ± 1.0) and permethrin (8.0 ± 0.9) being comparable, while fenvalerate (4.3 ± 0.9) continued to reduce the numbers of eggs oviposited. No significant differences between the control (6.4 ± 0.9), permethrin (7.1 ± 0.8), and fenvalerate (5.3 ± 1.1) treatments were observed on day four (9 days after treatment) and beyond. Cumulative egg production calculated on a per mite basis (Table V-2) showed the mean number of eggs produced by a female in the control (37.8 ± 4.2), permethrin (39.2 ± 3.2), and fenvalerate (29.3 ± 4.8) treatments were not significantly different, although oviposition in the fenvalerate treatment does appear to be somewhat reduced.

Mites from the pyrethroid treatments continued to oviposit significant proportions of their eggs suspended above the leaf surface, even though pyrethroid residues were not present on the leaf surface (Table V-3, "6 days on untreated"). Fenvalerate induced the most dramatic response, with only 15% of the eggs oviposited on the leaf surface. The response to permethrin was significantly less severe (63%), but still significantly different from the control where > 97% of the eggs were oviposited directly on the leaf surface. Treatment means in this case were considered significantly different on the basis of discrete rank groupings from the Kruskal-Wallis procedure.

<u>Experiment II</u>. This experiment was designed to evaluate the oviposition response of female mites (TSSM) over a seven day period following a direct application of fenvalerate and permethrin to the mite. Relative humidity ranged from 30 to 80% over the two day duration of the 120 ppm direct application experiment. The 120 ppm concentration of permethrin was found to be moderately lethal to females, resulting in 54% mortality after 24 hours (Table V-4) The same concentration of fenvalerate was found to be highly lethal, resulting in 83% mortality after 24 hours, and 100% mortality after 48 hours. No eggs were oviposited by the fenvalerate treated mites. Oviposition by the surviving permethrin treated mites at 24 hours after treatment (0.80 ± 0.46) was significantly less than the control (3.87 ± 0.51). Oviposition continued at significantly reduced levels in the permethrin treatment after 48 hours (2.56 ± 0.47), compared to the control (6.17 ± 0.46).

Table V-4. *Tetranychus urticae* Koch (TSSM). Direct treatment of TSSM with pyrethroids at 120 ppm. Percent mortality and eggs per mite-day oviposition, ± std. error of the mean.

		Hours Post Treatment			
		24		48	
Treatment	No. TSSM observed	Percent mortality[1]	Egg production[2]	Percent mortality[3]	Egg production[4]
Control	n=24	0	3.87a±0.51	4	6.17a±0.46
Permethrin	n=24	54	0.80a±0.46	54	2.56a±0.47
Fenvalerate	n=24	83	0.00a±0.00	100	--

[1] Chi square on 3 X 1 contingency Table = 34.7, df=2, $p<0.005$.

[2] Analysis of variance (fenvalerate treatment excluded), F=26.1, df=10, $p < 0.01$

[3] Chi-square on 3 X 1 contingency table = 44.3, df=2, $p<0.005$.

[4] Analysis of variance (fenvalerate treatment excluded), F=30.79, df=10, $p<0.01$.

The experiment was repeated with a ten-fold reduction in pyrethroid concentration, so that the applications were sublethal. Relative humidity ranged from 30 to 70% over the seven day duration of the experiment. The pyrethroid insecticides significantly reduced the number of eggs oviposited in the pyrethroid treatments (Table V-1, C) Pyrethroid treated mites initially displayed symptoms of pyrethroid poisoning, such as spasmodic movements of appendages, and difficulty in remaining secured to the leaf surface. Fenvalerate showed the more severe effect in reducing oviposition at the one (1.2 ± 0.5) and two (2.5 ± 0.2) day ratings. Oviposition in the permethrin treatment at 24 (4.3 ± 0.3) and 48 (5.2 ± 0.2) was significantly reduced compared to the controls (6.1 ± 0.4, 6.4 ± 0.3, respectively). The permethrin treatment values at both times were significantly greater than the corresponding fenvalerate values. No significant differences between the fenvalerate (4.2 ± 0.2), permethrin (5.4 ± 0.6), and control (6.2 ± 0.5) treatments were observed at the three day rating. However, oviposition data at 60 hours (2.5 days) after treatment (not included in Table V-1, C), show the rate of oviposition in the control (6.4 ± 0.2) not to be statistically different from oviposition in the permethrin treatment (6.1 ± 0.5), with oviposition in the fenvalerate treatment (3.6 ± 0.4) remained significantly reduced compared to the other treatments (analysis of variance, Fisher's Protected LSD, $p < 0.05$).

Cumulative numbers of eggs oviposited per mite over the seven day duration of the experiment (Table V-2) was comparable in the fenvalerate (26.5 ± 2.3) and permethrin (31.0 ± 2.0) treatments, but significantly less than oviposition in the control (37.9 ± 2.7). Direct treatment of females did not result in a significant alteration of egg distribution in the leaf cages (Table V-3). Greater than 97% of the total number of control eggs oviposited, were found directly contacting the leaf surface, compared to 96% in the permethrin treatment and 84% in the fenvalerate treatment.

Discussion

The decline in oviposition observed in the experiment I controls on days 4-6 post treatment was not expected and is unusual. The low values may mask any significance of pyrethroid effects on TSSM egg production during this time period. The recovery of oviposition to expected levels in the control on days 7 and 8 after treatment (listed as days 2 and 3 in Table V-1, B) revealed a continued suppression of egg production in the fenvalerate treatment. Normally, TSSM egg production declines over time in a smoother curve than that observed in experiment I (i.e. data from experiment II) The decline in leaf quality inside the cages is not severe, since feeding by 3-4 TSSM females on 130 mm^2 of leaf area is not a high level of feeding intensity. Cage structure itself did not visibly affect the leaf tissue.

Numbers of eggs oviposited daily by TSSM held on pyrethroid residues gradually increased over time. Dittrich et al. (1974) noted the possible influence of DDT residue age on the ability of the chemical to elicit a response in the spider mite, with fresher residues having greater activity. Southwick et al. (1983) in studies of permethrin compartmentalization in cotton leaves, noted a rapid decline in permethrin surface residues over the 5 days following application. This decline was attributed to volatilization losses, although pyrethroids as a class are considered to be only slightly volatile (Elliot et al. 1978). Either effect alone or both combined, might explain the gradual restoration of oviposition in the pyrethroid treatments. Overall, the supressive effect of fenvalerate on the numbers of eggs oviposited continued for three days following removal from the residues. If the "masking" assumption discussed above is real, permethrin may have continued depressing oviposition for one day following removal from residues. Results indicate fenvalerate to be slightly more active in depressing TSSM egg production than permethrin.

Data from experiment II suggest that the TSSM from the lab colony were susceptible to both pyrethroid insecticides, more so than colonies used in published slide dip toxicological studies (Roush and Hoy 1978, Rock 1979, Wong and Chapman 1979, Iftner and Hall 1983a). The parent stock colony has been in culture (USDA Floriculture Laboratory, Beltsville, MD, U.S.A.) for ca. 17 years on bush lima bean, with my subcolony maintained on soybeans for approximately one year.

Pyrethroid residues at 120 ppm are essentially non-lethal to even these highly susceptible TSSM. This agrees with Dennehy's et al. (1982) observations of the potential discrepancy in susceptibility of mites to residues versus direct contact.

Direct application of a 12 ppm concentration of permethrin to TSSM females (Table V-1 C) moderately reduced oviposition for at least 48 hours after treatment. Fenvalerate produced a greater reduction in oviposition, with the effect lasting an additional 12 hours. That TSSM eventually recovered from the effects of both insecticides is indicated by restored levels of egg production.

Slide dip toxicological tests have shown fenvalerate to be more toxic to TSSM than permethrin (Iftner and Hall 1983a). This relationship appears true for the degree and duration of the oviposition reduction observed in this study. TSSM afflicted with acute pyrethroid poisoning show symptoms of neural disfunction, such as uncontrolled appendage movements, and lack of motor coordination. TSSM with these symptoms have difficulty remaining attached to the leaf surface. Supression of oviposition remains even after the visible symptoms of the poisoning have disappeared, and feeding has resumed. The temporary continuation of the oviposition reduction effect following removal of the TSSM from actual contact with pyrethroid residues might be due to chronic poisoning of TSSM while in contact with residues. Over time, the toxins could be enzymatically metabolized gradually eliminating the toxins accumulated during the exposure period.

McKee and Knowles (1984) concluded that in general, pyrethroid insecticides stimulate TSSM respiration. The authors speculated that such a stimulation could eventually result in a stimulation of oviposition, and hence a mite outbreak, as would be predicted by the hormoligosis hypothesis. According to the reported data, fenvalerate and permethrin actually slightly depressed TSSM respiration, relative to the control. The results from my study do not lend support to the hormoligosis hypothesis, but closely agree with the TSSM oviposition response to fenvalerate reported by Penman et al. (1981).

There is a clear, physiological component to the pyrethroid-induced supression of TSSM oviposition. There may also be a behavioral component, as described by Iftner and Hall (1984). In this case the avoidance of pyrethroid residues by TSSM (Hall 1979, Penman and

Chapman 1983, Iftner and Hall 1983b) may result in reduced feeding, and greater energy expenditure, leading to a reduction in the energy available for egg production and oviposition.

TSSM continued to oviposit above the leaf surface in experiment I even after a transfer to untreated foliage. This observation suggests that the avoidance behavior may be more than a stimulus/response reaction to pyrethroid residues on the leaf surface. This oviposition behavior was observed over a time period where no significant pyrethroid-induced depression of oviposition was observed. From this, a conclusion could be drawn that the energy expended in ovipositing off the leaf surface did not reduce the amount of energy available for oviposition. Therefore, a behavioral component to the pyrethroid-induced depression of TSSM oviposition may be of only minor, if any, importance.

Results presented here add to an understanding of the factors which contribute to pyrethroid induced outbreaks of spider mites in soybeans, and other crops. From the results I infer that hormoligosis is not a likely contributor to TSSM outbreaks following pyrethroid applications. Further investigation into the complex pyrethroid avoidance behavior displayed by the TSSM, and the contribution of this factor to TSSM outbreaks is needed.

Chapter VI

OVIPOSITION RESPONSE OF *Tetranychus urticae* Koch (Acari: Tetranychidae) TO SOYBEANS, *Glycine max* (L.) Merrill, TREATED WITH FENVALERATE AND PERMETHRIN:

THE EFFECT OF PYRETHROID INDUCED CHANGES IN HOST PLANT QUALITY ON OVIPOSITION RESPONSE.

INTRODUCTION

Pyrethroid insecticides have been implicated in the resurgence phenomenon of spider mite populations in orchard systems around the world (Hoyt et al. 1978, Hislop et al. 1981, Penman et al. 1981, Hull and Starner 1983). The initial hypothesis explaining pest resurgence, predator destruction (Croft and Hoyt 1978, Aliniazee and Cranham 1980), has been broadened to a more holistic explanation, emphasizing the possible influences of host plant nutritional improvement, hormoligosis, and repellency factors, as well as predator demise.

Historically, pest stimulation through insecticide induced alterations of host plant physiology has been suspected as being a factor contributing to secondary pest outbreaks (Huffaker et al. 1969, van de Vrie et al. 1972). This hypothesis has been suggested as a partial explanation for spider mite outbreaks in orchard systems following pyrethroid applications (Hall 1979, Iftner and Hall 1983b). However, data on spider mite fecundity when maintained on pyrethroid treated foliage (but not exposed to residues) are lacking.

Spider mites are an occasional pest in Virginia soybeans (McPherson, personal communication). With the increasing use of pyrethroid insecticides for insect control, the effects of these products on the two spotted spider mite (TSSM) *Tetranychus urticae* Koch should be evaluated. Of particular interest is the impact on reproduction and behavior, with the larger goal of developing a strategy to minimize any population resurgence. The objectives of this study were to evaluate the influence of formulated permethrin and fenvalerate on TSSM oviposition response, and oviposition behavior, when females were placed on treated soybean foliage, but not directly exposed to residues.

Materials and Methods

The two spotted spider mites used in these experiments were drawn from a laboratory colony maintained on Essex soybeans held at 20-30°C, 30-60% r.h., and 16 hour photoperiod. Experiment I was conducted during August, 1984, at the Wye Research and Education Center (University of Maryland) Queenstown, MD. Experiments II and III were conducted in early 1985 at the Virginia Polytechnic Institute and State University, Blacksburg, VA.

Experiment I. Essex soybeans were drill planted on 20.3 cm (8") centers at 2.47 bu./ha on June 23. Trifluralin (Treflan ® 4 EC 0.84 kg a.i./ha) preplant incorporated, linuron (Lorox ® 4L 0.90 Kg a.i./ha) pre-emergence, and aciflourfen (Blazer ® 2 EC 0.42 kg a.i./ha) post-emergence were applied for weed control. 0-15-30 fertilizer was applied at 336 kg/ha.

With plants at full bloom, fenvalerate (Pydrin ® 2.4 EC) at 112 gm a.i./ha (0.1 lb. a.i../A) and permethrin (Pounce ® 3.2 EC) at 112 gm. a.i./ha (0.1 lb. a.i./A) were applied to plots 1.8 m X 9.1 m. with a CO_2 powered hand boom sprayer at 560 l./ha (60 G.P.A.). Lightweight leaf cages (designed according to Hughes et al. 1966) enclosing approximately 130 mm^2 of leaf area were attached to the abaxial surface, middle leaflet, of trifoliates randomly selected from the upper one third of the plant canopy, in the first one third of each plot. Nine to twelve cages were placed in each plot (treatment), the actual number varying with each of the three after application timings evaluated.

Young adult female TSSM were obtained from the laboratory colony by placing uninfested soybean plants inside the colony for twelve hours. Since young, fertilized females are most likely to disperse, the colonizing females were assumed to be of relatively uniform age. A 3/0 camel's-hair brush was used to place three TSSM in each leaf cage. Daily counts were made of TSSM present. Leaflets with cages were harvested after four days, taken back to the laboratory, and the number of eggs oviposited during the preceding four days counted under 20X magnification.

The leaf cage procedure was repeated at seven days after treatment and again at 14 days after utilizing the middle one third and last one third of the treated plots, respectively. A hygrothermograph was used to record ambient temperature and relative humidity during the study period.

Egg count data for each replication (nine to twelve replications per treatment per timing) were converted to an eggs per mite per day oviposition (MDO) value. Treatments and control within each timing were analyzed for significant differences using a one way analysis of variance procedure at $\alpha = 0.05$.

<u>Experiment</u> <u>II</u>. Essex soybeans were grown, two plants per 20 cm pot, in Metro-Mix 500® potting medium under greenhouse conditions and 16 hour photoperiod. Plants were cut back to eight nodes in order to promote branching normally observed in field-grown soybeans. Pots were randomly assigned to control, permethrin, and fenvalerate treatments, three pots (six plants) per treatment. Plants averaged 14.8 ± 0.68 (std. error of the mean) trifoliates, 18.4 ± 0.73 nodes, and 2.5 ± 0.26 branches. All plants were in the vegetative stage.

Five fully expanded trifoliates from each plant's most recent growth were tagged. Water emulsions of permethrin (Pounce 3.2 EC, 120 ppm) and fenvalerate (Pydrin 2.4 EC, 120 ppm) were prepared. Plants were placed in a sealed section of the greenhouse to minimize the impact of air currents on the application procedure. 12.6 ml ± 2.5 % of insecticide emulsion was applied to the plants in a single pot. A hand-held pump sprayer was used to spray the insecticides into the air above the plants, from three locations 120° apart, such that droplets fell vertically onto the adaxial leaf surfaces, leaving the abaxial leaf surfaces free of pyrethroid residue. Tagged leaves were selected for adequate spray coverage (i.e. 50% adaxial leaf surface covered) immediately post application.

Lightweight leaf cages (designed according to Hughes et al. 1966) enclosing approx. 130 mm^2 were attached to the abaxial ("untreated") surface of leaflets (tagged trifoliates), two cages/plant (four plants) and one cage/plant (two plants) for a total of ten cages (replications)/treatment. Three adult female TSSM, 1-72 hours old, were placed in each leaf cage using a 3/0 camel's-hair brush. The experimental units were placed in a plant growth chamber at 25°/19°C± 0.5°C and twelve hour photoperiod.

Daily counts were made of TSSM numbers present in the leaf cages. After four days, TSSM females in a cage were transferred to a new cage affixed to the abaxial surface of the adjacent leaflet. The original leaflet/cage was excised and the number and location of eggs recorded under 20X magnification. The experimental units were placed in the plant growth chamber and held for an additional five days. Daily counts of the TSSM numbers present in the leaf cages were continued. After five days the leaflets/cages were excised, and the number and location of eggs observed under 20X magnification. The proportion of the total eggs in a cage oviposited on the leaf surface vs. suspended was recorded. Egg production data were converted to an eggs per MDO value as in experiment I.

Egg production data at each time bracket was analyzed for significant differences with a one way analysis of variance (parametric), and the Kruskal-Wallis rank sum (non-parametric) test (Zar 1974). Egg distribution data were transformed using the arcsine square root probability transformation, the replication values ranked, and analyzed for significant differences using the Kruskal-Wallis Test (Zar 1974).

Experiment III. Plants used in experiment II were retained for use in experiment III. The experimental design and procedures followed in experiment II were repeated with a fresh cohort of TSSM females (1-72 hours old), for the after treatment timing brackets 15-20 and 20-25 days. The number of TSSM per cage was increased to four. Egg production and distribution data were collected as in experiment II. The experiment was terminated at 25 days after treatment. Developing soybean pods were harvested, pod numbers and green weight recorded. Treatment differences were analyzed as indicators of plant development, using the SAS ANOVA analysis of variance (SAS Inst. 1982).

Results

Experiment I. This experiment was designed to evaluate *T. urticae* oviposition response to field soybeans treated with a field use rate of fenvalerate and permethrin, over the 18 day period immediately following treatment. Soybeans were in early pod-fill at the end of the 18 day experimental period. No precipitation was received during the experiment. Relative humidity ranged from 50 to 98%. Day-degree accumulation ((high+low)/2)-50°F over the five day period bracketing each post-treatment timing was as follows: 0-4 days: 131, 7-11 days: 79, 14-18 days: 126. No significant differences in numbers of eggs oviposited were observed between treatments and controls 0-4 days, 7-11 days, and 14-18 days (Table VI-1) post-application. The reduced oviposition observed in the 7-11 day experiment may be a consequence of the unseasonably low temperatures during that week, as reflected in the lower day-degree accumulation compared to the earlier and later timing.

Experiment II. This experiment was designed to evaluate *T. urticae* oviposition, and oviposition site selection, responses to greenhouse-grown soybeans treated with a field use rate of fenvalerate and

Table VI-1. *Tetranychus urticae* Koch. (TSSM). Mean number of eggs oviposited per mite per day at three timings after pyrethroid application to field soybeans.

Treatment	0-4 Days After		7-11 Days After		14-18 Days After	
	No. TSSM	Mean Eggs[1]/ MDO±SEM[2]	No. TSSM	Mean Eggs[3]/ MDO±SEM[2]	No. TSSM	Mean Eggs[4]/ MOD±SEM[2]
Control	30	9.6a±0.2	27	6.5a±0.3	27	9.9a±0.3
Fenvalerate	33	9.4a±0.3	33	6.4a±0.3	30	10.4a±0.3
Permethrin	36	9.5a±0.3	33	6.1a±0.4	30	9.8a±0.5

[1] Means in column followed by the same letter are not significantly different. Analysis of variance, $F = 1.01$, $df = 32$, $p > 0.40$.
[2] Std. error of the mean.
[3] Means in column followed by the same letter are not significantly different. Analysis of variance, $F = 0.01$, $df = 30$, $p > 0.75$.
[4] Means in column followed by the same letter are not significantly different. Analysis of variance, $F = 0.91$, $df = 28$, $p = 0.44$.

permethrin, over the 9 day period immediately following treatment. Flowering was observed eight days after application. Relative humidity varied from 40-90% over the course of the experiment. No significant differences in numbers of eggs oviposited were observed between the treatments and control (Fig. VI-1). The analysis of variance procedure allowed a rejection of the null hypothesis at the $p = 0.058$ level in the 0-4 day timing. However, the non-parametric test (Kruskal-Wallis) clearly failed to reject the hypothesis of no treatment differences. The two types of analysis used on the 4-9 day data show close agreement in failing to reject the hypothesis of no treatment differences. There were no differences in vertical plane egg distribution (Table VI-2) between treatments and controls, with > 95% of the eggs oviposited on the leaf surface.

Experiment III. This experiment was designed to evaluate *T. urticae* oviposition, and oviposition site selection, responses to greenhouse grown soybeans treated with a field use rate of fenvalerate and permethrin, over the time period 15 to 25 days after treatment. Relative humidity varied from 40 to 90% over the course of the experiment. Results from the period 15 to 25 days following application (Fig. VI-2)

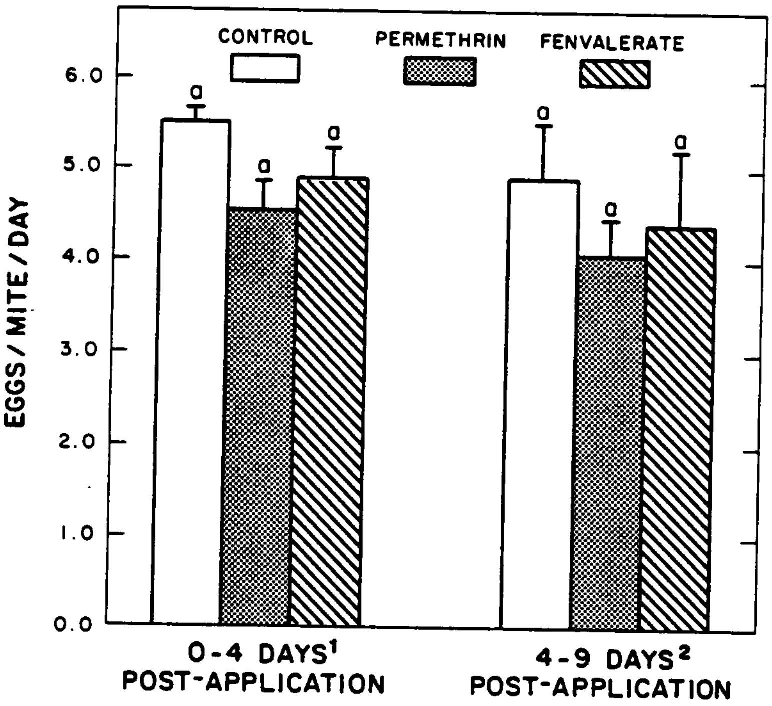

Figure VI-1. Tetranychus urticae Koch. Oviposition on pyrethroid treated soybeans 0-9 days after treatment.

[1] Bars with the same letter are not significantly different. Analysis of variance, F=3.28, df=25, p=0.058. Kruskal - Wallis non-parametric test, H=3.44, N=26, p=0.24. Small bar represents the std. error of the mean.

[2] Bars with the same letter are not significantly different. Analysis of variance, F=0.32, df=24, p=0.74. Kruskal - Wallis non-parametric test, H=1.28, N=25, p=0.54. Small bar represents the std. error of the mean.

Table VI-2. *Tetranychus urticae* Koch, (TSSM) Egg distribution; surface oviposited vs. suspended off the leaf surface, expressed as the percentage of total eggs oviposited on the leaf surface.[1,7]

	Days after application	
Experiment II:	0-5 days post[2]	5-9 days post[3]
Control	96.2a ± 1.1[6]	100.0a ± 0.0[6]
Permethrin	98.2a ± 0.5	99.7a ± 0.0
Fenvalerate	98.6a ± 0.8	99.9a ± 0.0

	Days after application	
Experiment III:	15-20 days post[4]	20-25 days post[5]
Control	85.1a ± 4.6[6]	86.3a ± 3.4[6]
Permethrin	64.0a ± 7.3	96.2a ± 8.4
Fenvalerate	72.7a ± 8.1	83.1a ± 17.9

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[1] Means followed by the same letter are not significantly different, p = 0.05.

[2] Kruskal-Wallis non-parametric test, H=3.49, N=26, p=0.44.

[3] Kruskal-Wallis non-parametric test, $H=1.77$, $N=23$, $p=0.70$.

[4] Kruskal-Wallis non-parametric test, $H=4.19$, $N=35$, $p=0.31$.

[5] Kruskal-Wallis non-parametric test, $H=1.99$, $N=22$, $p=0.66$.

[6] Std. error of the mean.

[7] All data transformed arcsine p .

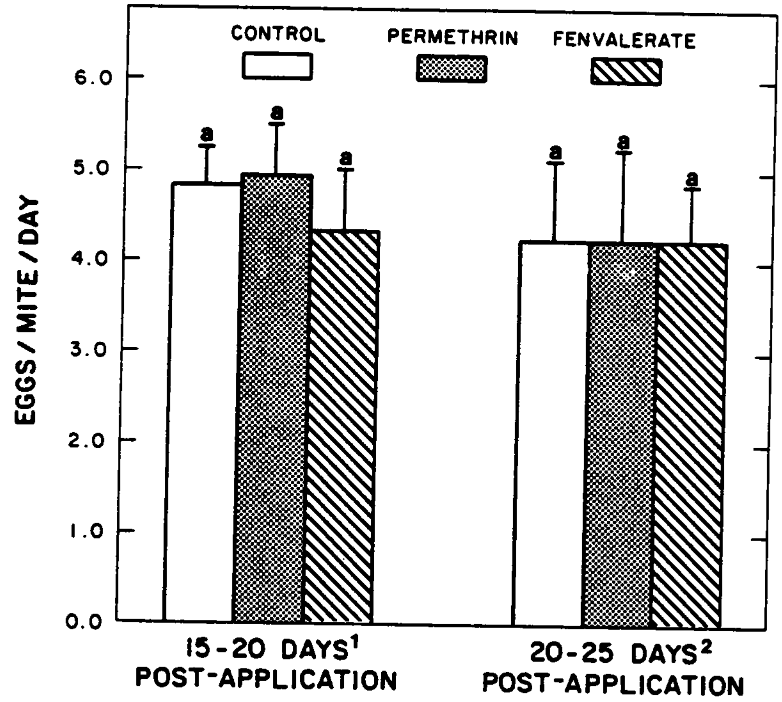

Figure VI-2. <u>Tetranychus</u> <u>urticae</u> Koch. Oviposition on pyrethroid treated soybeans 15-25 days after treatment.

[1] Bars with the same letter are not significantly different. Analysis of variance, F=0.08, df=23, p=0.71. Kruskal - Wallis non-parametric test, H=0.35, N=24, p=0.85. Small bar represents the std. error of the mean.

[2] Bars with the same letter are not significantly different. Analysis of variance, F=0.0, df=21, p> 0.99. Kruskal - Wallis non-parametric test, H=0.12, N=22, p > 0.90. Small bar represents the std. error of the mean.

show no significant differences in oviposition response between the treatments and controls. Again, the two types of analysis, parametric and non-parametric, show close agreement in failing to reject the hypothesis of no treatment differences. Increasing the number of mites per cage from three to four apparently did not reduce the observed variability in oviposition response within treatments. No differences were found in vertical plane egg distribution (Table VI-2) between treatments and controls. More than 99% of the eggs were oviposited on the leaf surface. Although not statistically comparable, oviposition levels observed in experiment II (Fig. VI-1) when the plants were in the late vegetative stages of development were similar to the levels observed in experiment III (Fig. VI-2), when the plants were in the pod-fill stages. Soybean yields (Fig. VI-3) were not significantly different, based on mean pod yield per plant (Fig. VI-3A), mean number of pods per plant (Fig. VI-3B), and mean weight per pod (Fig. VI-3C).

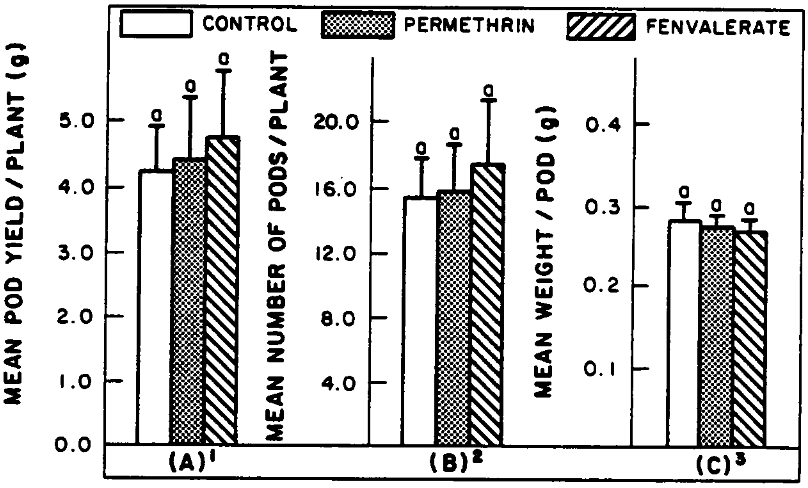

Figure VI-3. Soybean development parameters, pyrethroid treated vs. control, 26 days after treatment. Bars with the same letter are not significantly different.

[1] Analysis of variance (SAS ® ANOVA), F=0.08, df=17, $p > 0.92$.

[2] Analysis of variance (SAS ® ANOVA), F=0.14, df=17, $p > 0.87$.

[3] Analysis of variance (SAS ® ANOVA), F=0.08, df=17, $p=0.92$.

Discussion

Spider mite oviposition (fecundity) is highly sensitive to variations in host plant nutritional quality (Wrensch and Young 1975), and can serve as an indicator of spider mite fitness, when maintained on a given resource. Oviposition has been used to evaluate spider mite resistance in peanut cultivars (Johnson et al. 1980), and reproductive response to organophosphate insecticides, and treated plants (Maggi and Leigh 1983). Numbers of eggs oviposited by TSSM in this study were not evaluated on a daily basis, due to the difficulties of accurately counting mites in the field and on large plants.

Fenvalerate residues have been demonstrated to suppress TSSM oviposition (Penman and Chapman 1983, Iftner and Hall 1984). Iftner and Hall (1984) reported little or no suppression of TSSM oviposition when mites were exposed to permethrin residues. Since laboratory/greenhouse studies have shown that both fenvalerate and permethrin suppress TSSM oviposition (see chapter V), it was deemed necessary to prevent the contact of TSSM females with pyrethroid residue, in order to avoid confounding any host plant alteration effect with a residue effect on mite egg production.

In experiment I, the dense canopy formed by the drill planted soybeans, the use of flat fan nozzles at a relatively low pressure (85 psi), and a moderate water rate (60 gpa) all served to minimize the amount of spray reaching the abaxial leaf surfaces. Spray conditions in experiments II and III were closely controlled. Vertical plane egg distribution was not significantly affected by any of the treatments. An alteration in egg distribution on the leaf has been observed when TSSM are exposed to pyrethroid residues on leaf surfaces (Iftner and Hall 1984). As a result the experiments were analyzed with the assumption that TSSM females did not directly contact pyrethroid residues. The vertical plane egg distribution data show that TSSM females do not exhibit the avoidance response to pyrethroid treated foliage that is observed when they are exposed directly to pyrethroid residues (Hall 1979, Iftner and Hall 1983b, Penman and Chapman 1983, Iftner and Hall 1984).

A significant treatment effect on the numbers of TSSM eggs oviposited was not observed in any of the experiments. The disparity in the results of the two statistical analyses used on the 0-4 day experiment II data underscores the need for caution when analyzing data with relatively small sample sizes. A single application of fenvalerate or permethrin applied to soybeans in the late vegetative stages of development apparently does not improve the plant as a resource, based on TSSM oviposition response. Treated plants did not significantly differ from control plants according to criteria such as time to flowering and pod yield. Pyrethroid insecticides are not translocated, and are slowly metabolized by plants (Elliot et al. 1978). Southwick et al. (1983) found permethrin levels in cotton leaves increased only slightly in the period up to five days post-application, while surface residues decreased rapidly, the losses attributed to volatilization. Toscano et al. (1982) demonstrated a permethrin induced reduction in photosynthesis and stomatal closure in lettuce. In the same study, twice weekly applications of fenvalerate did not reduce lettuce yields, although similar applications of methyl-parathion did reduce yields. Apparently, pyrethroids can have a subtle influence on the physiology of some plants, but any changes in the soybean plant, if present at all, had no demonstrable effect on TSSM oviposition response.

Higher levels of TSSM oviposition were observed in the field than in the greenhouse. A similar observation was made by Maggi and Leigh (1983) of spider mite population development on greenhouse versus field-grown bean plants. Differences were attributed to the higher nutritional quality of the field-grown plants. In this study, differences in heat unit accumulation and photoperiod could also have contributed to the observed differences. The reduced level of egg production observed in the 7-11 day experiment I coincided with a week of lower temperatures.

Numbers of eggs oviposited on soybeans in the late vegetative stage (experiment II) and in the late flower-pod fill stages (experiment III) were very similar. Soybeans are considered to be most susceptible to spider mite damage during pod-fill, and this is when field infestations are most likely to be observed (Poe 1980). The flowering and fruiting stages of a plant are generally thought to be most nutritionally supportive of high spider mite fecundity (Huffaker et al. 1969). Additional research is needed to determine the relative contribution of soybean phenology and environmental conditions (i.e. hot and dry late summer weather around the time of pod-fill) to spider mite populations outbreaks.

The findings in this study should help entomologists better understand the factors which are responsible for pyrethroid-induced spider mite outbreaks in soybeans, as well as other cropping systems. Fenvalerate and permethrin do not increase TSSM fecundity through an alteration of soybean physiology. Since these insecticides depress TSSM egg production following direct contact, further investigation into the relationship of induced-dispersal with spider mite outbreaks is warranted. Until the factors contributing to outbreaks of spider mites following pyrethroid applications are understood, prudent use of these materials during periods of hot/dry weather is advocated.

CHAPTER VII

SUMMARY AND CONCLUSIONS

Introduction

The pyrethroids fenvalerate and permethrin are effective insecticides recommended for insect control in Virginia soybeans (Smith et al. 1984). The pyrethroids are a relatively new class of synthetic organic insecticides which provide the advantages of low mammalian toxicity, low dosage rates, and broad spectrum insecticidal activity. However, they have the drawback of frequently inducing spider mite outbreaks in crops where they are used. Workers since 1978 have documented the problem of spider mite outbreaks in orchard agroecosystems, outbreaks which appear induced by pyrethroid insecticides (Hoyt et al. 1978, Hall 1978, Riedl and Hoying 1980, Hislop et al. 1981, Penman et al 1981, Riedl et al. 1981, Hull and Starner 1983, Iftner and Hall 1983b, Penman and Chapman 1983, Iftner and Hall 1984). However, little has been done to assess the impact of pyrethroid insecticides on *Tetranychus urticae* Koch, individuals and populations, in soybean fields.

Historically, several mechanisms have been hypothesized as contributing to agrochemically induced outbreaks of spider mites. The most common hypothesis is that pesticides kill mite predators, leading to a breakdown in natural control (Huffaker et al. 1969). A second mechanism is hormoligosis (Luckey 1968), that is, sublethal quantiities of an agricultural chemical (in this case a pyrethroid insecticide) stimulate increased levels of fecundity (Riedl and Hoying 1980, Maggi and Leigh 1983). A third hypothesis is that pesticides in general (van de Vrie et al. 1972) and pyrethroids in particular (Hoyt et al. 1978) induce a physiological change in the host plant which makes the treated plant more suitable for mite reproduction. A fourth hypothesis is that pesticide residues (van de Vrie 1972), and pyrethroid residues in particular (Penman and Chapman 1983) act as repellents, inducing spider mite populations to disperse to untreated foliage. This induced dispersal releases the spider mite population from certain inter- and intraspecific density-dependent population regulating factors, resulting in a rapid increase in population size.

The objectives of my study were to:

1. Investigate certain behavioral responses of the two spotted spider mite, *Tetranychus urticae* Koch to residues of formulated fenvalerate and permethrin on soybean foliage.

2. Evaluate *Tetranychus urticae* Koch oviposition response after direct treatment, and contact with formulated fenvalerate and permethrin residues on soybean foliage.

3. Evaluate *Tetranychus urticae* oviposition response on soybeans treated with formulated fenvalerate and permethrin.

Chapter 3

Greenhouse experiments were conducted to evaluate *Tetranychus urticae* Koch dispersal response to fenvalerate and permethrin residues on soybean foliage; partition the dispersal response into walkoff and spindown components so that the significance of each could be evaluated; and develop a simple bioassay to evaluate spider mite dispersal responses to pesticides. Both insecticides were found to induce a dispersal. The response to fenvalerate was more extreme than the response to permethrin. The dispersal response has two components; walkoff and spindown. The components were of equal importance in *T. urticae* escape from permethrin residues at a field use rate. Spindown was the most significant component of _T. urticae_ escape from fenvalerate residues. A petri dish spider mite trap was developed, and proved to be reliable in separating walkoff from spindown, as well as being inexpensive and easy to use.

Chapter 4

A greenhouse experiment was conducted to evaluate _Tetranychus urticae_ Koch oviposition site selection response to residues of fenvalerate and permethrin at two levels of "spray" coverage; runoff and non-coalesced droplets. Lightweight leaf cages were used to retain the mites on the treated surfaces. Both pyrethroids were found to alter the distribution of eggs within the leaf cages. When treated and untreated folige was available in a leaf cage, eggs were almost always found directly on the untreated surface. When untreated foliage was not available, a substantial portion of eggs were suspended in webbing above the treated surface. No significant differences in egg distribution between the two spray coverage treatment levels was observed. Since spider mites are not known to actively seek out oviposition sites, the alterations in egg distribution likely reflects a general pyrethroid avoidance response.

Chapter 5

Greenhouse experiments were conducted to evaluate Tetranychus urticae Koch oviposition response under three conditions of exposure to fenvalerate and permethrin. Whole soybean plants and lightweight leaf cages were used in all experiments. The first condition involved direct exposure to residues at a field use rate. The second condition involved removal of the mites from the first set of conditions, and transferring them to untreated foliage for continued observation. The third condition involved direct treatment of the mites with pyrethroids, followed by placement on untreated foliage for observation.

Contact with permethrin and fenvalerate residues at a field use rate resulted in reduced egg laying. Fenvalerate produced a significantly stronger effect. The effect is reversible, as the mites resumed normal levels of oviposition within several days after removal from contact with residues. Mites were slower to recover from fenvalerate, than from permethrin.

The females used in the study were relatively susceptible to direct applications of pyrethroid insecticides, than those toxicological studies reported in the literature. The normal field use rate of permethrin was moderately lethal when applied directly to females. The normal field use rate of fenvalerate was lethal. A ten-fold reduction in the chemical rate was sublethal, although outward signs of poisoning were visible. Both insecticides applied at the reduced rate significantly suppressed oviposition for several days following treatment. The response to fenvalerate was more extreme, and longer lasting than the response to permethrin.

Females are far more susceptible to direct contact applications of pyrethroids than to contact with dried residues. Pyrethroid induced suppression of oviposition had a strong physiological component. The findings of this study do not support the contribution of the pyrethroid avoidance response (behavioral component) to the observed suppression of oviposition. Under the conditions of this study the data do not support the homoligosis hypothesis.

Chapter 6

Field and greenhouse experiments were conducted to evaluate Tetranychus urticae Koch oviposition response to soybeans treated with a field use rate of permethrin and fenvalerate. Mites were prevented from directly contacting pyrethroid residues, to avoid confounding any host plant effect with the direct chemical effect on mite oviposition. Oviposition was evaluated in field plots using a lightweight leaf cage technique over the time period 0 to 18 days after treatment. Oviposition was evaluated on greenhouse-grown soybeans for the time period 0 to 25 days after treatment.

Significant differences in the numbers of eggs oviposited between treatments and controls were not detected under any set of conditions tested. Significant differences in the distribution of eggs in the leaf cages were not detected under any set of conditions. Significant differences in soybean development parameters were not observed between treatments in the greenhouse experiment. Fenvalerate and permethrin do not appear to alter the physiology of the soybean plant in a way which improves the plant as a host for spider mite reproductive development.

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