

LEPTOTHRIPS MALI (FITCH): A POTENTIALLY
IMPORTANT PREDATOR IN VIRGINIA APPLE ORCHARDS

by


Michael Peter Parrella

Dissertation submitted to the Graduate Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY
in
Entomology

APPROVED:



Dr. R. L. Horsburgh, Chairman



Dr. L. T. Kok



Dr. R. L. Pienkowski



Dr. W. A. Allen



Dr. J. A. Barden

June, 1980

Blacksburg, Virginia

LD
5655
V356
1980
P377
c.2

To My Parents -
with all my love

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Dr. R. L. Horsburgh for guiding my research and developing my knowledge of the apple orchard. I was fortunate to have someone with such an immense talent by my side. I would like to express my appreciation to Drs. L. T. Kok and R. L. Pienkowski who aided my development as a researcher and teacher during the past 5 years. My gratitude is extended to Drs. W. A. Allen and J. A. Barden for helpful critical reviews of the manuscripts and dissertation proper.

Special thanks are extended to Dr. W. H. Robinson for timely guidance and assistance during some particularly disorganized periods.

I would like to thank Brian Pitkin of the British Museum (Natural History) for his interest in this project and for his continued correspondence regarding taxonomic problems.

I am indebted to my colleague and friend Joseph McCaffrey for his guidance, advice and assistance throughout this dissertation. I also would like to thank John Trumble for some excellent critical reviews and counsel along the way. My friendship with Joe and John has been a highpoint of my years at Virginia Tech.

Edith McGranahan and Leo Ponton deserve special thanks for their incredible cooperation on many aspects of this study. They both added a touch of class to the Shenandoah Valley Research Station.

Finally, I thank Deborah Rowe who was my technician, librarian, secretary, guidance counselor, etc. I could have asked for nothing more.

TABLE OF CONTENTS

	<u>Page</u>
I. INTRODUCTION.....	1
II. LITERATURE REVIEW.....	5
Thysanoptera.....	5
A. The Genus <u>Leptothrips</u> (Hood): Comparisons with the Genus <u>Haplothrips</u> Amoyt and Serville.....	10
B. <u>Leptothrips mali</u> (Fitch).....	12
Thrips and Biological Control.....	15
A. Predatory Control.....	15
B. Phytophagous Thrips.....	16
Predator-Prey Interactions: The Functional and Numerical Response.....	17
Pest Management in Virginia Apple Orchards.....	27
III. POPULATION DYNAMICS OF PHYTOPHAGOUS ARTHROPODS AND THEIR PREDATORS UNDER DIFFERENT PESTICIDE PROGRAMS IN VIRGINIA APPLE ORCHARDS.....	31
Introduction.....	31
Materials and Methods.....	32
A. Statistical Analyses.....	40
Results.....	40
A. Arthropod Pests.....	40
B. Arthropod Predators.....	41
C. Predator-Pest Relationships.....	49
D. Comparison of Spray Programs.....	51
Discussion.....	52

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
Conclusions.....	55
IV. BIONOMICS OF <u>LEPTOTHRIPS MALI</u> (FITCH): A COMMON PREDATOR IN VIRGINIA APPLE ORCHARDS.....	56
Introduction.....	56
Materials and Methods.....	56
A. Description of Developmental Stages.....	57
B. Development at Different Temperatures.....	58
C. Preoviposition, Fecundity and Longevity of Adults.....	61
D. Development on Selected Food Sources.....	61
E. Prey Relationships.....	62
F. Statistical Analyses.....	63
Results.....	63
A. Description of Developmental Stages.....	63
B. Development at Different Temperatures.....	70
C. Preoviposition, Fecundity and Longevity of Adults.....	77
D. Development on Selected Food Sources.....	77
E. Prey Relationships.....	79
Discussion.....	79
V. FUNCTIONAL AND NUMERICAL RESPONSES OF <u>LEPTOTHRIPS MALI</u> TO DENSITIES OF <u>PANONYCHUS ULMI</u>	83
Introduction.....	83
Materials and Methods.....	83
A. Functional Responses of 1st Stage Larvae.....	83
B. Functional Responses of 2nd Stage Larvae.....	86

TABLE OF CONTENTS (CONTINUED)

	<u>Page</u>
C. Functional and Numerical Responses of Adults.....	86
D. Statistical Analyses.....	88
Results.....	88
Discussion.....	93
Conclusions.....	95
VI. TOXICITY OF SELECTED PESTICIDES TO <u>LEPTOTHRIPS</u> <u>MALI</u>	99
Introduction.....	99
Materials and Methods.....	101
Results and Discussion.....	102
VII. COMPATIBILITY OF <u>LEPTOTHRIPS</u> <u>MALI</u> WITH <u>STETHORUS</u> <u>PUNCTUM</u> AND <u>ORIOUS</u> <u>INSIDIOSUS</u> : PREDATORS OF <u>PANONYCHUS</u> <u>ULMI</u>	106
Introduction.....	106
Materials and Methods.....	106
A. Statistical Analyses.....	109
Results.....	109
Discussion.....	114
VIII. COMPARISON OF TWO SAMPLING METHODS FOR <u>LEPTO-</u> <u>THRIPS</u> <u>MALI</u> IN VIRGINIA APPLE ORCHARDS.....	117
Introduction.....	117
Materials and Methods.....	117
Results and Discussion.....	119
SUMMARY.....	122
LITERATURE CITED.....	126
VITA.....	138

LIST OF FIGURES

<u>Figure No.</u>	<u>Page</u>
1. Orchards blocks A, B and C, Tyro, Virginia.....	33
2. Populations of selected pests and predators, Block A, 1977.....	42
3. Populations of selected pests and predators, block A, 1978.....	43
4. Populations of selected pests and predators, block B, 1977.....	44
5. Populations of selected pests and predators, block B, 1978.....	45
6. Populations of selected pests and predators, block C, 1977.....	46
7. Populations of selected pests and predators, block C, 1978.....	47
8. Populations of aphids and leafrollers, blocks A, B and C, 1977.....	48
9. Rearing cage for <u>Leptothrips mali</u> : A) apple leaf, B) plastic ring, C) friction sealed plastic top.....	59
10. Egg of <u>L. mali</u> on the adaxial side of an apple leaf along the midvein.....	64
11. Eggs and 1st stage larvae of <u>L. mali</u> on filter paper. Eyespots and antennae visible through the chorion indicate imminent eclosion.....	66
12. <u>L. mali</u> 1st stage larva - 3 days post eclosion.....	67
13. <u>L. mali</u> 1st stage larva - 5 days post eclosion.....	68
14. <u>L. mali</u> 2nd stage larva - 5 days post ecdysis.....	71
15. <u>L. mali</u> prepupa within an apple leaf mine.....	72
16. <u>L. mali</u> pupa I.....	73
17. <u>L. mali</u> pupa II.....	74

LIST OF FIGURES (CONTINUED)

<u>Figure No.</u>	<u>Page</u>
18. <u>L. mali</u> adult female.....	75
19. Placement of <u>P. ulmi</u> eggs for determination of <u>L. mali</u> 1st stage larval functional response.....	85
20. Functional response of 1st stage larval <u>L. mali</u> to densities of <u>P. ulmi</u> eggs at 3 temperatures.....	89
21. Functional response of 2nd stage larval <u>L. mali</u> to densities of adult female <u>P. ulmi</u> at 3 temperatures.....	90
22. Functional response of field collected adult female <u>L. mali</u> to densities of adult female <u>P. ulmi</u> at 3 temperatures.....	91
23. Functional response of field collected male and lab-reared adult female <u>L. mali</u> to densities of adult female <u>P. ulmi</u> at 23.9°C.....	92
24. Interaction arena: A) plastic petri dish, B) water saturated cotton, C) apple leaves, D) Stikem barrier, E) leaf section fastened with a minuten.....	107
25. <u>O. insidiosus</u> (5th stage nymph) feeding on <u>L. mali</u> 2nd stage larva).....	112
26. Relationship between the number of <u>L. mali</u> limb- tapped and observed from 6 Golden Delicious trees on 5 sampling dates, 1978 ($R^2 = 0.76$).....	120

LIST OF TABLES

<u>Table No.</u>		<u>Page</u>
1.	Spray Schedule for Orchard Block A.....	34
2.	Spray Schedule for Orchard Block B.....	35
3.	Spray Schedule for Orchard Block C.....	37
4.	Measurements (mm) of <u>L. mali</u> Developmental Stages.....	69
5.	Development (\bar{X} No. days \pm S D) of <u>L. mali</u> at Selected Temperatures.....	76
6.	Preoviposition Period, Fecundity and Longevity of Lab-Reared and Field Collected <u>L. mali</u>	78
7.	Mean No. Adult Female <u>P. ulmi</u> Killed and Oviposition Rates/ <u>L. mali</u> Female/2 days (\pm S E) in Leaf Cages for a 30 Day Period.....	94
8.	Relative Toxicity of Selected Pesticides to <u>L. mali</u>	103
9.	Effects of Predation by <u>L. mali</u> and <u>S. punctum</u> Individually and in Combination on <u>P. ulmi</u> in Leaf Arenas.....	110
10.	Effects of Predation by <u>L. mali</u> and <u>O. insidiosus</u> Individually and in Combination on <u>P. ulmi</u> in Leaf Arenas.....	113

INTRODUCTION

Apple production in commercial orchards in Virginia totaled 515 million pounds in 1979¹ ranking it fourth among states in total production; only Washington, Michigan and New York had higher production. Some Virginia growers spray as many as 15-20 times during the season when following the spray bulletin² provided by the Extension Service of VPI and SU. As many as 5 of these sprays (acaricides) may be directed specifically for mite control. However, mite pests on apples are characterized as "secondarily induced pests" (Croft 1975a) which exceed economic thresholds due to the misuse of some of the other 15 sprays. This has been recognized in other major fruit growing areas where integrated pest management (IPM) programs have been developed to maximize the utility of beneficial arthropods through the selective and judicious use of pesticides (Hoyt and Caltagirone 1971; Croft 1975a; Tette et al. 1979; Asquith and Colburn 1971). Pesticides are still vital parts of these programs, but through quantitative evaluation of pest and beneficial arthropod populations and a knowledge of economic thresholds, accurate predictions can be made as to whether pesticides should or should not be applied. Pimentel et al. (1977) documented a reduction in pesticide use in New York of ca. 30 lbs/acre during the past 25 years; reduction of total pesticide usage has

¹Va. Crop Reporting Service, USDA and Va. Dept. Agric. Consumer Serv. Apples. 1979 Production by Varieties. Jan. 21, 1980.

²1979 Virginia Spray Bulletin for Commercial Tree Fruit Growers. Publ. 219. Ext. Div., VPI and SU, Blacksburg, Va.

probably been realized in other areas adopting IPM methodology. Despite Virginia's high ranking in total apple production and the importance of this crop to the economy of the state (5th in total revenues from farm income)³, IPM has not been emphasized in Virginia apple orchards. It is often said that IPM techniques today are just a revitalization of those used prior to the advent of insecticides in the 1940's. This is only partially true. Many of the pre-1940 techniques are important and are used in present-day IPM programs, but there have been significant advances in our understanding of the ecology of managing pests, particularly in the area of quantitative ecology which has led to modeling or simulation of insect populations for decision making purposes (Berryman and Pienaar 1974). A quantitative approach to managing pest populations relies heavily on basic information involving pests, beneficial arthropods, and the relationship of all these to the environment. Research on fruit insects in Virginia has contributed to this pool of basic information, particularly the work of Cagle (1946) on the European red mite. The mite IPM programs in Michigan (Dover et al. 1979) and Pennsylvania (Mowery et al. 1975) relied heavily on his biological study of this mite species. A vital component of any IPM program is to determine the effect of commonly used pesticides on beneficial arthropods; little research has been done regarding this in Virginia orchards. Only 2 studies, those of Clancy and Pollard (1948; 1952) investigated this important area. It is interesting that this work was done early in the evolution of IPM.

³Virginia Apple and Peach Tree Survey. 1977. Va. Crop Reporting Service Bull. No. 43, 56 pp.

Picket (1949) was credited with pioneering IPM principles in apple orchards working in Nova Scotia.

The year 1976 has been selected as the beginning of the era of IPM (Metcalf 1980), but it was rare to find research conducted on insect control during the past decade that did not include some IPM concept. In more recent IPM studies in Virginia, McCaffrey (1978) detailed the spider fauna inhabiting central Virginia apple orchards with notes on their importance in controlling orchards pests. Thomas (1979) developed a method of determining the economic threshold for leafrollers in Virginia and evaluated biological insecticides for control of these serious pests; the rationale for their inclusion in an IPM program was discussed. This research forms important parts of the puzzle that will one day comprise an IPM program in Virginia orchards.

My research is directed at providing information on the pest and predator complexes in Virginia apple orchards which will add to the base on which to build an IPM program.

The major arthropod pests in Virginia apple orchards are leaf-rollers, mites and aphids. A preliminary study (Parrella et al. 1978) of the population dynamics of these pests revealed that Leptothrips mali (Fitch) (Thysanoptera:Phlaeothripidae), Haplothrips subtilissimus Haliday (Thysanoptera:Phlaeothripidae), Orius insidiosus (Say) (Hemiptera:Anthocoridae), Stethorus punctum LeConte (Coleoptera:Coccinellidae), Deraeocoris nebulosus Uhler (Hemiptera:Miridae), and Chrysopa spp. (Neuroptera:Chrysopidae) were the major predators in Virginia apple orchards. The most abundant of these predators was L. mali and since there has been only a limited study of its biology

(Bailey 1940), I decided to evaluate this insect with respect to its potential for inclusion in an IPM program for Virginia apples.

My research explored the following areas: 1) the population dynamics of this thrips and other predators in the field with the objective of looking at their temporal and numerical coincidence with major pests, 2) the detailed bionomics of L. mali, 3) the predator-prey interaction between L. mali and Panonychus ulmi (Koch) as shown by the numerical and functional responses, 4) the toxicity of commonly used orchard pesticides to L. mali, 5) the compatibility of L. mali with O. insidiosus and S. punctum, two other major predators in Virginia apple orchards, and 6) the comparison of two sampling methods for this thrips.

II. LITERATURE REVIEW

Thysanoptera

The Thysanoptera, or Thrips, are distributed throughout the world with most species occurring in the tropics, many in temperate regions, and a few extending into the arctic. Their habitats range through forests, grasslands, scrub, desert, most cultivated crops and gardens and include phytophagous and carnivorous species, gallmakers and inquilines. They also serve as prey for other arthropods and vertebrates. More than 6000 species have been recorded and Hood (1917) believed ultimately there will be 25,000 species described.

The asymmetry of the ventral surface of the head, the vestigial right mandible and the presence of a protrusible tarsal bladder have imposed stability and independent status to the Thysanoptera since the Permian period (Ananthakrishnan 1979). The fringed nature of the wings, although a striking feature, is not present in all species and is also characteristic of trichogrammatid Hymenoptera and some psocids. The delicately fringed wings give the order its scientific name, Thysanoptera, derived from two Greek words Thysano = fringe and ptera = wing. The common name, thrips, is also derived from the Greek, meaning a "wood louse." Other names are bladderfeet (Physopoda) because of the unique terminal tarsal segment; fringewings; and thunderflies or stormflies, names attributable to the frequent appearance of some species in stormy weather (Lewis 1973). The taxonomic and systematic classification of this group has largely been documented since the year 1900. However, many revisions of the early

descriptive work are necessary and new taxonomic work is needed (Lewis 1973). Compared with many groups of insects, few early entomologists specialized in the study of the Thysanoptera. However, since thrips were recognized as economically important insects, first as pests damaging crops in many parts of the world (Marsham 1796), then as potential predators of crop pests (Walsh 1864), as potentially important pollinators (Shaw 1914), as vectors of plant virus and bacterial diseases (Pittman 1927), and finally as biological control agents of noxious weeds (Simmonds 1933), they have received progressively more attention.

There are two principal suborders, Terebrantia and Tubilifera. Only the latter will be discussed. The Tubilifera lack an ovipositor and have the tenth segment of the abdomen drawn out into a tube. The absence of wing veins and setae on marginal veins, two-segmented maxillary palps, and the maxillary stylets usually retracted far into the head, are very characteristic. Two pupal stages succeed the prepupa during postembryonic development. Only 1 family, Phlaeothripidae is recognized in this suborder.

Thrips are usually recognized as exopterygote insects and are placed with the hemipteroid orders even though their postembryonic development more closely resembles the holometabolous transformations found in the Endopterygota. This intermediate type of metamorphosis has caused considerable controversy with some authors calling the immatures nymphs and others calling them larvae and pupae. Recent histological studies have provided evidence that during myogenesis,

changes occur at least as great as those in holometabolous metamorphosis of many Endopterygota. As a result, the quiescent instars of the Thysanoptera are true pupal stages (Davies 1969). The holometabolous type of metamorphosis in the Thysanoptera developed independently of that of the Endopterygota. The selective value of two or three pupal stages in the Thysanoptera, when only one is usually necessary for similar transformations in the Endopterygota, is still unknown. Based on a study of mouthparts, the Thysanoptera are placed before the Hemiptera in phylogenetic sequence (Heming 1978). Most recent publications on tubiliferous Thysanoptera have referred to the immatures as larvae and have recognized a prepupa, pupa I and pupa II. This format was followed in this dissertation.

The Thysanoptera are a distinct part of the Hemiptera-Corrodentia unit, with Corrodentia primitive to the Thysanoptera. This has been substantiated by the homology of the maxillary stylets of thrips with the lacinia of Corrodentia, by the more complicated stylets of the Homoptera, by the similarity of the antennal sense cones of thrips, aphids and some psocids, by the absence of ocelli in larvae, and by the reduction in the number of malpighian tubules (Stannard 1968). Studies on the functional morphology of the thysanopteran pretarsus (Heming 1971) and on the postembryogenesis and imaginal morphology of the female reproductive system of some Thysanoptera (Heming 1970) has supplied further evidence of the close relationship between the Thysanoptera and Hemiptera. Thysanoptera probably evolved from insects in which both mandibles were reduced and the asymmetry resulting from enlargement of the left mandible is believed to be a secondary

development associated with pollen feeding (Mound and O'Neill 1974). The evolution of the Thysanoptera has been marked by a reduction in the tentorium (Lewis 1973). Heming (1978) believed the Thysanoptera to be a sister group of the Hemiptera with mouthparts intermediate between psocids and true bugs. He speculated that a long period of continuous independent evolution occurred after the thysanopteran line diverged from the psocopteroid line probably some time in the Carboniferous period.

From a phylogenetic viewpoint, the Phlaeothripidae has a wide range of forms limited by intermediates. It did not attain the status of a major group until late in the tertiary period. The evolution of the family is so recent that many precursors and intermediates have not been eliminated by the hazards of changing environments that occurred over long periods of time (Stannard 1957). Further evidence supporting the recent evolution of the Tubilifera is their absence, or rarity, in fossil beds before the Oligocene epoch. No other group of Thysanoptera present such a diverse variety of structural modifications as in the Tubilifera which comprise so many closely intergrading genera that it is often difficult to determine the transitional species.

While the main body of the Terebrantia continued to live in leaf and flower niches, a majority of the Tubilifera branched off to a fungal habitat and a number of phytophagous species became gall-formers. Such habitats are relatively constant and this constancy in the environment, particularly in the tropics, enables intermingling of individuals which not only reduces the rate of speciation but also

increases the chances of survival of relict species (Lewis 1973). The lack of host specificity in many of the mycophagous Tubilifera is also a possible explanation for complex relationships among various forms. Internal environmental factors within the fungal feeding habitat has stimulated the evolution of winged and apterous morphs in many species as well as the production of a structurally diverse series of forms resulting in gynecoid and oedymorous males and major and minor females (Ananthakrishnan 1979). This has led to considerable confusion regarding generic classification and species determination. All characteristics of individuals of a species tend to be highly polygenic as well as pleiotropic, and all genotypes tend to produce a range of phenotypes. Phenotypic flexibility is very characteristic of mycophagous Tubiliferan populations, with a degree of phenotypic modification being under genetic control (Ananthakrishnan 1979).

No single morphological criterion has yet been found which indicates the taxonomic level. Several characteristics or groups of characteristics have been found useful in determining taxa at the family, subfamily, tribal, generic and specific levels. Traditional characters for all Thysanoptera have been color, chaetotaxy, body sculpture, number and proportion of antennal segments, number of sense cones on antennae, nature of mouth cone, maxillary stylets and palps. Stannard (1957) stressed the significance of the pelta, praepectus, mesopraesternum and propinasternum as useful taxonomic criteria in the Tubilifera. Perfect mounts are absolutely essential to the proper identification of the Thysanoptera (Priesner 1964).

Sexual reproduction is prevalent among the Thysanoptera with

females larger and more predominant than males. Female thrips are always diploid and males haploid (Stannard 1968), so males are derived from unfertilized eggs. Such arrhenotoky occurs in many Thysanoptera, and as in the Hymenoptera, it characteristically produces unequal sex ratios (Hamilton 1967).

A. The Genus *Leptothrips* Hood: Comparisons with the Genus *Haplothrips* Amyot and Serville

The close relation of *Leptothrips* to *Haplothrips* has been emphasized by Hood (1927) who believed that the absence of a midlateral bristle in *Leptothrips* was sufficient to warrant the retention of the two genera as distinct entities. However, as suggested by Hood (1927) intermediate forms have been discovered in which the midlateral bristle is present, though vestigial, and others in which the bristle is completely developed. According to Cott (1956), the genus *Leptothrips* is very unstable, particularly in the west, and clearcut species as are known in other genera do not exist. There is abundant evidence that the genus *Leptothrips* is nothing more than a series of species complexes and should be the subject of an extensive and thorough revision (Cott 1956). An additional character which has not been given sufficient consideration is the absence of a tarsal tooth in *Leptothrips* and the constant presence of such a structure in *Haplothrips* (Cott 1956). Also the two genera differ in feeding habits: *Leptothrips* spp. are predaceous and most of the members of the genus *Haplothrips* are phytophagous.

Cott (1956) stressed the amount of variation within the genus

Leptothrips; primarily in overall size, proportions of the head and antennal segments, number of intercalated hairs on the forewings, and relative length of the legs. Any detailed study of variation in this genus is limited by the quality of the slide mounts available for study. Members of the genus Leptothrips are among the most trying of all native tubilifera to mount satisfactorily (Hood 1909; Cott 1956). Cott (1956) indicated that difficulties in mounting specimens in this genus were most pronounced in L. mali. He stressed that specimens should be collected in alcohol of reduced strength (50% or less) and that they should be prepared within 2 or 3 days after collection to avoid decomposition.

Cott (1956) believed that in the genus Leptothrips there are a few highly variable species or there are numerous closely related ones. Cott (1956) stated that J. D. Hood agreed with the latter premise since he has named 9 North American members of this genus. However, Cott (1956) was not sure that these are all entitled to species rank or are simply varieties of L. mali and one reason he gave was that the incomplete description of L. heliomanes by Hood (1927) prevented comparisons. Cott (1956) also stated that there has not been a more detailed description of this species since 1927. However, Pitkin (1978) in a study of certain species of thrips described by J. D. Hood designated a lectotype of L. heliomanes indicating that he believed the genus and species to be valid. Stannard (1968) did not believe Leptothrips was a valid genus and relegated it to subgenus status within Haplothrips. He stated "Although there may be little need to keep Leptothrips as a separate entity, it has been done so

here for the sake of custom and tradition." Stannard (1968) believed that the taxonomic characters stated by Cott (1956) to separate Leptothrips from Haplothrips were overshadowed by the great number of similarities between them. Stannard (1968) indicated that Leptothrips was a taxon of closely related species and is probably a species group with the malifloris complex.

Members of the genus Leptothrips are easily distinguished from those in Haplothrips by the following characters: head much longer than wide, the eyes prolonged ventrally more than dorsally and having strong longitudinal striae on the metanotum. These characters were used to separate L. mali from Haplothrips subtilissimus Haliday and Haplothrips leucanthemi (Schrank), two other Tubiliferan thrips found in Virginia apple trees.

The thrips studied in this dissertation was identified as Leptothrips mali (Fitch) by Mr. Brian R. Pitkin, Department of Entomology, British Museum (Natural History), London, England.

B. Leptothrips mali (Fitch)

This thrips was originally described by Asa Fitch (1855) and given the name Phloeothrips mali Fitch. In a revision by Hood (1914), it was renamed Leptothrips mali (Fitch) which is the accepted specific name today. Many authors prefer the genus Haplothrips to Leptothrips, so quite often this species will appear in one or the other. Cott (1956) lists the following synonyms:

Phloeothrips mali Fitch

Leptothrips mali Hood

Cryptothrips asperus Hinds
Phyllothrips asperus Hood
Leptothrips (Cryptothrips) asperus Bagnall
Leptothrips asperus Hood
Leptothrips asperus Moulton
Leptothrips asperus macro-ocellatus Watson
Cryptothrips californicus Daniel
Cryptothrips californicus Moulton
Leptothrips californicus Hood
Liothrips mcconneli Crawford
Liothrips mcconelli Trybom
Liothrips mcconelli Karny
Liothrips maconnelli Watson
Cryptothrips pini Watson
Haplothrips pini Watson
Haplothrips cassiae Watson
Zygothrips cassiae Watson
Cryptothrips adirondacks Watson
Leptothrips adirondacks Watson

Stannard (1968) also listed Zygothrips floridensis Watson as a synonym. However, he believed that C. californicus Daniel and L. mcconnelli Crawford are not synonyms but separate species. Detailed taxonomic descriptions were provided by Hinds (1902), Cott (1956) and Stannard (1957; 1968). Stannard (1968) illustrated the head and prothorax and Bailey (1940) provided illustrations of the adult female, 2nd larval stage, antennal segments III, IV and V, and the

foretarsus. de Gryse and Treherne (1924) illustrated the male genitalia.

Recognition characters adopted by Cott (1956) (used in this study) are the long head, relatively long third antennal segment, presence of intercalated hairs on the forewings, ventrally prolonged eyes and coarsely, transversely striate pronotum bearing eyelike foveae.

L. mali is one of the most widespread and abundant of the North American Tubilifera; the northern and southern limits of its distribution are not clearly defined. L. mali has been called the "Apple Thrips" (Fitch 1855), the "Black Garden Thrips" (Watson 1918) and the "Black Hunter" (Watson 1923). No common name is officially recognized by the Entomological Society of America. An official common name for this insect is important for standardization in pest management programs. This is particularly true at the grower level where specific names tend to cause confusion. I submitted the common name "Black Hunter" to the ESA Committee on Common Names (D.W.S. Sutherland, chairman) in July of 1979. It was turned down by the committee due to vagueness and possible confusion with the masked hunter (Reduvius personatus (L.)) (Hemiptera: Reduviidae). The name was subsequently modified to "Black Hunter Thrips" and resubmitted to the committee. I have been told by Dr. Sutherland that this name is acceptable and will appear in the Bulletin of the ESA for general membership approval during 1980.

The predaceous habit of L. mali was first observed by Fernald (1892) and has since been well documented in many references cited by Bailey (1940). This thrips has been identified as part of the predator complex associated with arthropod pests in many diverse apple

growing areas: West Virginia (Jaynes and Marucci 1947; Clancy and McAlister 1956), Virginia (Clancy and Pollard 1948; 1952), Nova Scotia (Lord 1949; 1956; MacPhee and Sanford 1954; 1956; 1961), New Jersey (Thomas et al. 1959), Ohio (Holdsworth 1968; 1972a; 1972b), Pennsylvania (Horsburgh and Asquith 1968), Quebec (Parent 1967; 1973), Illinois (Meyer 1974) and Missouri (Childers and Enns 1975). A preliminary survey undertaken in 1977 in central Virginia apple orchards revealed that L. mali was one of the most abundant mite predators (Parrella et al. 1978). The only biological information available on this potentially important predator has been reported in a limited study by Bailey (1940).

Thrips and Biological Control

A. Predatory Thrips

Predatory thrips feed principally on mites and mite eggs, other thrips, coccids, eggs of lepidoptera, whiteflies, aphids, leafhoppers and tingids (Lewis 1973). Larvae and adults of carnivorous thrips pierce their prey and remove the contents in a way similar to sap feeders (Lewis 1973), but Mound (1971) indicated that information on the feeding of thrips is inadequate, particularly if thrips with different feeding strategies are to be compared. Less than 50 species are known to be predatory, feeding mostly on mites, scales and other thrips. General reviews of thrips known to be predaceous have been prepared by Lewis (1973) and Ananthakrishnan (1976).

The Terebrantia include some effective predators belonging to the genera Aeolothrips Haliday, Scolothrips Hinds and Franklinothrips

Back. However, it is among the Tubilifera that the maximum number of predaceous species occurs; major predaceous genera include Karnyothrips Watson, Podothrips Hood, Haplothrips Haliday and Leptothrips Hood. Lewis (1973) indicated that predaceous thrips were unlikely to be key factors in limiting pest populations because they breed too slowly and are less fecund than their hosts. Other factors must be considered before this generalization can be made.

While there have been many observations of predatory thrips, the biology of only a few species has been studied including Scolothrips sexmaculatus Pergande (Bailey 1939, Coville and Allen 1976, Gilstrap and Oatman 1976); Frankliniella tritici (Fitch)(Barney et al. 1979); Aeolothrips intermedius Bagnall (Bourmier et al. 1978); Haplothrips faurei Hood (Putman 1942; 1965; MacPhee 1953) and Leptothrips mali (Fitch)(Bailey 1940; Parrella and Horsburgh 1979). Many of these biological studies have been published within the past 5 years. The basis for Lewis' (1973) statement that thrips have limited potential as control agents comes from the work of Bailey (1939, 1940) in which the fecundity of S. sexmaculatus and L. mali is estimated at less than 5 eggs/female. More recent studies on S. sexmaculatus (Coville and Allen 1976; Gilstrap and Oatman 1976) indicated its fecundity to be over 100 eggs/female and Parrella and Horsburgh (1979) found that fecundity of L. mali was ca. 40 eggs/female.

B. Phytophagous Thrips

Two species of thrips, both in the Tubilifera, have been employed as agents of weed control. The first was the introduction of

Liothrips urichi Karny to Fiji from Trinidad to control the weed Kost-er's curse (Clidemia hirta D. Dom) (Simmonds 1933). This thrips attacks the terminal shoots and subsequent growth of the plant is arrested. Thus, competing plants are able to outgrow it, further reducing its spread. The use of L. urichi for control of C. hirta is a classic example of weed control by an insect where the weed is not killed but just weakened (inhibition of growth) so that it is unable to compete with surrounding vegetation. In open pastures where taller plant competition is absent, the thrips is unable to satisfactorily control the weed. L. urichi has since been introduced into Hawaii to control C. hirta (Lewis 1973) with similar results.

Amynothrips andersoni O'Neill, the 2nd thrips used in a weed biological control program, was imported from Argentina into Florida, South Carolina and Georgia for control of Alligatorweed (Alternanthera philoxeroides (Mart.) Griseb. Thrips populations capable of effectively damaging alligatorweed have not developed in any areas of its establishment (Coulson 1977). Predation by Orius spp. is believed to be a major factor in reducing A. andersoni populations.

Predator-Prey Interactions: The Functional and Numerical Response

Reduction in the abundance of a prey population through predation is a function of the number of predators present and their ability to locate and kill prey. In studying the population dynamics of predation, a distinction is made between those factors affecting predator abundance and those affecting predator searching efficiency. As a result, two predator responses are recognized: the functional and the

numerical response. This terminology was developed by Solomon (1949) and more fully developed by Holling (1959a; 1959b; 1961; 1965; 1966). The functional response is a short-term behavioral phenomenon defined in terms of the relationship between the number of prey consumed per predator and prey density. The numerical response is the relationship between the number of predators and prey density; this is often broken down into the aggregative response (Hassell 1966) where predators converge on areas of high prey density and the intergenerational response (Dempster 1975) defined by increased predator survival or improved reproduction.

The functional and numerical responses are closely correlated and should be considered together (Laing and Osborn 1974). Assessment of the efficiency of a natural enemy by comparing its numerical response with the prey's reproductive ability is misleading because the functional response of the predator partially or entirely negates the reproductive ability of its prey. Likewise, to assume that a predator cannot regulate its prey because the functional response of the predator does not equal or exceed the reproductive ability of the prey is again misleading because the numerical response of the predator increases the predator population and thus its overall functional response. This is true despite the possibility that the efficiency of individual predators will decline with increasing predator density. The effectiveness of a predator population can be assessed by comparing the reproductive capacity of the predator and its prey only if the progressive effect of predation is considered. (Laing and Huffaker 1969). A predator may have a low functional

response and a lower numerical response than its prey (progeny/unit time) but still regulate the prey population over a wide range of prey densities provided that the generation time of the predator is equal to or shorter than that of the prey.

The functional and numerical responses of a predator to prey density are crucial components of any realistic predator-prey model. Michigan's European red mite control simulation utilizing Amblyseius fallacis Garman (Dover et al. 1979) makes use of temperature mediated functional response data and Pennsylvania's computer simulation of the control of Panonychus ulmi (Koch) with Stethorus punctum LeConte (Mowery et al. 1975) relies heavily on S. punctum's numerical (aggregative) response. An analysis of the functional and numerical response has been done to determine the potential of predators to suppress a prey population (Sandness and McMurtry 1970) and to detect interference between predators and prey (Laing and Osborn 1974). Knowledge of a predator's functional response has been used to determine evolutionary aspects of predator prey relationships (Livdahl 1979), a predator's preference when presented with several prey (Murdoch 1969) and for expressing predator fecundity in terms of prey density (Beddington et al. 1976). Murdoch (1972) suggested it may be useful in screening potential enemy species. A general formula for predatory functional response can be used to analyze a predator's behavior and can lead to behavioral interpretations of how predators respond under different ecological settings (Real 1979).

A more detailed breakdown of the functional and numerical responses was provided by Hassell et al. (1976) where they viewed prey

density as only one of many independent variables affecting prey consumption and predator numbers. This is a more realistic approach with emphasis on the field situation. For example, Hassell et al. (1976) indicated that the searching efficiency of a predator can be influenced by 1) climatic conditions, 2) the density of prey (functional response), 3) prey distribution, 4) density of predators, 5) refuge for the prey, 6) alternate prey, and 7) competing predator species. Hassell (1978) devotes almost one chapter to the discussion of each of these.

It is logical to expect a functional response to take the form of an increasing number of prey eaten per predator as prey density increases, up to some limiting value which represents maximum prey consumption in the given time interval. Holling (1959a) considered three types of these responses: type I where the response rises linearly to a plateau; type II where the response rises in a negatively accelerating rate to a plateau, and type III where the response is sigmoid. For most predators, linear functional responses are an inadequate description of their response to prey density, since searching time cannot be a constant (Hassell 1978). Some time will be spent over each prey item consumed, thus progressively reducing searching time as more prey are eaten. This is an important aspect of the type II response. However, Hull et al. (1977a), Chant (1961) and Atival and Sethi (1963) have reported type I responses in describing the relationship between predator consumption and prey density. The most common response of insect predators is exhibited by type II, although some do not fit this form as well as others, i.e.,

the domed-shaped curves obtained by Sandness and McMurtry (1970) and Mori and Chant (1966). Murdoch and Oaten (1975) and Holling (1965) present in tabular form numerous predator-prey interactions and the type of functional response obtained.

The parameter which separates type II responses from those of type I is handling time. This was first detailed by Holling (1959b) and is a broad term which includes the act of subduing, killing, and eating a prey. It can also include any other time-consuming activities such as cleaning and resting. To put this in mathematical terms, a distinction is made between the total time initially available for search, T , and the actual searching time, T_s , which depends on the number of prey encountered and is given by

$$T_s = T - Th(N_e/Pt) \quad (1)$$

where Th is the handling time, N_e is the number of encounters with prey and Pt is the number of predators. The above equation can be substituted into an equation describing the type I response (Hassell 1978) yielding

$$\frac{N_e}{Pt} = \frac{a' T Nt}{1 + a' Th Nt} \quad (2)$$

where a' is the attack rate, instantaneous rate of search or how rapidly the curve approaches the upper asymptote, and Nt is prey density. In this equation T/Th defines the maximum number of prey that can be eaten. Equation (2) is commonly used to describe data of a Type II functional response with a' and Th obtained from a linear

regression of $N_e/(NtPt)$ versus N_e/Pt . The regression coefficient is $a'Th$ and the intercept is $a'T$. Because T is known, the division of the intercept by T yields a' , and the division of $-a'Th$ by $-a'$ yields Th . This technique, however, is inappropriate and will yield biased estimates of a' and Th unless the actual encounters with a constant prey density are being recorded. Quite often the numbers of prey eaten are obtained over a fixed time interval (i.e., 24 h) without prey replenishment; thus as the predator feeds it decreases its food supply and spends more and more time searching for its prey. To overcome this problem, the functional response must be expressed in terms of N_a , the number of prey eaten, rather than N_e and a prey exploitation model is suggested. The appropriate equation for this is given by Royama (1971) and Rogers (1972):

$$N_a = Nt \left[1 - \text{Exp} \left\{ -a'Pt \left(T - Th \frac{N_a}{Pt} \right) \right\} \right] \quad (3)$$

This exploitation equation assumes the predator searches at random. The assumption of random search is probably biologically unrealistic although mathematically convenient since random search is highly inefficient (Everson 1980).

Hassell (1978) recommends estimating a' and Th from the above equation (3) using a non-linear least squares technique. However, Glass (1970) indicates that iterative least square techniques are preferred if the values are to be used in simulation studies where a high degree of precision is necessary. Fortunately SAS 79 (NLIN Procedure, Blair et al. 1979) performs this non-linear iterative technique utilizing the Marquardt, Gauss-Newton and Gradient methods.

The above models (2)(3) have performed well in describing data, but it is unlikely that both a' and T_h are constant and independent of prey density. Each is a function of several components which have been reviewed by Holling (1965; 1966). The attack rate a' is possibly a function of the predators reactive distance, the speed of movement of predator and prey, the proportion of attacks that are successful, etc. The handling time T_h will depend upon the time spent pursuing and overcoming an individual prey, the time spent eating each prey, any time spent resting or cleaning as a result of feeding, etc. For many predators, one or more of these components are known to vary with prey density, predator feeding rate, environmental conditions and the time elapsed since the last meal; all of which are likely to be interrelated (Hassell 1975). The assumption of constant a' and T_h is adequate for many predators despite variations in their sub-components which allows the simple description of many functional response data. Some of the changes in these sub-components have relatively little effect or tend to cancel each other out. The assumption of constant a' and T_h becomes inadequate where more complex responses occur, as in the type III response.

The effect of a type II functional response on the stability of a prey population was clearly presented by Poole (1974) and Hassell (1978). Per cent predation decreases as prey density increases because of the negatively accelerated feature of the response. As a result, predators with type II responses are not able to stabilize prey density (at least theoretically). In the laboratory, functional responses to a single prey system are almost universally destabilizing

(type II)(Murdoch and Oaten 1975). However, other complications must be considered: resource limitation in the prey; refuges for the prey; an invulnerable class of prey and spatial heterogeneity. These complications exist in nature and may be both necessary and sufficient stabilizing mechanisms.

Historically, the literature (Holling 1965; Murdoch and Oaten 1975) has supported the idea that the sigmoidal (type III) functional responses are typical of vertebrate predators, while type II responses are characteristic of invertebrates. Recent data has indicated that sigmoidal responses do exist among arthropod predators (Hassell et al. 1977). A possible explanation for this is that the predators tend to search more actively as prey density rises, making one or more of the components of predator searching activity dependent on prey density. This precludes a predator searching at random; it implies an intricate searching behavior modified by chemical cues or sight. The fundamental difference between the type II and III responses is the tendency for the rate of search (a') to increase over an initial range of low prey densities in a type III response, but to remain constant at low prey densities in a type II response (Hassell et al. 1977). By plotting rate of search (a') versus prey density an idea of whether a type III response is possible can be obtained. Hassell et al. (1977) provided an equation for the type III functional response where a' is dependent on the number of prey available at any moment:

$$N_a = N_t \left[1 - \exp \left\{ - \frac{bPt}{c} \left(T - \frac{ThNa}{Pt} - \frac{Na}{bNtPt(Nt-Na)} \right) \right\} \right]$$

where b and c (constants) and T_h can be obtained iteratively by the Newton-Raphson technique (Hassell et al. 1977). The detailed derivation of this equation is given by Hassell (1978).

Sigmoid functional responses are density dependent up to some threshold prey density and are widely assumed to contribute to the stability of predator-prey interactions (Hassell 1978). This is particularly true with generalist predators where their population fluctuations tend to be unrelated to the density of a specific prey. Stability is enhanced if the predator: 1) actively selects areas of high prey density (Murdoch and Oaten 1975), 2) travels between patches of prey (Murdoch and Oaten 1975), 3) possesses an age dependent or developmental response (Hassell 1978; Murdoch and Oaten 1975), and 4) switches feeding based on prey species' relative frequency (Murdoch and Oaten 1975). These predator characteristics (1-4) add stability to a predator-prey model where the predator exhibits a type II or type III functional response. The sigmoidal functional response is not likely to stabilize a system at low equilibrium levels; predators aggregating in regions of high host density (a form of numerical response) can be of the greatest importance to stability in this situation (Hassell 1978).

The majority of classical successes in the biological control of insect pests have been with parasites rather than predators. A common explanation for the relatively poor showing of predators in biological control programs is that they are generally more polyphagous, have a lower search rate and are not as able to aggregate in patches of high host density as are parasites. An additional

feature of predators is that they possess a threshold of prey consumption below which they cannot reproduce (Hassell 1978). Because of this a predator-prey model will have markedly different stability properties in different geographic areas, with the result that an equilibrium might not be achieved due to an inappropriate initial ratio of predators and prey. Biological control programs utilizing one major predator and/or parasite are still being intensively investigated, but attention is gradually being focused on the potential of predator complexes to control pests (Tamaki et al. 1974; Tamaki and Long 1978). Murdoch and Oaten (1975) point out that while specific parasites are important in the control of introduced pests, the major control of cotton pests in California is carried out by a predator complex consisting predominantly of Hemiptera. These predators have generation times equal to or larger than those of the pests which suggests that their functional response is at least as important as the numerical response. Hassell and May (1973) indicate that the functional response of a predator complex may be less important for stability than are interactions among predators, which vary as a function of predator density. Current population models are too simple to evaluate this and there is an absence of good field data in this area (Murdoch and Oaten 1975). There is a great need for field work on the basic components of a relatively simple predator-prey interaction; particularly with emphasis on which components are stabilizing and destabilizing and how these components actually operate. The value of the study of predator-systems through mathematical and laboratory analyses is that they point out those features

in the field that should be investigated.

Pest Management in Virginia Apple Orchards

Compared to other fruit growing states, the current status of pest management in Virginia apple orchards is still in its infancy. Education of the growers through weekly orchard tours is an important part of Virginia's program. At these tours, proper horticultural practices are reviewed, the identification of beneficial and pest arthropods is stressed, and the current status of disease problems is discussed. These tours are for growers from no more than 3 counties with ca. 20-30 growers at each. Winter and summer fruit schools draw growers from all over the state, but there are usually less than 6 schools/year. At these schools, pest management strategies are not discussed because the information necessary for successful programs in Virginia is yet to be obtained. A large amount of basic and applied research must be done before Entomologists can feel confident of the program and convey this confidence to the growers. Pennsylvania is the nearest apple growing state with a successful pest management program and attempts have been made to adopt some of their strategies in central Virginia. These attempts have failed, one reason being that the fauna in central Virginia is different from that in Pennsylvania (section III). It is probable that the apple orchard fauna in the Winchester area, where 2% of the total U. S. apple crop is produced, may be similar to that in Pennsylvania. In particular, we tested Mitesim^R (Mowery et al. 1975) a computer simulation which predicts the control of the European red mite with the black lady-bird

beetle, Stethorus punctum LeConte. Following the model, we were never able to obtain the necessary number of S. punctum to effect a reduction in European red mite densities. However, this model has potential to be adapted to Virginia apple orchards through the addition of predation by several predators abundant in Virginia.

For the past 2 years ca. 10 growers in Nelson County have been involved in a rudimentary pest management program utilizing the services of a scout. The cost per grower was ca. \$14.00/acre/season with each grower having 10-30 acres on the program. The scout visited each orchard on a weekly basis; each scouting report applied to a 10-acre block of apples. The scout filled in a prepared form which included information on destructive and beneficial arthropods and diseases. Pheromone traps for the major Lepidopteran pests (paid for by the grower out of the \$14.00) were checked and the number of adults trapped was recorded on the form. The form used by the scout detailed sampling procedures for European red mites and S. punctum and how to use this data in Mitesim. Other arthropods and diseases were sampled at random by the scout. The scout, primarily Edward Seaman, was trained by the personnel at the Shenandoah Valley Research Station on pest and beneficial arthropod recognition. I prepared a "Pictorial Guide to Pests and Beneficials in Virginia Apple Orchards" to aid him in the identifications; he carried this with him on all scouting trips. Ed Seaman was an apple grower himself, so he was readily accepted by the growers on the program. He usually scouted all orchards in one day and received \$50.00/day.

The data obtained by the scout were useful in detailing the

beneficial fauna present and specific pest and disease problems. This information has tremendous potential for future use, particularly in looking at the seasonal population dynamics of Lepidoptera caught in the pheromone traps. The scout made three copies of the form; one for himself, one for the grower, and one for the Shenandoah Valley Research Station. The scout talked to the grower upon handing him the form and the question "what should I do?" was inevitably asked. The scout was not authorized to make recommendations on spraying to the grower. This was the responsibility of the research station. Unfortunately, we often did not know what decision was best based on the scouting form, particularly with the data on pheromone trap catches. Information on how the traps can be used for the most effective timing of sprays is needed before accurate decisions can be made. As a result, the data collected during the past 2 years will probably be of more use in the future than when it was obtained. The program did have its rewards; for the first time many of the growers went for a period of ca. 3 weeks and did not spray as a direct result of our scouting report.

The majority of growers were pleased with the program; a few were dissatisfied. Some of the growers on the program are cooperators with the research station and as a result get far more visits by research and extension personnel than was paid for by their \$14.00/acre. These growers are very satisfied with the program, but their view is biased. As more information is gathered on specific pest problems in Virginia, this same form will be more useful to the grower because extension personnel will be better able to analyze its content. This program

will probably be modified to allow the grower to make his own recommendations.

III. POPULATION DYNAMICS OF PHYTOPHAGOUS ARTHROPODS
AND THEIR PREDATORS UNDER DIFFERENT PESTICIDE
PROGRAMS IN VIRGINIA APPLE ORCHARDS⁴

Introduction

Several major deciduous fruit growing areas have developed control strategies for phytophagous mites which utilize native predators that have the greatest control potential. Phytoseiids are the key predators in Michigan (Croft 1975b), Illinois (Meyer 1974), New Jersey (Knisely and Swift 1972), North Carolina (Rock 1972) and Washington (Hoyt and Caltagirone 1971). Pennsylvania (Asquith and Colburn 1971) relies heavily on the coccinellid, S. punctum LeConte, while programs in Missouri (Childers and Enns 1975), Ohio (Holdsworth 1968) and Nova Scotia (Lord 1949) emphasize phytoseiids supplemented with a complex of general predators. Early attempts to manage phytophagous mites in Virginia have indicated that the most important predators were phytoseiids and S. punctum (Clancy and Pollard 1948; 1952). More recently a two-year (1977-1978) survey of predators in Virginia apple orchards partially supported these findings, but deemphasized the utility of predaceous mites and placed more importance on other predators (Parrella et al. 1978). The final analyses of this two-year study designed to investigate the population dynamics of phytophagous mites and their predators under different pesticide programs with reduced application rates (Horsburgh 1977) are presented in this section.

⁴This section presents results of a joint project by the Shenandoah Valley Research Station involving Joseph McCaffrey and myself.

Since most of these beneficial arthropods are not obligate acarine predators, the study included other prey falling within their host ranges. The objective was to determine which predators should be emphasized in a management program for various pests by comparing their numerical and temporal relationship to pest populations under specific chemical regimes.

Materials and Methods

The research area consisted of 3 adjacent 1.6 ha. blocks of Red Delicious, Rome, Winesap and Jonathan apple trees in Nelson Co., Va. These blocks designated A, B, and C (Fig. 1), were managed under different pesticide programs (Tables 1-3). In A and B, materials were applied as 6X concentrates to alternate rows (Lewis and Hickey 1967) with a truck-mounted Swanson^R air blast sprayer, calibrated for 233.75 l/ha (25 g.p.a.). The insecticide-fungicide combinations (Tables 1-2) were applied at ca. seven-day intervals beginning in mid to late March or early April and were decreased to ca. 14-day intervals from mid-June through August. Block C was under the supervision of a cooperating grower and applications made every 7-10 days from March-August. Materials were applied as 6X concentrates to alternate rows with a John Bean^R air blast sprayer calibrated for 299.2 l/ha (32 g.p.a.).

The orchard was homogeneous, all trees were 4-5 m tall and 7 years old. The trees were planted in alternating double rows of each cultivar with 30 trees/row; Red Delicious was the only variety sampled.

Samples of pests were taken from 1/2 of 4 trees (two adjacent



Fig. 1 - Orchard blocks A, B and C, Tyro, Virginia

Table 1 - Spray Schedule for Orchard Block A^a

1977		1978			
Material	Amt/ha	Dates	Material	Amt/ha	Dates
Dodine 65W	1.12 kg	March 17	Superior Oil 70 sec. Dodine 65W	37.40 l 0.84 kg	March 30
Dikar ^R 76W	2.80 kg	March 25,30 April 6,13	Dikar ^R 76W	2.80 kg	April 10,14
Dikar ^R 76W	2.80 kg	April 20,27	Dodine 65W	0.84 kg	April 28
Phosalone 25W	1.15 kg	May 5,12,19,26	Dikar ^R	2.80 kg	May 2,12,17,29
Dikar ^R 76W	2.80 kg	June 3,13,27	Phosalone 25W	1.12 kg	June 9,20 July 3,13,27; August 8
Thuricide IIPC ^R	1.12 kg	July 8			
Dikar ^R 76W	2.80 kg	July 27	Maneb 80W Phosalone 25W	4.48 kg 1.12 kg	August 17
Dikar ^R 76W Phosalone 25W	2.80 kg 1.12 kg	August 9			
Dikar ^R 76W	2.80 kg	August 18			

^aFollowing Horsburgh (1977); rates vary with tree size, environmental conditions and pest pressure.

Table 2 - Spray Schedule for Orchard Block B^a

		1977		1978	
Material	Amt/ha	Dates	Material	Amt/ha	Dates
Dodine 65W	1.12 lg	March 17	Dodine 65W	0.84 kg	April 4
Superior Oil 70 sec.	18.70 l				
Benomyl 50W	0.28 kg	March 25,30	Benomyl 50W	0.28 g	April 10,14
Superior Oil 70 sec.	2.33 l		Maneb 80W	1.40 kg	
Polyram 80	1.40 kg				
Benomyl 50W	0.28 kg	April 6,28	Dodine 65W	0.84 kg	April 28
Superior Oil 70 sec.	2.33 l				
Polyram 80W	1.40 kg				
Benomyl 50W	0.28 kg	April 20,29	Benomyl 50W	0.28 kg	May 2,12,17 ^b ,26;
Azinphosmethyl 50W	0.28 kg		Phosmet 50W	1.12 kg	June 9,20;
					July 3,13,27;
Benomyl 50W	0.28 kg	June 3			August 8,17
Dipeik W	0.58 kg				
Phosphamidon 8 EC	0.29 l				
Benomyl 50W	0.28 kg	June 13,27			
Dipel ^R W	0.57 kg	July 8			
Benomyl 50W	0.28 kg	July 27			

Table 2 - Spray Schedule for Orchard Block B^a (continued)

		1977		1978	
Material	Amt/ha	Dates	Material	Amt/ha	Dates
Benomyl 50W	0.28 kg	August 5			
Phosmet 50W	1.12 kg				
Benomyl 50W	0.28 kg	August 18			

^aFollowing Horsburgh (1977); rates vary with tree size, environmental conditions and pest pressure.

^bPhosphamidon 8 EC (0.44 l/ha) also applied.

Table 3 - Spray Schedule for Orchard Block C^a

1977		1978			
Material	Amt/ha	Dates	Material	Amt/ha	Dates
Captan ^R 50W	1.17 kg	March 15	Superior Oil 70 sec.	0.33 l	March 31
Captan ^R 50W	2.33 kg	March 28;	Captan ^R 50W	1.80 kg	April 10,12 ^c
Ferbam 76W	0.70 kg	April 8	Thiram 65W	0.56 kg	
			Sulphur 53W	0.60 kg	
Polyram 80W	2.80 kg	April 19	Azinphosmethyl 50W	0.44 kg	
Captan ^R 50W	2.33 kg	April 25	Captan ^R 50W	1.80 kg	April 18,28 ^d
Thiram 65W	0.70 kg		Thiram 65W	0.56 kg	
Azinphosmethyl 50W	0.58 kg		Sulphur 53 W	0.60 kg	
Captan ^R 50W	2.33 kg	May 2	Benomy1 50W	0.12 kg	May 4,11 ^e ,18 ^e
Thiram 65W	0.70 kg		Captan ^R 50W	1.28 kg	
Azinphosmethyl 50W	0.58 kg		Thiram 65W	0.56 kg	
Demeton 6 EC	0.18 l		Azinphosmethyl 50W	0.44 kg	
			Demeton 6 EC	0.18 l	
Captan ^R 50W	2.33 kg	June 6	Captan ^R 50W	1.80 kg	May 20
Thiram 65W	0.70 kg		Thiram 65W	0.56 kg	June 5
Azinphosmethyl 50W	0.58 kg		Parathion 15W	1.80 kg	
			Sulphur 53W	0.60 kg	
Captan ^R 50W	2.10 kg	June 16	Captan ^R 50W	1.80 kg	June 12,22
Thiram 65W	0.63 kg		Penncap MR	0.35 l	
Cyhexatin 50W	0.26 kg		Sulphur 53W	0.60 kg	
Azinphosmethyl 50W	0.52 kg				

Table 3 - Spray Schedule for Orchard Block C^a (continued)

1977		1978			
Material	Amt/ha	Dates	Material	Amt/ha	Dates
			Captan ^R 50W	1.80 kg	July 5,17
			Azinphosmethyl 50W	0.44 kg	
			Sulphur 53W	0.60 kg	
			Dikar ^R 76W	1.20 kg	July 27
			Parathion 15WP	1.20 kg	August 8
			Sulphur 53W	0.60 kg	
			Captan ^R 50W	0.60 kg	August 15
			Zineb 75W	0.60 kg	
			Azinphosmethyl 50W	0.30 kg	
			Captan ^R 50W	0.60 kg	August 28
			Folpet 50W	0.60 kg	
			Azinphosmethyl 50W	0.30 kg	
			Sulphur 53W	0.60 kg	

^aFollowing Horsburgh (1977); rates vary with tree size, environmental conditions and pest pressure.

^bSprays discontinued because of fruit loss due to frost.

^cPhosphamidon 8 EC added at 0.14 l/ha.

^dAzinphosmethyl 1 added at 0.20 l/ha.

^eDemeton 6 EC omitted.

trees/row) facing the same sprayer lane. Ten leaves per half tree were randomly chosen, brushed, and mites and mite eggs counted (Henderson and McBurnie 1943); mites and mite eggs were expressed as mean number/leaf. Aphids were sampled by examining five leaf clusters (without regard to cluster type) equally spaced along the full length of a limb. Two limbs/tree were randomly chosen and aphids were expressed as percent infested clusters per 4 trees (apterous aphids present); aphid species were combined for analyses. Lepidopterous leafroller larvae were counted by visually searching the foliage for 3 minutes from the trees' periphery. Leafrollers, considered as a complex, were expressed as total numbers observed/four trees.

Predators were sampled by limb-tapping 1/4 of 4 trees (2/row). The inner quadrant adjacent to those trees sampled for pests (facing the same sprayer lane) was limb-tapped over a 1m^2 muslin cloth covered tray. Predators were expressed as total numbers of each species/four trees; predaceous Thysanoptera and Neuroptera were each analyzed as complexes. When larger, easily dislodged fruit were present, the limbs were only lightly tapped and this was supplemented with a thorough hand-brushing of the foliage.

Sampling was at two-week intervals from mid-April through early September in 1977. This was modified in 1978 to ca. every ten days in June and July, weekly in August, and once in early September. Sampling was in the early afternoon at least one day after the most recent pesticide application. A Bendix^R hygrothermograph located within Block B recorded relative humidity and temperature.

One thousand apples per block were examined for insect damage

prior to harvest to further evaluate the effectiveness of the chemical control program. The apples were examined individually for damage by the "green fruitworm" (Lithophane app.)(Lepidoptera:Noctuidae), codling moth (Laspeyresia pomonella L.), oriental fruit moth (Grapholitha molesta Busck)(Lepidoptera:Olethreutidae), leafrollers, San Jose scale (Quadraspidiotus perniciosus Comstock)(Homoptera:Coccidae), aphids and tarnished plant bug (Lygus lineolaris Palisot de Beauvois)(Hemiptera:Miridae).

A. Statistical Analyses

Linear regression analyses (General Linear Model, Barr et al. 1976) were used to determine relationships between predators (independent variables) and pests (dependent variables). R square values from regression equations with significant ($p < 0.10$) F values are reported. Only predators and phytophagous arthropods found on at least two sampling dates were included in the analyses.

Results

A. Arthropod Pests

Mite species collected were: the European red mite (Panonychus ulmi (Koch)(Tetranychidae), the apple rust mite (Aculus schlechtendali (Nalepa)(Eriophyidae), the two-spotted spider mite, (Tetranychus urticae Koch)(Tetranychidae) and a tarsenomid mite, (Tarsenomus setifer (Ewing)(Tarsenomidae). The only species found consistently were P. ulmi and A. schlechtendali.

Two species of aphids were collected: the spirea aphid, Aphis

citricola Van der Goot and the rosy apple aphid, Dysaphis plantaginea Passerini (Homoptera:Aphididae). Both species reached high levels during this study.

Leafroller larvae collected were the "variegated leafroller," Platynota flavedana Clemens, the red-banded leafroller Argyrotaenia velutinana (Walker), the "tufted apple bud moth," Platynota idaeusalis (Walker) (Lepidoptera:Tortricidae) and an oecophorid, Antaeotricra sp. (Lepidoptera:Oecophoridae). This leafroller complex, the most abundant of which was P. flavedana, constitute the most serious threat to commercial apple production in Virginia (Thomas 1976).

Population fluctuations of P. ulmi (active stages and eggs) and A. schlechtendali are presented graphically (Figs. 2-7) for blocks A, B and C in 1977 and 1978. Aphid and leafroller populations were similar in 1977 and 1978 for all blocks; 1977 data are presented graphically (Fig. 8).

B. Arthropod Predators

L. mali and H. subtilissimus were the predaceous thrips collected. These were abundant throughout the study and collectively comprised 62 and 30 percent of the total predators collected during 1977 and 1978, respectively.

The "black ladybird beetle," S. punctum, was regularly collected and accounted for 14 and 30 percent of the total predators in 1977 and 1978, respectively.

Four genera of true bugs were collected: O. insidiosus (Hemiptera: Anthocoridae), D. nebulosus, Dereaocoris spp., Phytocoris spp.,

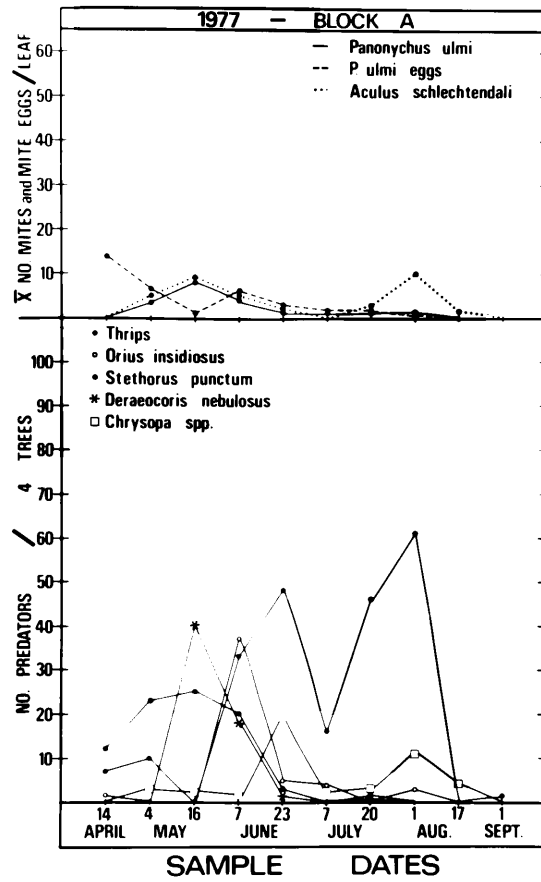


Fig. 2 - Populations of selected pests and predators in block A, 1977

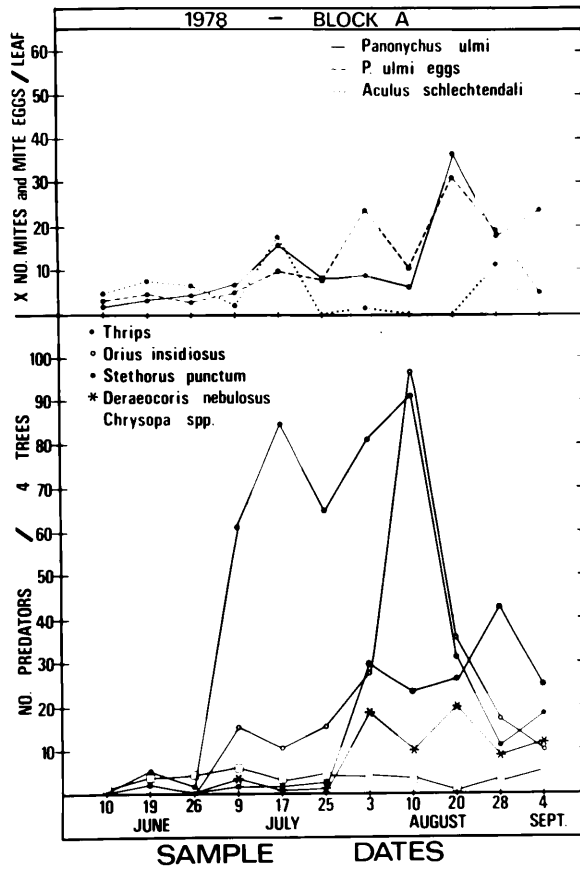


Fig. 3 - Populations of selected pests and predators in block A, 1978.

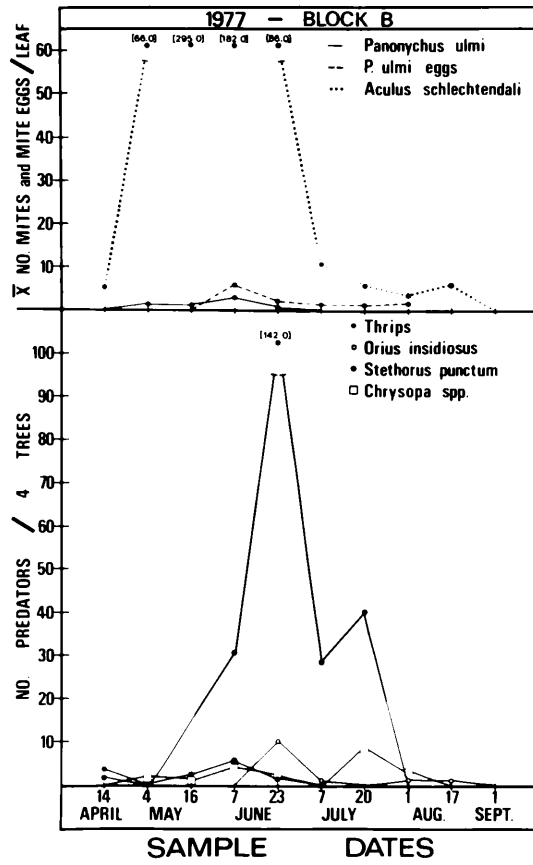


Fig. 4 - Populations of selected pests and predators in block B, 1977

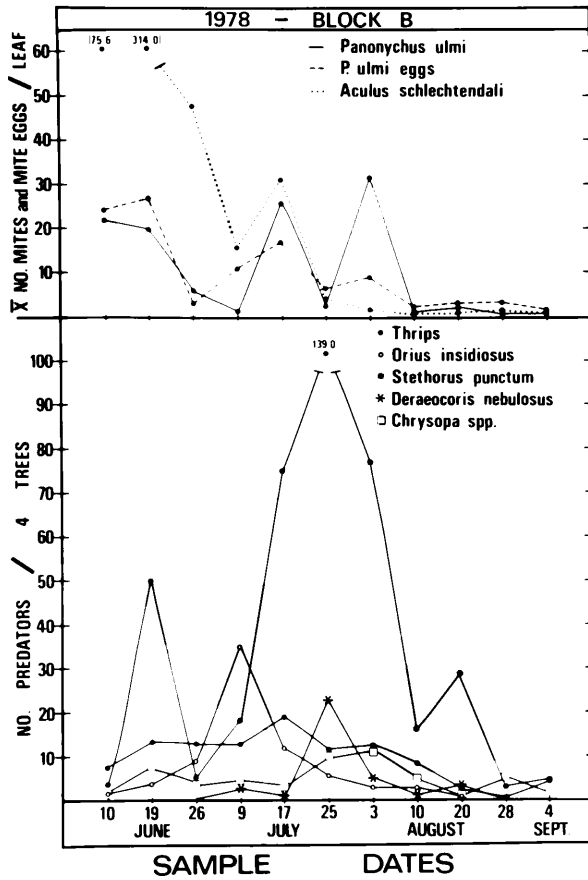


Fig. 5 - Populations of selected pests and predators in block B, 1978.

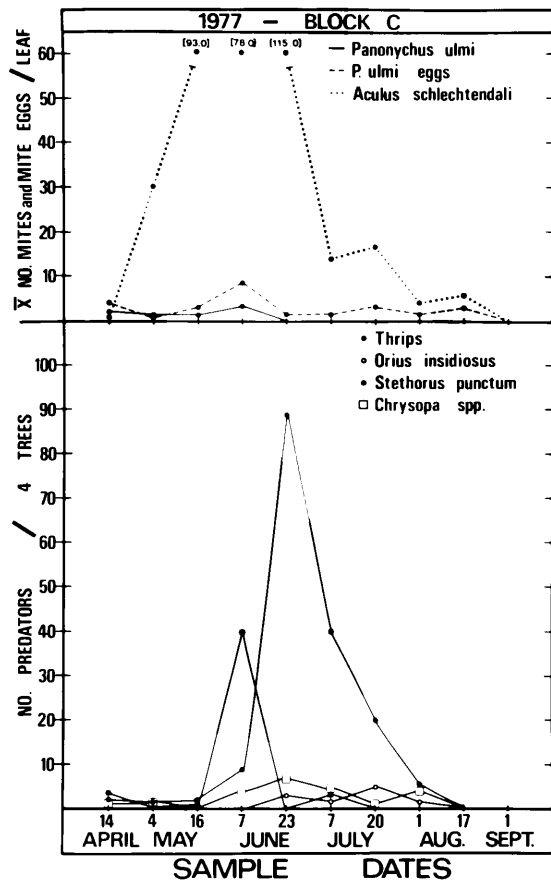


Fig. 6 - Populations of selected pests and predators in block C, 1977

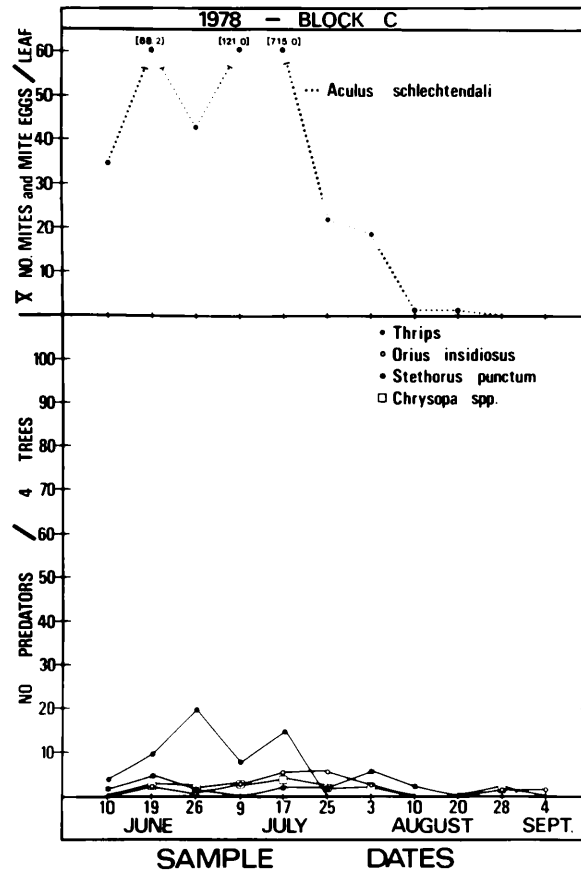


Fig. 7 - Populations of selected pests and predators in block C, 1978.

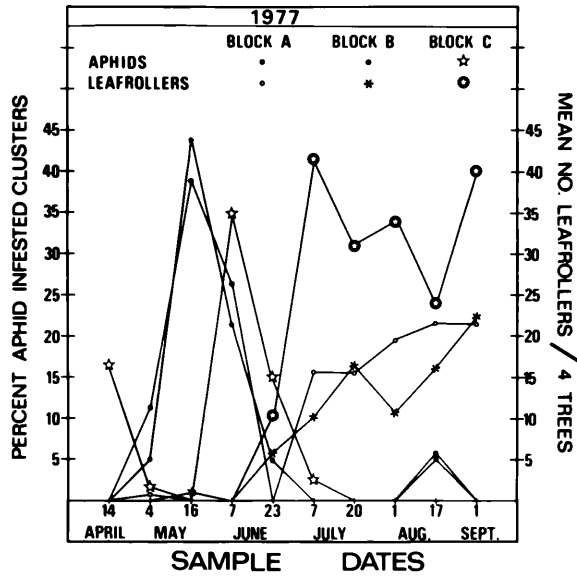


Fig. 8 - Populations of aphids and leafrollers in blocks A, B and C, 1977.

(Hemiptera:Miridae), Hyaliodes harti Knight and H. vitripennis (Say) (Hemiptera:Miridae). Only O. insidiosus and D. nebulosus were collected consistently. O. insidiosus comprised 6.7 and 20 percent of the total predators and D. nebulosus, 6.5 and 5.7 percent, during 1977 and 1978, respectively.

Aphid lions were collected in both years of the survey; Chrysopa carnea Stephens and C. oculata (Say) were the most abundant species. These predators comprised 10.3 and 6.3 percent of total predators in 1977 and 1978, respectively.

Spiders (Arachnida:Araneida) were a conspicuous part of the predator complex inhabiting Virginia orchards. The spider fauna were studied separately (McCaffrey 1978; McCaffrey and Horsburgh 1980b) and were not included in this study.

Predaceous mites were occasionally collected and included the following species: Neoseiulus fallacis (Garman), Galendromus pomi (Parrott), G. delicatus DeLeon (Acarine:Phytoseiidae) and Agistemus fleschneri (Summers) (Acarina:Stigmaeidae). These were found infrequently and in low numbers in our samples and were not included in the analyses.

Population fluctuations of thrips, S. punctum, O. insidiosus, D. nebulosus and Chrysopa spp. are presented graphically (Figs. 1-6) for blocks A, B and C in 1977 and 1978.

C. Predator-Pest Relationships

L. mali and H. subtilissimus have wide host ranges, but primarily feed on mites and mite eggs (Bailey 1940, Putman 1965). In 1977

significant R square values were obtained with A. schlechtendali populations in blocks A and C (0.30 and 0.24, respectively). During 1978 significant R square values were obtained with motile stages and eggs of P. ulmi in block B (0.26 and 0.32, respectively) and with A. schlechtendali in block C (0.30).

S. punctum - Mites and Mite Eggs

Members of the genus Stethorus LeConte are obligate mite predators; tetranychids are their principal food (McMurtry et al. 1970). High R square values were obtained with motile stages of P. ulmi as prey during 1977 (0.83, 0.95, 0.95 in blocks A, B and C, respectively). In 1978, a significant relationship was obtained with motile stages and eggs of P. ulmi in Block A (0.31 and 0.46, respectively).

O. insidiosus and D. nebulosus - Mites and Mite Eggs, Aphids, Leafrollers

These Hemiptera are general predators with wide host ranges. While populations of O. insidiosus were often high, no statistically significant relationship was found with O. insidiosus and any pest in 1977, and in 1978 the only significant R square value was obtained with aphids in block A (0.33). With D. nebulosus significant R square values were obtained in 1977 within block A for leafrollers (0.22), motile stages of P. ulmi (0.78) and aphids (0.98). In 1978 significant R square values were obtained for D. nebulosus in block A with P. ulmi (motile stages, 0.48; eggs, 0.83) and aphids (0.28) and in block C with P. ulmi (motile stages, 0.67; eggs 0.28) and leafrollers (0.38).

Chrysopa spp. - Mites and Mite Eggs, Aphids, Leafrollers

Members of the genus Chrysopa Leach are polyphagous. No significant relationships were found for Chrysopa spp. and any prey in 1977. In 1978, significant R square values were obtained in block A with P. ulmi (motile stages, 0.32; eggs, 0.52); in block B with leafrollers (0.31) and in block C with A. schlechtendali (0.39).

D. Comparison of Spray Programs

In 1977 and 1978 the spray programs in blocks A and B permitted predators to remain in the orchard. In 1977, block C under limited pesticide application had predator populations comparable to blocks A and B, but in 1978 with regular pesticide application, few predators were found. P. ulmi exceeded economic levels (> 15/leaf) (Croft 1975a) in 1978 on 3 and 4 sampling dates in blocks A and B, respectively; moderate bronzing of the foliage was observed. Aphid populations followed similar cycles in blocks A, B and C during 1977 and 1978; more than 35% of the clusters were infested on at least 2 sampling dates. Despite this high infestation, there were very few apples damaged by aphids based on 1,000 apples examined per block at harvest. Leafroller populations were very high in all blocks in 1977, particularly in block C, which reflected the limited pesticide application. In 1978, leafroller numbers were less than half that in 1977; block B had the highest populations. Despite this reduction, leafrollers were at intolerable levels during 1977 and 1978 in all blocks and damaged as much as 6% of the fruit. Damage by all other insect pests was well below 1% of the fruit at harvest (Croft 1975a). No significant

relationship was found between temperature or humidity and any pest or predator population during 1977 or 1978 under any pesticide regime.

Discussion

Thrips were abundant predators in 1977 and 1978 and may have contributed to the reduction of P. ulmi densities even though they apparently did not appear to respond numerically to this mite species. Low R square values for P. ulmi were obtained in just 1 block (block B-1978); however, the regression analyses have to be interpreted carefully and tempered with biological knowledge of each arthropod. The analyses will yield high R square values for predators and prey only when predators exhibit an immediate density-dependent numerical response towards the prey. For example, comparing thrips and A. schlechtendali yields low R square values in 3 blocks (A, C in 1977; C in 1978) but graphs of these populations (Figs. 1,5,6) show a delayed response by the thrips towards A. schlechtendali: in all other blocks (1977 and 1978) the thrips responded directly to A. schlechtendali (Figs. 2,3,4) despite non-significant R square values. Thrips populations which develop in response to A. schlechtendali will probably extend their feeding to P. ulmi but an increase in thrips' numbers due to the presence of P. ulmi was not found. The presence of A. schlechtendali as a food source for L. mali and H. subtilissimus may lead to the development of large numbers of these predators in Virginia apple orchards.

S. punctum responded strongly to P. ulmi densities in 1977 as

shown by high R square values in all blocks; this may explain why P. ulmi did not reach damaging levels. In 1978, S. punctum populations increased in a less pronounced density-dependent manner which might have allowed P. ulmi to reach economically damaging levels. Low R square values were obtained in only 1 block in 1978 for the S. punctum - P. ulmi relationships. Attempts in 1978 to apply the predictive table of Mowery et al. (1975) developed in Pennsylvania failed as S. punctum populations remained too low to effect a reduction of P. ulmi densities. Despite this, there were no extended periods of high P. ulmi populations. Block A had <15 mites/leaf until August 20 when mites exceeded economic levels through Sept. 4. Block B had damaging mite populations on June 10, 19, July 17 and Aug. 3. Fluctuating mite populations as in blocks A and B are probably not as damaging as extended periods with high levels (Briggs and Avery 1968); moderate bronzing was evident but no other adverse effects were observed. Croft (1975b) indicated 15-20 mites/leaf can be tolerated for a maximum of 10-14 days before fruit production or tree vigor are adversely affected.

Numbers of the general predator, O. insidiosus, in samples from all blocks, began increasing by mid-June which coincided with a decline in aphid populations. The response was slow and a low R square value for the relationship with aphids was found only in block A and only in 1978. Unless O. insidiosus responds to aphids earlier in the season, its ability to regulate these pests is limited. However, the slow numerical response of O. insidiosus to aphids may provide populations of this predator which will switch feeding to P. ulmi later in

the summer as aphid populations decline. This additional predation on P. ulmi (together with predation by thrips and S. punctum) may be partly responsible for the fluctuations of the mite populations observed in blocks A and B. Members of the genus Orius Wolff are considered natural enemies of the Thysanoptera (Lewis 1973); O. insidiosus is capable of utilizing L. mali and H. subtilissimus as a food source. During 1977 and 1978 in blocks A and B, O. insidiosus may have been responding numerically to increases in thrips' densities. This may have caused a reduction in the number of predaceous thrips and such predation may have helped keep O. insidiosus in the orchard. The latter possibility may increase P. ulmi control because O. insidiosus has a feeding capacity for P. ulmi ca. 5X that of the thrips'. However, laboratory studies have suggested that L. mali and O. insidiosus may be compatible as predators of P. ulmi (Parrella et al. 1980).

The general predator, D. nebulosus appeared early (mid-May) in block A in 1977 but was not found in blocks B or C. In block A it responded numerically to the presence of aphids; very high R square values were obtained. In 1978, D. nebulosus appeared later (early June) in blocks A and B and did not increase in numbers until much later (late July or early August) in the summer. Aphids may play an important role in attracting D. nebulosus into orchards, where it can later transfer its feeding to other prey (as with O. insidiosus); significant relationships were found between D. nebulosus and both leafrollers and P. ulmi (1977 and 1978).

Chrysopa spp. remained at consistently low levels in most blocks

in 1977 and 1978 and may have had a moderating effect on the population levels of both predators and pests.

Conclusions

The major predators that should be emphasized in a pest management program for mites, aphids, and leafrollers in Virginia apple orchards are thrips (L. mali and H. subtilissimus), S. punctum, O. insidiosus and D. nebulosus. Although P. ulmi populations exceeded economic levels on several occasions, they did not remain at these damaging levels for extended periods. The pesticide program of Phosalone and Dikar (block A) permitted the buildup of the largest number of predators compared to the other pesticide combinations and proved satisfactory in controlling most major arthropod pests. The most damaging pests encountered in this study were leafrollers which exceeded economic levels regardless of the predator populations or pesticide regimes in blocks A, B and C. Data on how predator and/or parasite populations affect the leafrollers under pesticide applications are needed. A preliminary survey of the parasite complex associated with leafrollers in blocks A and B in 1979 revealed 10 species (Hymenoptera -9; Diptera -1) primarily attacking early season larvae. This parasite complex merits further investigation. Also, improved timing of insecticide application without increasing the total amount of pesticide/ha could significantly reduce leafroller damage and have a minimal effect on the beneficial fauna (Hill and Cobb 1979).

IV. BIONOMICS OF LEPTOTHRIPS MALI (FITCH):
A COMMON PREDATOR IN VIRGINIA APPLE ORCHARDS

Introduction

Leptothrips mali (Fitch) is one of the most abundant and wide-spread of indigenous North American Tubilifera (Cott 1956). Its predaceous habit was first observed in 1892 (Fernald 1892), and has since been well documented in numerous references cited by Bailey (1940). L. mali has been identified as part of the predator complex associated with European red mites (Panonychus ulmi (Koch)) and other pests in apple orchards in many diverse apple growing regions: West Virginia (Jaynes and Marucci 1947; Clancy and McAlister 1956), Virginia (Clancy and Pollard 1948; 1952), Nova Scotia (Lord 1949; 1956, MacPhee and Sanford 1954; 1956; 1961), New Jersey (Thomas et al. 1959), Ohio (Holdsworth 1968; 1972a; 1972b), Pennsylvania (Horsburgh and Asquith 1968), Quebec (Parent 1967; 1973), Illinois (Meyer 1974), Missouri (Childers and Enns 1975). A preliminary survey undertaken in 1977 in central Virginia apple orchards revealed that L. mali was one of the most abundant predators of the European red mite (Parrella et al. 1978). The only biological information available on L. mali was reported in a limited study by Bailey (1940). This thrips may have potential to reduce P. ulmi populations in Virginia apple orchards. Aspects of its development, biology and prey relationships were investigated in the laboratory and are presented in this section.

Materials and Methods

Laboratory colonies of L. mali were established in 1977 and 1978

with adults and 2nd stage larvae collected from apple orchards in Rock-bridge, Augusta, Amherst, and Nelson counties, Virginia. These thrips were maintained on apple leaves infested with all stages of P. ulmi in 120 ml plastic containers⁴ (ca. 30 adults or larvae/container). The containers were modified by replacing the tops with 100-mesh screening⁵ and punching a hole in the snap-on plastic bottoms. Leaf petioles were extended through the holes into water. Mite infested leaves were replaced every two days and thrips' eggs were removed from the old leaf material with a wetted minuten probe and transferred to moist filter paper in plastic egg cups⁶ (4.1 cm d x 2 cm deep) with solid friction tops. The egg cups were checked daily and newly eclosed 1st stage larvae were used for description, feeding studies or to begin a laboratory culture of known feeding history (P. ulmi) whose offspring would be used for development, fecundity and longevity studies. Approximately 100 field collected L. mali adults were maintained in the laboratory. The laboratory culture was in a Sherer-Gillette^R environmental chamber at $23.9 \pm 1.0^{\circ}\text{C}$, 80% RH, and with a 14L/10D photoperiod regime at 550 f.c. These conditions were the same for all subsequent studies except development at different temperatures.

A. Description of Developmental Stages

Eggs were removed from apple leaves, transferred to filter paper

⁴Thorton Plastic Co., 745 Pacific Ave., Salt Lake City, Utah.

⁵McMaster-Carr Supply Co., Chicago, Illinois.

⁶Bradley Ind., Div. of Richardson-Merrill Inc., Franklin Park, Illinois.

and measured with an American Optical^R dissecting microscope fitted with an ocular micrometer; length and width were determined. Since the eggs taper anteriorly, width was determined at the widest point.

Larvae and pupae were cleared in 10% KOH and then mounted directly in Hoyer's medium bypassing a dehydration schedule. Vance (1974) demonstrated that Thysanoptera mounted in Hoyer's and ringed with fingernail polish remained in good condition for more than 20 years.

Immature stages were also mounted in Balsam for a more permanent record. Adult thrips were mounted on slides in Canada balsam as described by Heming (1969). Body length and the ratio of head capsule length: width were determined for adult males and females and for the larval and pupal stages; measurements were made using a Nikon^R phase-contrast microscope fitted with an ocular micrometer. Measurements were made of newly eclosed 1st stage larvae and late 1st stage larvae (5 days post eclosion) and newly molted 2nd stage larvae and late 2nd stage larvae (5 days post ecdysis).

B. Development at Different Temperatures

Newly oviposited eggs (ca. 12 h old) were removed from the laboratory culture and transferred to moist filter paper in plastic containers (ca. 20/container) described previously. The containers were placed in environmental chambers at 18.3, 23.9 and $29.4 \pm 1.0^{\circ}\text{C}$ with a 14L/10D photoperiod regime; development of eggs was checked every 24 h. Upon eclosion, 1st stage larvae were transferred to the adaxial side of an apple leaf within a small plastic container (2 larvae/container)(4.1 cm d x 2.0 cm deep) (Fig. 9). The container

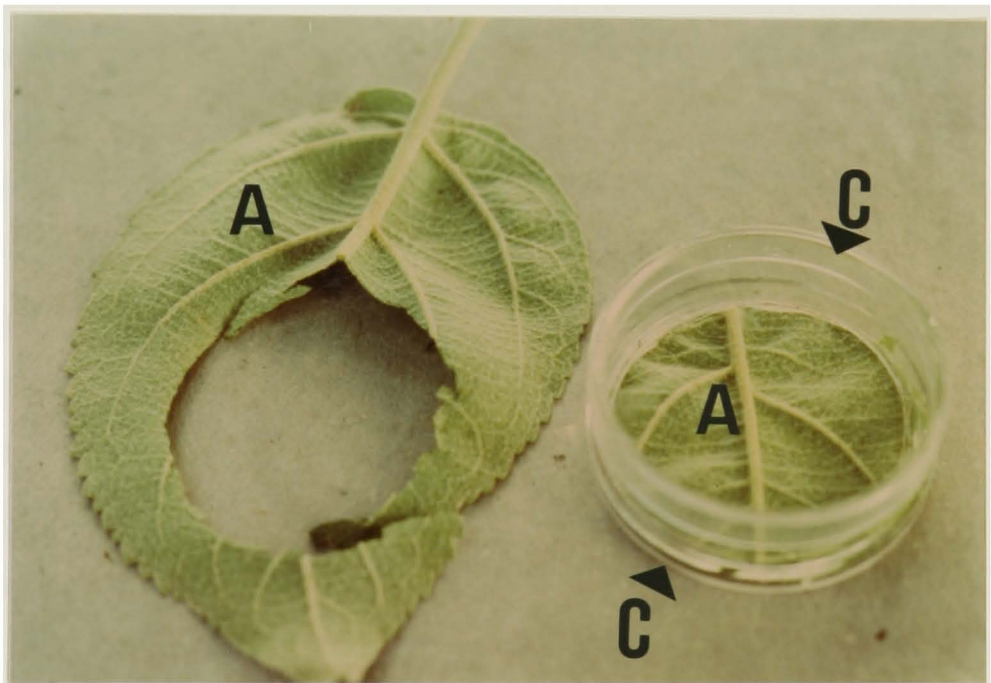
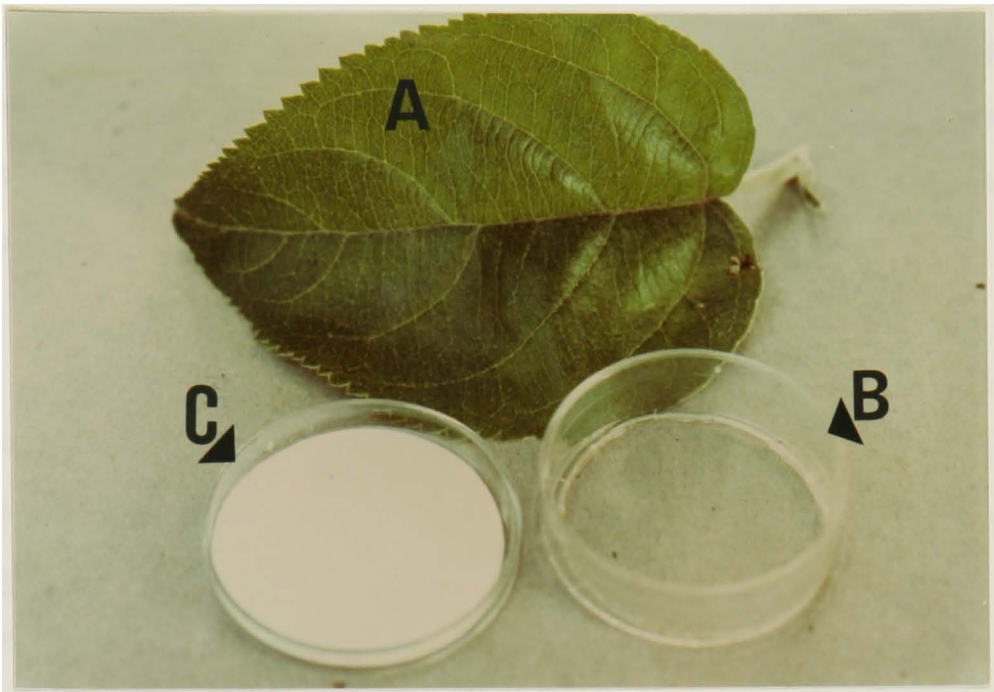


Fig. 9 - Rearing cage for Leptothrips mali: a) apple leaf, b) plastic ring, c) friction sealed plastic top.

was modified by removing its bottom which produced a plastic ring. This was forced down through an apple leaf and into a plastic lid originally made for the top of the container; moistened filter paper was placed in the lid prior to positioning the plastic ring and leaf. A plastic lid identical to that used for the bottom was placed over the top of the ring which formed a closed container. Slightly wilted apple leaves produced the best fit and prevented mites and thrips from escaping. All leaves used were taken from one unsprayed apple tree. First stage larvae transferred to the containers were provided with at least 60 P. ulmi eggs/day/larva at 18.3, 23.9 and 29.4° ± 1.0°C, respectively. P. ulmi adult females were added at the rate of 10/day/larva when the 1st stage larvae were 3 days post eclosion. Second stage larvae were provided with 75 adult female P. ulmi/day; this was supplemented with at least 20 P. ulmi eggs/day. Containers were checked every 24 h; development of the larvae were recorded and new mites and/or mite eggs added. All containers were cleaned after 2 days and supplied with new leaf material, mites and mite eggs.

Upon pupation, the thrips were allowed to crawl into a natural pupation site, the mines of Phyllonorycter crataegella (Clemens) (Lepidoptera:Gracillariidae) an apple leaf miner. The section of leaf containing the mine with the thrips was placed in a small plastic container and kept at the same temperature; development of the prepupa was checked every 12 h; all other readings were taken at 24 h intervals. All recordings of development for egg, larval and pupal stages were made at the same time each day. Stage length was

measured from the time half of the individuals entered the stage until half had left, following the method of Dowell and Fitzpatrick (1978).

C. Preoviposition, Fecundity and Longevity of Adults

Adult L. mali reared in the laboratory from the egg stage and field collected 2nd stage larvae reared to adults with a surplus of P. ulmi (ca. 75 adult female P. ulmi/day/thrips) were used in this test. Newly emerged unmated females and males were caged individually in 120 ml plastic containers as described for the laboratory colony. Other newly emerged females were caged with males on mite infested apple leaves in 120 ml containers; after 72 h males were removed. Daily checks of the containers were made until oviposition after which observations were made every 2 days; the number of eggs oviposited and condition of the females were recorded until their death. The males in containers were checked every 48 h until their death. All containers were cleaned and fresh leaves infested with at least 150 adult female P. ulmi were added every 48 h.

D. Development on Selected Food Sources

Newly eclosed, 1st stage larvae, from eggs originating in the laboratory colony, were placed on apple leaves in plastic containers similar to those used in the development-temperature test. Each container was supplied with one of the following food sources:

1) Golden Delicious apple pollen⁷ (brushed on until a fine powder

⁷Antles Pollen Supply Co1, Wenatchee, Washington.

covered most of the leaf); 2) P. ulmi eggs (60/day); 3) pollen plus eggs (in amounts equal to 1 and 2); 4) all stages of P. ulmi (at least 50 adults and immatures and 30 eggs/day plus pollen and 5) the apple leaf only (washed with moistened cheese cloth). Adults (4 days post ecdysis) were also caged with only the apple leaf to determine how long they could survive. These adults were confined with a surplus of P. ulmi prior to being caged with an apple leaf. Each container was checked daily for the condition and development of the thrips and additional food was provided. All containers were cleaned and new leaves and food added every 48 h.

E. Prey Relationships

Four day old 2nd stage larval L. mali placed within cages similar to those used in the development-temperature test were provided with the following potential orchard prey: adult female Tetranychus urticae (Koch), adult A. schlechtendali, eggs of L. pomonella and P. flavedana, 2 and 4 day old 2nd stage larval L. mali; 2nd stage larval H. subtilissimus, crawlers of Lecanium corni Bouche (Homoptera: Coccidae) nymphs and alate adults of A. citricola, adult Proprioseius oudemansi Chant (Acarina:Phytoseiidae) and 3rd stage larval S. punctum. Feeding tests were replicated at least 2 times. In each case the thrips was provided several of the same prey. After 24 h the containers were checked to determine if feeding occurred.

F. Statistical Analyses

Analysis of variance and the Student-Newman-Kuels test were used to determine differences between the longevity of adult males and females (unmated and mated) and preoviposition period and fecundity of adult females (unmated and mated). Data obtained for adults were also analyzed for differences between laboratory reared and field collected individuals. Prior to Anova, the F max test (Sokal and Rohlf 1969) was used to check for homogeneity of variances. The relationship between temperature and development time was determined by performing regression analyses (General Linear Model, Barr et al. 1976) with the reciprocals of days needed for development of each stage as dependent variables and temperatures as independent variables.

Results

A. Description of Developmental Stages

Eggs were oviposited on the adaxial side of apple leaves. A common site was along the mid-vein, particularly at an angle formed by the mid-vein and a side vein (Fig. 10). Out of a total of 1521 eggs oviposited on apple leaves, 92% (1406) were along the mid-vein and 8% (115) were along lateral veins. The majority of eggs were oviposited singly; 44 pairs were found. No eggs were observed on the abaxial side of apple leaves. The eggs of L. mali are morphologically similar to those described for the phytophagous thrips Haplothrips niger (Osborn) (Loan and Holdaway (1955); except that the round knoblike process at the anterior end is not as distinct as that

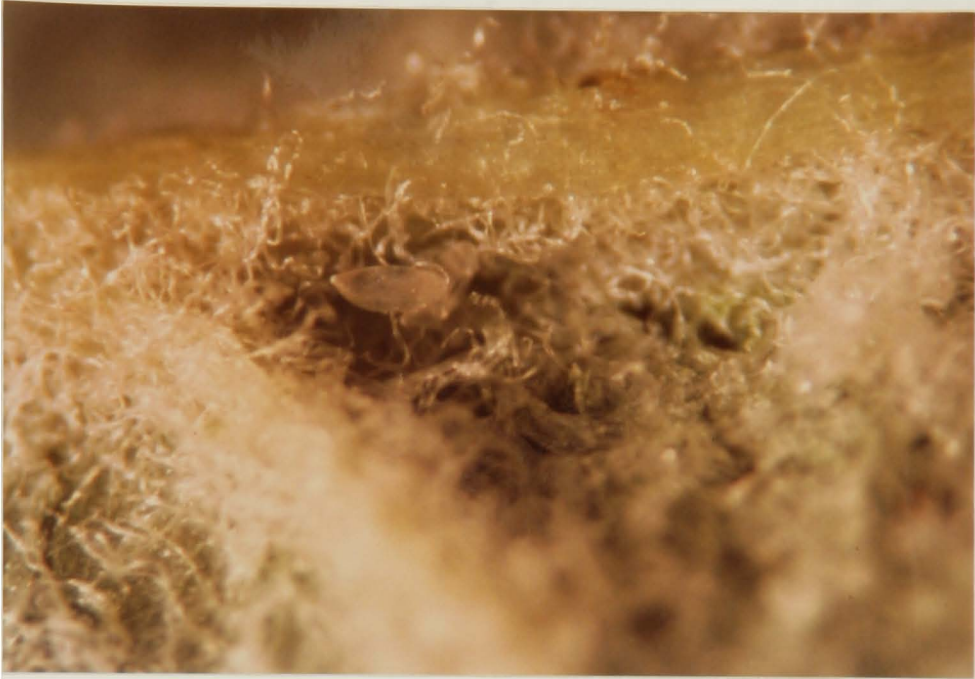


Fig. 10 - Egg of L. mali on the adaxial side of an apple leaf along the midvein.

described for H. niger. The mean length:width (range) of L. mali eggs (N=12) were 0.42:0.16 (0.39-0.44:0.14-0.17)(mm). When first oviposited, eggs were translucent until ca. 3 days old when eyespots and antennae began to darken. These features became more pronounced as the egg developed and could easily be observed through the chorion just prior to eclosion (Fig. 11).

Newly eclosed 1st stage larvae (3-5 minutes post eclosion) are almost colorless (Fig. 11), except for the dark eyespots and antennae. The larvae are capable of feeding on eggs and quiescent stages of P. ulmi. At this time in their development, the larvae are too feeble to feed on any active mite stages. The body cavity turns yellowish red as soon as feeding commences. One larva can completely consume a mite egg in ca. 12 minutes. After 3 days (Fig. 12), 1st stage larvae are capable of utilizing all stages of P. ulmi as food. Gradually the thorax and abdomen become a deep burgundy color and the legs, head capsule and antennae become colorless (Fig. 13); when this change occurs the larvae are within hours of molting into the 2nd stage.

Newly eclosed 2nd stage larvae are similar to late 1st stage larvae with deep burgundy coloration and clear appendages, head capsule and antennae. The newly molted 2nd stage larvae are usually a smaller size than 5 day old 1st stage larvae (Table 4) but are much more active and are capable of feeding on all stages of P. ulmi immediately after molting. The larvae more than double their size in 5 days; at this time they are capable of completely removing the contents of a mite egg in ca. 2 minutes. Near the end of this



Fig. 11 - Eggs and 1st stage larvae of *L. mali* on filter paper. Eye-spots and antennae visible through the chorion indicate imminent eclosion.



Fig. 12 - L. mali 1st stage larva - 5 days post eclosion.



Fig. 13 - L. mali 1st stage larva - 5 days post eclosion.

Table 4. Measurement (mm) of *L. mali* Developmental Stages.

Stage	Measurements	
	\bar{X} Body Length (range) ^a	\bar{X} Head Capsule Length:Width (range) ^b
<u>1st Larva:</u> Newly eclosed (N=15)	0.79 (0.74-0.85)	0.16:0.11 (0.15-0.17:0.10-0.12)
5 days post eclosion (N=8)	1.30 (0.96-1.85)	0.18:0.10 (0.13-0.24:0.09-0.11)
<u>2nd larva:</u> Newly ecdysed (N=3)	0.99 (0.96-1.01)	0.21:0.11 (0.19-0.22:0.09-0.12)
5 days post ecdysis (N=15)	2.14 (1.38-2.50)	0.22:0.14 (0.19-0.24:0.10-0.14)
Prepupa (N=9)	1.94 (1.60-2.20)	0.22:0.14 (0.17-0.26:0.08-0.26)
Pupa I (N=9)	2.01 (1.90-2.24)	0.31:0.20 (0.25-0.35:0.17-0.22)
Pupa II (N=5)	2.10 (2.00-2.20)	0.37:0.19 (0.36-0.40:0.17-0.22)
<u>Adult</u> Male (N=13) Female (N=15)	2.10 (1.89-2.30) 2.61 (2.40-2.80)	0.35:0.15 (0.30-0.39:0.14-0.16) 0.41:0.17 (0.37-0.43:0.15-0.19)

^aFrom end of tube to frontal process of the head between bases of antennae.

^bLength determined from labium to frontal process of head between antennae; width determined at widest point excluding the eyes.

stadium (Fig. 14) the larvae search for an isolated location (i.e., leaf mine) where they begin pupation.

L. mali is a typical thrips in the suborder Tubilifera characterized by having 3 distinct non-feeding, motile pupal stages (Figs. 15, 16, 17); prepupa, pupa I and pupa II (Lewis 1973). These pupal stages are very similar to those described and illustrated by Loan and Holdaway (1955) for H. niger. Individual L. mali normally pass through all pupal stages in the same secluded area, but if disturbed, will search for another suitable site. There was a gradual increase in size with each pupal stage (Table 4).

Newly emerged adults are pale grey, but within 5 h become glossy-black in appearance (Fig. 18). The adult female, illustrated by Bailey (1940), is considerably larger than the male (Table 4). A detailed morphological description was provided by Cott (1956).

All stages are thigmotactic, but only adults are gregarious. It was common to find 3 or more thrips (adults and/or larvae) on the same mite infested apple leaf; contact between them was rare and if this occurred it was usually followed by rapid retreat of both individuals.

B. Development at Different Temperatures

An inverse linear relationship was found with development time and temperature for most stages (Table 5). Regression equations and coefficients of determination for selected stages were: egg, $Y = 0.0038X - 0.1502$ ($R^2 = 0.92$); 1st larva, $Y = 0.0057X - 0.2502$ ($R^2 = 0.80$); 2nd larva, $Y = 0.0097X - 0.5341$ ($R^2 = 0.82$); pupa II,



Fig. 14 - L. mali 2nd stage larva - 5 days post ecdysis.



Fig. 15 - L. mali prepupa within an apple leaf mine.



Fig. 16 - L. mali pupa I.



Fig. 17 - L. mali pupa II.



Fig. 18 - L. mali adult female.

Table 5. Development^a (\bar{X} No. Days \pm S D) of L. mali at Selected Temperatures.

Temperature	Stage						Total (egg-adult)
	Egg	1st	2nd	Prepupa	Pupa I	Pupa II	
(°C)							
18.3 ^b	11.1 ± 0.3	8.5 ± 0.7	10.0 ± 0.0	3.5 ± 0.7	3.0 ± 0.0	8.0 ± 0.0	44.0 ± 1.7
23.9 ^c	7.3 ± 1.6	5.7 ± 0.65	5.4 ± 0.5	1.0 ± 0.0	1.5 ± 0.5	4.0 ± 0.5	25.6 ± 1.2
29.4 ^d	6.0 ± 0.4	4.2 ± 0.4	3.4 ± 0.6	1.0 ± 0.0	1.0 ± 0.0	2.7 ± 0.5	19.0 ± 1.0

^aMeasured from when half of the individuals entered the stage until half had left (Dowell and Fitzpatrick 1978); except egg-adult which is total time for all individuals.

^bAcross row N=13, 4, 3, 3, 3, 3, 3.

^cAcross row N=148, 18, 23, 26, 15, 20, 15.

^dAcross row N=25, 19, 7, 8, 6, 5, 6.

$Y = 0.0102X - 0.5032$ ($R^2 = 0.75$) egg-adult, $Y = 0.0015X - 0.0729$ ($R^2 = 0.96$). The F values for all regression equations were highly significant ($P < 0.0001$). The relationship between development and temperature for the prepupa and pupa I ($R^2 = 0.56$ and 0.52 , respectively) was not as pronounced, due to their shorter development times (Table 5).

C. Preoviposition, Fecundity and Longevity of Adults

Preoviposition periods determined for lab-reared and field collected mated and unmated females did not differ significantly ($P > 0.05$); the range of means was 5-7 days (Table 6). L. mali is arrhenotokous; fecundity of unmated and mated females did not differ significantly ($P > 0.05$). Field collected individuals produced more eggs than those reared in the laboratory (Table 6), but only field collected unmated females had significantly greater fecundity ($P < 0.05$). Mean longevity of males was less than that for females but differences were not significant ($P > 0.05$). No significant differences ($P > 0.05$) were found between the longevity of lab reared vs. field collected females, either mated or unmated (Table 6).

D. Development on Selected Food Sources

L. mali required significantly ($P < 0.05$) more days to complete development on Golden Delicious pollen (\bar{X} no. days = 23.0, $N=6$) compared to diets of P. ulmi eggs plus pollen ($\bar{X} = 16.0$, $N=11$) and P. ulmi eggs alone ($\bar{X} = 19.0$, $N=10$); the latter two did not differ significantly ($P > 0.05$). The development time required on a diet

Table 6. Preoviposition Period, Fecundity and Longevity of Lab-Reared^a and Field-Collected^b L. mali

<u>L. mali</u>	Preoviposition Period (\bar{X} No. days) ^c	Fecundity (\bar{X} No. eggs/female) ^c	Longevity ^c (\bar{X} No. days)
Lab-Reared:			
Unmated females	7.0 a (N=6)	11.7 a (N=9)	50.1 a (N=9)
Mated females	5.0 a (N=6)	13.0 a (N=9)	45.3 a (N=9)
Males	-	-	24.8 a (N=6)
Field-Collected			
Unmated	6.5 a (N=10)	45.1 b (N=14)	54.2 a (N=10)
Mated females	6.4 a (N=5)	28.0 a (N=5)	35.8 a (N=5)
Males	-	-	27.6 a (N=5)

^aFrom egg-adult on P. ulmi.

^bAs late 2nd stage larvae, then reared to adults on P. ulmi.

^cMeans in the same column followed by the same letter are not significantly different ($P > 0.05$), Student-Newman-Kuels Test.

of all P. ulmi stages plus pollen ($\bar{X} = 20.3$, $N=9$) did not differ significantly ($P > 0.05$) from the other diets. Newly eclosed 1st stage larvae and 4 day old adults survived for a short time on apple leaves alone (\bar{X} No. days \pm S D = 2.6 ± 0.6 ($N=11$); 5.5 ± 2.1 ($N=4$), respectively).

E. Prey Relationships

Four day old 2nd stage larval L. mali fed on T. urticae, A. schlechtendali, eggs of L. pomonella and P. flavedana, 2 day old 2nd stage larval L. mali, 2nd stage larval H. subtilissimus, crawlers of L. corni and the phytoseiid P. oudemansi. No feeding was observed on A. citricola, S. punctum, or 4 day old 2nd stage larval L. mali.

Discussion

Difficulty in preparing satisfactory microscopic slide mounts of member of the genus Leptothrips Hood (especially L. mali) as discussed by Cott (1956), was encountered in this study. Numerous slide mounts of each stage were prepared but very few of these were considered satisfactory for making measurements.

An inverse linear relationship was found with development and temperature for the egg, 1st and 2nd stage larvae, pupa II and total egg-adult development. This relationship was not found for the pre-pupa and pupa I due to their shorter development times. Observations must be made at shorter intervals (< 12 h) to determine the development-temperature relationship of these stages. Data on the development of each stage at more temperatures are needed before an accurate

thermal unit accumulation system can be calculated for L. mali. Also if data on development of males and females were recorded separately, higher coefficients of determination and more accurate temperature threshold calculations could probably be obtained.

Fecundity obtained for L. mali revealed a large difference between lab-reared and field collected individuals, the latter being much higher. This may indicate that food sources (other than the European red mite) available to L. mali as an immature in an apple orchard provide additional nutrition which affects oviposition. This varied nutrition was not available to immature L. mali in the laboratory fed only P. ulmi. There is a possibility that the nutritional history of adults also affects egg laying. The opposite was found with Typhlodromus occidentalis Nesbitt (Chant 1961); nutrition of the adults rather than immatures affected oviposition. A source of additional nutrition in the field may be A. schlehtendali, which may be important in the development of large numbers of L. mali in apple orchards (Bailey 1940; Parrella et al. 1978). Greater variability was found in the number of eggs laid by field collected females compared to those reared in the laboratory. The type of female and the respective range of oviposition for each were: lab-reared unmated, 1-22; lab-reared mated, 1-38; field-collected unmated; 12-84; and field-collected mated, 11-52. The only previous reported estimate of fecundity for L. mali was by Bailey (1940) who indicated a maximum of 2 eggs from a field-collected mated female (the number of individuals tested or environmental conditions were not specified).

This study confirms that the reproductive potential of L. mali

is much greater than previously recorded. Consequently, the value of this thrips as a potential control agent should be reevaluated with respect to this new data on its fecundity.

A large amount of variability was found when determining the longevity of adult males and females (lab-reared and field collected) and no significant differences ($P > 0.05$) were found when comparisons were made even though there were large differences between their respective \bar{X} development times (Table 6). One field-collected mated female fed on a diet of P. ulmi plus Golden Delicious pollen survived in the laboratory for over 150 days; fecundity was not determined. A diet of P. ulmi supplemented with pollen may extend the life of a laboratory colony.

L. mali completed development on a strict diet of Golden Delicious pollen; \bar{X} development time was longer than on other diets tested. The vigor of the individuals reared on pollen appeared normal, but their longevity and fecundity were not determined. These probably would have been affected as have been reported for other closely related thrips (Loan and Holdaway 1955; Putman 1965). L. mali should be able to find food other than pollen within the apple orchard, but it is important that it can utilize this protein source if available. The shortest development times were recorded with diets of P. ulmi eggs and P. ulmi eggs plus pollen. All stages of P. ulmi are acceptable as food for L. mali, but the egg stage may be more suitable. L. mali adults and 1st stage larvae lived for a short time on an apple leaf devoid of prey; they probably are unable to derive nourishment from the leaf itself.

L. mali is capable of feeding on several orchard pests and their eggs. If populations of this thrips can be maintained in an apple orchard, reduction in densities of other pests in addition to P. ulmi may occur. S. punctum is an important predator in Virginia apple orchards and since L. mali did not feed on this predator, the two may be compatible control agents. L. mali was found to feed on a predaceous phytoseiid mite which may indicate that the compatibility of the thrips with this group of predators is limited. Cannibalism occurred only when there was a great disparity in size; 4 day old 2nd stage larval L. mali fed on 2 day old 2nd stage larvae but not on other 4 day old larvae. This would probably not be a problem in the field where other food sources would be available to L. mali.

V. FUNCTIONAL AND NUMERICAL RESPONSES OF
LEPTOTHIRIPS MALI TO DENSITIES OF PANONYCHUS ULMI

Introduction

A predator can respond in many ways to changes in the density of its prey. The functional and numerical responses have been widely investigated and information regarding these has been determined for various parasites and predators. Knowledge of these simple responses can be useful in screening potential enemy species, determining control potential of indigenous parasites or predators, comparing the relative effectiveness of natural enemies in controlling a common prey, etc. The functional response has been used to investigate the evolutionary aspects of predator-prey behavior (Livdahl 1979), to determine prey preferences of a predator (Murdock 1969), and temperature mediated functional response data have been employed in decision making pest management models (Dover et al. 1979). Leptothrips mali (Fitch), an indigenous predator, is under evaluation by this researcher to determine its mite control potential in Virginia apple orchards. Laboratory studies were designed to determine the functional response of each feeding stage of L. mali to densities of Panonychus ulmi (Koch) at 3 temperatures; its numerical response (via oviposition) was also investigated.

Materials and Methods

A. Functional Response of 1st Stage Larvae

A laboratory colony of L. mali was maintained as outlined in

Section IV; the containers used in this section were employed in all functional and numerical response studies. Two day old 1st stage larvae were transferred to the adaxial side of apple leaves within small plastic containers and were provided with 5, 10, 15, 20, 25, 30, 40 or 60 eggs of P. ulmi obtained by brushing mite infested apple leaves (Henderson and McBurnie 1943) over a glass plate. Eggs were transferred with a 000 artist's brush to the adaxial side of apple leaves and placed in a straight line ca. 5 mm on either side of the mid-vein (Fig. 19); the distance between eggs varied with each mite density because they were situated across the diameter of the leaf container (4.1 cm). To accurately determine the functional response of 1st stage larvae, individual larvae were tested at ages of 2, 3 and 4 days post eclosion at each mite density. Five 1st stage larvae within each age class/mite density were established, thus replicating mite densities 15 times. The number of mite eggs fed upon after 24 h was recorded and thrips were transferred to new leaf cages containing fresh mite eggs at the original density. The apple leaves were also examined for newly eclosed mite larvae to separate mite eggs completely emptied by the thrips from those which eclosed. Feeding of each 1st stage larval age class/mite density was determined at 18.3, 23.9 and 29.4 \pm 1°C. In a separate test, 1st instars (3 days post eclosion) were provided with 5, 10, 15 or 20 adult female P. ulmi at 23.9°C; each mite density was replicated 5 times. Mites were obtained directly from infested apple leaves and transferred by hand with a 000 brush to leaf cages. This enabled selection of the most vigorous mites. From 2-5 controls (no predator) were established for every



Fig. 19 - Placement of *P. ulmi* eggs for determination of *L. mali* 1st stage larval functional response.

5 treatments. The number of mites killed after 24 h were recorded; control mortality was also determined. It is common for L. mali to kill a mite and not feed on it, particularly at higher mite densities. Thus there are mites in the leaf cages that are dead after 24 h, but it is difficult to determine if this death resulted from natural mortality or L. mali. Mortality in the controls was used to correct for this potential bias. These procedures for transferring mites, establishing controls and recording data were followed in tests involving 2nd stage larvae and adults. The method of recording data was modified when the functional and numerical responses of adults were determined concurrently.

B. Functional Response of 2nd Stage Larvae

Second stage larvae (2 days post ecdysis) were obtained from the laboratory colony and provided with 5, 10, 15, 20, 25, 30, 40, 60, or 75 adult female P. ulmi. Mite densities were supplied to 2nd stage larvae at the time of transferral and after 3 and 4 days post ecdysis. Each age class/mite density was replicated 5 times effectively replicating each mite density 15 times at 18.3, 23.9 and 29.4°C.

C. Functional and Numerical Responses of Adults

Adults used to determine the functional response were obtained from 2 sources: 1) collected as adults from apple trees heavily infested with P. ulmi and 2) collected as 2nd stage larvae from these apple trees and reared to adults in the lab on P. ulmi. All stages were allowed to feed on a surplus of all P. ulmi stages for 4 days

prior to testing. Mite densities used were the same as that for 2nd stage larvae with 5 replicates/mite density. Observations on each adult were made over two 24 h periods, thus replicating each mite density 10 times. Only field collected adults were tested at 18.3, 23.9, and 29.4°C; all others were at 23.9°C. Functional response data were also obtained for field collected adult male L. mali.

Numerical and functional responses were determined concurrently for adults reared in the laboratory (egg-adult) on a surplus of all stages of P. ulmi. Newly emerged adult females were placed with males (1 female and 1 male/cage); after 4 days males were removed. The females were transferred to new leaf cages at the following adult female P. ulmi densities: 5, 10, 20 or 40/leaf cage. The same procedure was followed for other newly emerged adult females but these were not caged with males. Every 48 h the thrips were transferred to new leaf cages with fresh mites at the original density and the number of mites eaten and thrips' eggs oviposited were determined. Oviposition and feeding rates were recorded in this manner for 30 days. Each mite density was replicated 5 times for mated and unmated thrips. Two controls (no predators) were maintained for every 5 treatment replicates; after 2 days control mortality was recorded and new controls established. Leaf cages were held at 23.9°C.

All experiments with 1st and 2nd stage larvae and adults were conducted at a 14L/10D photoperiod regime with high R.H. (80-100%) due to the closed cages used; each contained an apple leaf section placed over moistened filter paper.

D. Statistical Analyses

The Analysis of Variance and the Student-Newman-Kuels Test (Sokal and Rohlf 1969) were used to determine differences in feeding between field collected adult males and females and lab-reared adult females. Prior to analysis, all data were checked for homogeneity of variances using the F max test (Sokal and Rohlf 1969). The T Test was employed to determine significant differences between oviposition and feeding rates of mated and unmated females.

Results

Temperature had very little effect on the functional response of L. mali 1st stage larvae (Fig. 20); no consistent relationship was found between the number of eggs consumed and temperature. A functional response was not observed when 1st stage larvae were provided with adult female P. ulmi. The number of mites killed (\pm S D) at mite densities of 5, 10, 15 and 20 were 3.0 ± 1.0 , 2.8 ± 1.0 , 2.6 ± 1.0 and 3.0 ± 1.0 , respectively.

A pronounced effect of temperature was observed on the functional response of 2nd stage larvae and adult females (Fig. 21 and 22). The number of mites killed increased with increasing temperature at most mite densities; the greatest effect of temperature was observed with adult female L. mali at 29.4°C.

Adult male L. mali collected in the field and females reared in the laboratory exhibited a functional response to adult female P. ulmi similar to L. mali females field collected as adults (Fig. 23). No significant difference ($p > 0.05$) was found between the feeding rates

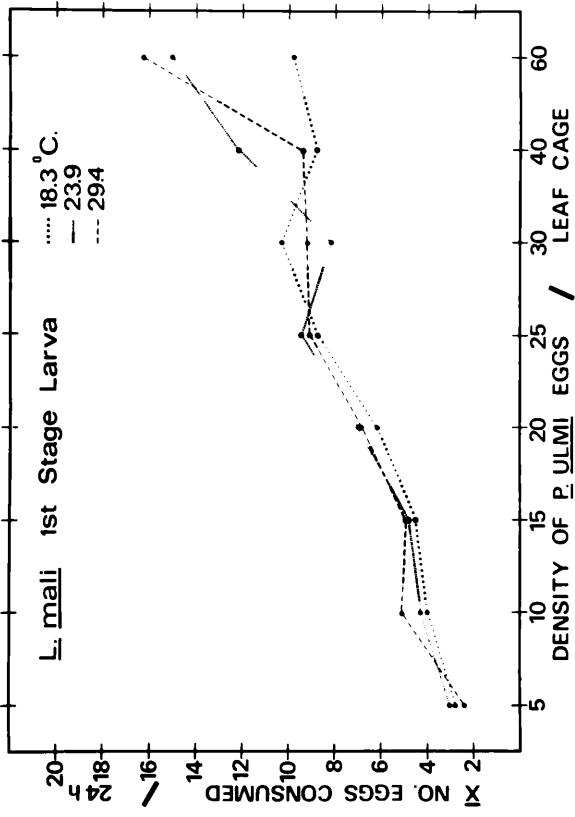


Fig. 20 - Functional response of 1st stage larval L. mali to densities of P. ulmi eggs at 3 temperatures.

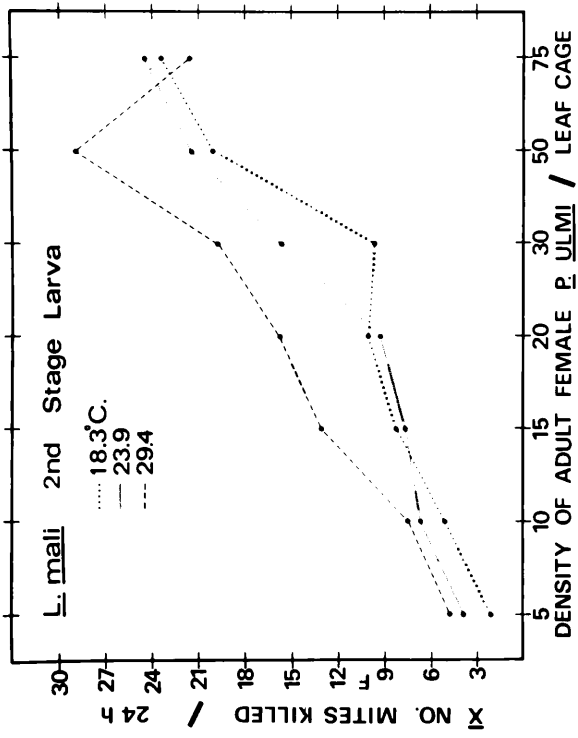


Fig. 21 - Functional response of 2nd stage larval L. mali to densities of adult female P. ulmi at 3 temperatures.

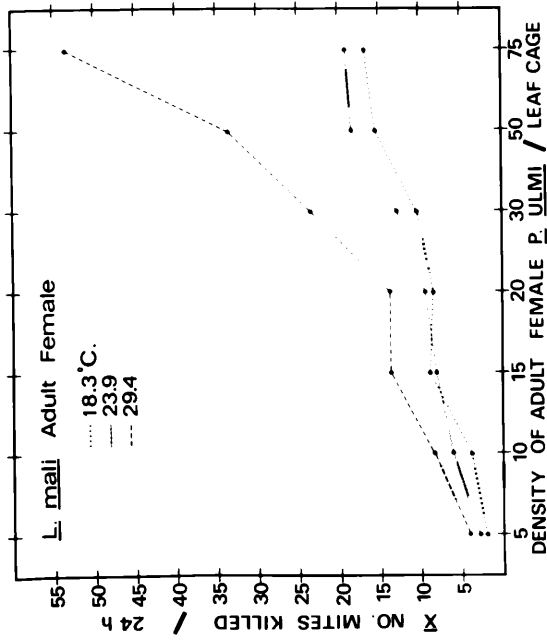


Fig. 22 - Functional response of field collected adult female L. mali to densities of adult female P. ulmi at 3 temperatures.

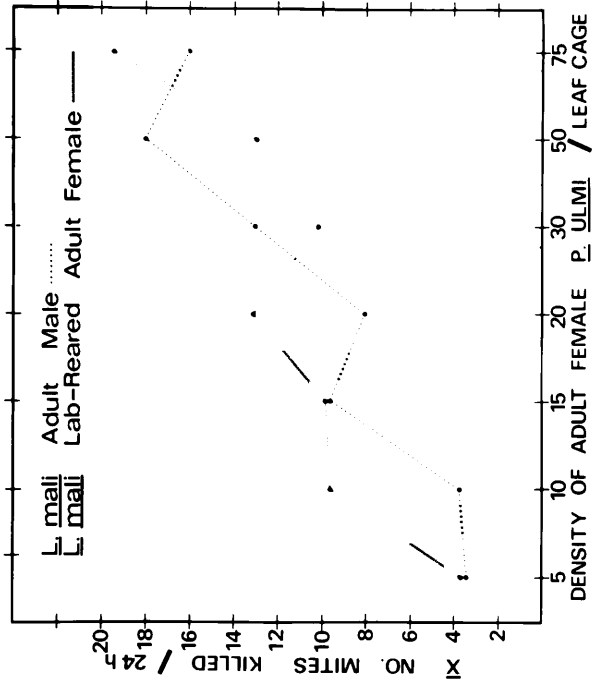


Fig. 23 - Functional response of field collected adult male and lab-reared adult female *L. mali* to densities of adult female *P. ulmi* at 23.9°C.

of lab-reared and field collected adult females at any mite density. Males killed significantly fewer ($p < 0.05$) mites compared to females at mite densities of 10 and 20; there were no significant differences ($p > 0.05$) at other mite densities.

No significant difference ($p > 0.05$) was found in the number of P. ulmi killed between mated and unmated female L. mali (Table 7). Mated females had significantly greater ($p < 0.05$) oviposition rates than unmated females when provided mite densities of 5 and 10 per 2 days; no differences were found at the higher mite densities.

Discussion

The functional response of 1st stage larvae to eggs of P. ulmi rises to a plateau (Fig. 20) at 18.3°C, but did not level off at the higher temperatures. Maximum consumption in 24 h was ca. 10, 15 and 17 eggs at 18.3, 23.9 and 29.4°C, respectively. This consumption may be higher than what would be expected if the eggs were placed randomly on the apple leaf; L. mali often follows the leaf mid-vein when searching. If 1st stage larvae were provided with immature stages of P. ulmi (larvae or nymphs) or had been given finely graded densities (1, 2, 3, etc.) of adult female P. ulmi, a functional response probably would have been found. Adult female P. ulmi are not preferred prey for 1st stage larvae but when the only food source, they will feed on them at a maximum rate of ca. 3 per 24 h.

Second stage larvae and adult females exhibited a functional response curve which rose to a plateau at 29.4° and at 18.3 and 23.9°, respectively (Figs. 21 and 22). There was an indication that the

Table 7. Mean No. Adult Female *P. ulmi* Killed and Oviposition Rates/*L. mali* Female/2 days (\pm SE) in Leaf Cages for a 30 Day Period.

<u>Prey Density</u>	<u>Unmated Females^a</u>		<u>Mated Females^a</u>	
	<u>Prey Killed</u>	<u>Eggs</u>	<u>Prey Killed</u>	<u>Eggs</u>
5	3.93 \pm 0.21	0.00 \pm 0.00	4.53 \pm 0.10	0.27 \pm 0.11
10	7.92 \pm 0.33	0.23 \pm 0.08	7.63 \pm 0.37	0.43 \pm 0.09
20	15.53 \pm 0.63	0.55 \pm 0.17	14.50 \pm 0.80	0.51 \pm 0.14
40	27.16 \pm 1.90	0.77 \pm 0.27	23.60 \pm 2.13	0.67 \pm 0.18

^a5 replicates/prey density.

functional response of the 2nd larval stage was beginning to level off at 18.5 and 23.9°C, but the functional response of adults at 29.3°C was almost linear. At most mite densities, 2nd stage larvae had a greater consumption capacity than adults. The presence of mite eggs, particularly at the higher mite densities, may have reduced feeding on adult mites. Other evidence (Parrella et al. 1980; Section IV) indicated L. mali may have a feeding preference for eggs of P. ulmi.

The functional response of lab-reared mated and unmated females was similar (Table 7), and the number of prey killed after 48 h at the lower mite densities (5 and 10) was similar to that obtained for field collected adults after 24 h at 23.9°C (Fig. 22). At the higher mite densities (20 and 40) the thrips killed less mites than what would be expected based on the 24 h functional response curve. The numerical response of mated and unmated females was similar at the higher mite densities (20 and 40), but differed significantly ($p < 0.05$) at the lower mite densities (5 and 10). Unmated females oviposited 0 eggs when provided 5 adult mites/48 h while mated females at the same mite density and time oviposited a mean of 0.27 eggs.

Conclusions

L. mali responded both functionally and numerically to densities of P. ulmi. The consumption capacity of 2nd stage larvae and adults for tetranychid mites is greater than the phytoseiid mites Amblyseius fallacis (Garman) utilizing Tetranychus urticae (Dover et al. 1979); Phytoseiulus persimilis Athias-Henriot utilizing T. urticae; A. largoensis (Muma), A. concordis (Chant) and Typhlodromus floridanus

(Muma) utilizing Oligonychus punicae (Hirst) (Sandness and McMurtry 1970); T. occidentalis Nesbitt utilizing T. telarius (Chant 1961). L. mali consumes more P. ulmi than the stigmaeid mite Zetzellia mali (Ewing) (Santos 1976a). The consumption capacity of L. mali in a 24 h period is ca. 1/5 that of Stethorus punctum LeConte (Hull et al. 1977a) and Orius insidiosus Say.

When a predator is given varying densities of one prey species and mortality of the prey determined, the results are almost always a destabilizing curvilinear rise to a plateau (Type II functional response, Holling 1959b) unless some other complication is added (Murdoch and Oaten 1975). One such complication is predator switching (Murdoch 1969) where a predator may feed on several prey species causing stabilizing mortality on some of these species. Information on the population dynamics of L. mali and its principal mite prey, P. ulmi and Aculus schlechtendali (Nalepa) (Acarina: Eriophyidae) (Section III) have shown that the thrips responds numerically to A. schlechtendali in the field, but not to P. ulmi. Many times L. mali increased in numbers in response to A. schlechtendali and has been at high levels when the P. ulmi population began to increase and the A. schlechtendali population began to decline. It is possible that switching predation from A. schlechtendali to P. ulmi will have a stabilizing effect on the population of P. ulmi. Research with the predaceous stigmaeid mite, Z. mali, has found that no switching occurred between P. ulmi and A. schlechtendali (Santos 1976b). Z. mali encounters its prey by random searching and does not fit the behavioral characteristics of predators which would encourage

switching (Murdoch and Marks 1975). L. mali is similar to Z. mali in that it probably encounters prey through random search and by this criterion is unlikely to switch. However, every predator must be considered individually. A predator evolving in an environment of fluctuating populations of two or more prey species is likely to develop switching behavior. Z. mali has evolved under these conditions but does not switch leading Santos (1976b) to conclude that other precursors may be involved in the development of switching behavior. L. mali has a much wider host range than Z. mali (Santos 1976a; Section IV) and has probably evolved within an environment of fluctuating prey populations but certainly other factors have influenced its evolution. Unlike Z. mali, L. mali will probably switch predation from A. schlechtendali to P. ulmi.

The numerical response of L. mali is smaller than that determined for the predaceous mites Z. mali (Santos 1976a), A. largoensis, A. concordis, and T. floridanus (Sandness and McMurtry 1970) and T. occidentalis (Chant 1961). Although no numerical response data on S. punctum or O. insidiosus are available, the fecundity of L. mali (Section IV) is less than the fecundity of these two predators (Colburn and Asquith 1971). In Table 7, the numerical response of L. mali does not appear to reach a plateau, but based on the fecundity of lab-reared females (Section IV), 0.70 eggs/female/2 days is probably close to the maximum for this species. In Virginia apple orchards L. mali has reached populations of > 30 per 1/2 semi-dwarf apple tree. This high population was probably attained through an aggregation response (Hassell 1966), another aspect of the numerical

response. More information is needed on the aggregation response of L. mali before its overall numerical and functional response can be evaluated in the field for control of P. ulmi.

VI. TOXICITY OF SELECTED PESTICIDES
TO LEPTOTHRIPS MALI (FITCH)

Introduction

Integrated pest management represents an ecologically sound approach to pest control. The use of pesticides fits within this framework provided that this use is both judicious and selective. The apple grower must satisfy consumer demand for cosmetically perfect fruit which forces his economic threshold to be very low; ca. 1% of fruit damaged at harvest (Croft 1975a). A Virginia apple grower loses ca. 20¢ for each lb of fruit that goes for juice instead of the fresh market. Also, the fruit grower must combat a group of insects called "Direct Feeders" (Croft 1975a) that attack the fruit itself and for which the equilibrium position is above the economic threshold (Luckman and Metcalf 1975). Faced with these constraints, the apple grower relies on pesticides to protect his crop. Research has concentrated on utilizing pesticides so that they will complement other control options (particularly beneficial arthropods) available in an integrated pest management program. Using the correct application equipment, timing the applications and selecting the proper pesticide and dosage are vital to insure this compatibility. Air blast sprayers lessen the effect of pesticides on beneficial arthropods particularly when the alternate row spray technique (Lewis and Hickey 1967) is employed. Pheromone trapping of Lepidopteran pests has been used in predicting the temporal occurrence of life history events through heat summation for the most effective timing of pesticide

sprays (Batiste et al. 1973; Reidl et al. 1976). Pickett (1949) in Nova Scotia apple orchards was the first to realize that certain insecticides were more compatible with the survival of natural enemies and should be favored for use. This concept has been well documented in fruit and other crops (Ripper 1956; Stern et al. 1959; 1960, Bartlett 1958, Jeppson et al. 1975; Lingren and Ridgway 1967; Van den Bosch et al. 1956). Most spray schedules and label directions for insecticide-use prescribe inflated dosages of insecticides (Metcalf 1980). The utilization of reduced dosages of pesticides can increase their selectivity because they decrease natural enemy mortality, as demonstrated in cotton (Van den Bosch and Stern 1962, Reynolds et al. 1975, Adkisson 1971), soybeans (Newsome 1978) and fruit (Madsen and Williams 1968, Croft 1975a).

Many fruit growers in Virginia use air blast sprayers in alternate row applications and a few utilize pheromone traps to monitor moth populations. The number employing these techniques should increase with educational programs offered to the growers and with additional research on pheromone traps as predictive tools (Horsburgh, pers. comm.). One of the most abundant predators in Virginia apple orchards is Leptothrips mali (Fitch) (Parrella et al. 1978). Data on the toxicity of pesticides to this predator are available from field studies (Clancy and Pollard 1948; 1952, Lord 1949; 1956, MacPhee and Sanford 1954; 1956; 1961, Clancy and McAlister 1956; Holdsworth 1968; 1972a, Meyer 1974). However, no information is available on the toxicity of pesticides to L. mali currently recommended in the pest management guide for apples in Virginia (Horsburgh 1979). Laboratory

studies were designed to determine the relative toxicity of some of these materials to L. mali.

Materials and Methods

Adult L. mali used in assessing relative pesticide toxicity were collected from an apple orchard in Augusta Co., Va. which had not been sprayed for ca. 10 years. Apple tree limbs were tapped with a rubber coated stick over a 1 m² muslin cloth covered tray. All adult thrips falling on the tray were transferred with a 000 artist's brush to apple foliage within plastic bags. Insulated coolers were used to carry these back to the laboratory where the thrips were transferred to test cages; 120 ml plastic containers were used as described (Section IV) with 10 L. mali/container. Each dosage of pesticide was replicated at least 4 times (40 L. mali/dose; 10 L. mali/container; control replications equalled that for each dose). Rates of materials tested represented a low volume half spray per acre (alternate middle) and a low volume spray per acre (every middle) following Horsburgh (1977); materials were in 1 gal of water based on the original concentration in 100 gal. All container parts (plastic container, snap-on lid, cheesecloth, apple leaves) were dipped in the appropriate concentration of pesticide and allowed to dry for ca. 3 h; controls were dipped in water. The containers were assembled with 2 leaves/container as described previously (Section IV). L. mali, without regard to sex, were added to the containers and mortality recorded after 24 h. Thrips were considered dead when they did not move when touched with a small probe. All containers were kept in a screened

insectary; temperature and humidity were monitored using a Bendix^R hygrothermograph.

Results and Discussions

The toxicity of 5 selected pesticides are shown in Table 8. The range of temperature and humidity was 16-25°C and 46-100%, respectively. Mortality from the recommended dosage was greater than that from 1/2 the recommended rates. Of the insecticides, phosalone was less toxic than phosmet and azinphosmethyl. The fungicide-miticide combination Dikar^R was moderately toxic to L. mali; it caused higher mortality than the miticide cyhexatin. These laboratory results are supported by earlier field observations (Section III) where larger populations of L. mali developed under a pesticide regime with the major insecticide phosalone compared to one with phosmet or azinphosmethyl. The field study, Section III, demonstrated that 1/2 the recommended pesticide rates were sufficient to control most orchard pests and permitted the buildup of large predator populations, only leafrollers (Lepidoptera: Tortricidae) caused economic damage. The lower pesticide rates may be effective against leafrollers through better timing of sprays to coincide with peak adult flight or egg eclosion.

Large populations of L. mali developed in the apple orchard in response to apple rust mite (Aculus schlechtendali (Nalepa)) populations (Section III). The presence of apple rust mites may be an important prerequisite before L. mali populations will begin to increase. Therefore, the compatibility of A. schlechtendali with pesticide

Table 8. Toxicity of Selected Orchard Pesticides to L. mali

Material	Kg(1b/378.5L) ^a	Formulation	Percent Cent Mortality ^b
Azinphosmethyl ^c	0.28(0.60)	50W	100.0
	0.14(0.31)	50W	100.0
Phosmet ^c	0.68(1.50)	50W	100.0
	0.34(0.75)	50W	76.5
Phosalone ^d	0.91(2.00)	25W	22.0
	0.45(1.00)	25W	17.5
Dikar ^{Rc}	2.94(6.50)	80W	90.0
	1.17(2.60)	80W	70.0
Cyhexatin ^c	0.17(0.50)	50W	22.5
	0.06(0.13)	50W	7.5

^aFollowing Horsburgh (1977); 378.5L = 100 gal.

^bRecorded after 24 h and corrected for control mortality with Abbott's formula (Healy 1952).

^c10 thrips/replicate; 4 replicates/treatment.

^d10 thrips/replicate; 8 replicates/treatment.

application may be just as important as the compatibility of the thrips with pesticides. Croft and Hoying (1977) found that azinphosmethyl and phosmet were relatively non-toxic to A. schlechtendali compared to phosalone. They determined that Dikar and cyhexatin were highly toxic (95% mortality) to the apple rust mite. Our results supported this in the field (Section III); low apple rust mite populations were found under a pesticide regime of phosalone-Dikar compared to a program of azinphosmethyl or phosmet-benomyl. Benomyl is only slightly toxic to A. schlechtendali (Croft and Hoying 1977). Although benomyl was not tested against the thrips in this study, it probably has low toxicity to L. mali because it is a fungicide with less miticide activity than Dikar.

The major insecticide-fungicide combination that will allow A. schlechtendali populations to increase in the orchard and not terminate the thrips responding numerically to the rust mites is phosalone-benomyl. Croft and Hoying (1977) reported 66% mortality to A. schlechtendali with the lowest rate of phosalone tested (1/4 pt/100 gal which has a per cent active ingredient similar to the rate tested against L. mali in this study. Croft and Hoying (1977) tested the 3EC formulation of phosalone against A. schlechtendali, which may have caused greater mortality than would have been obtained with the W formulation.

There are many insecticides available to the commercial grower in Virginia but the majority use azinphosmethyl, phosmet or phosalone. The grower can select from a large number of fungicides; many use

Dikar and/or benomyl. The toxicity of other fungicides listed by Horsburgh (1979), should be tested against L. mali and A. schlechtendali.

The insecticide-fungicide combination phosalone-benomyl is only slightly toxic to Orius insidiosus (Say) (McCaffery and Horburgh 1980a) and Stethorus punctum LeConte (Hull 1979), two other important predators in Virginia apple orchards (Parrella et al. 1978).

VII. COMPATIBILITY OF LEPTOTHRIPS MALI WITH STETHORUS PUNCTUM
AND ORIUUS INSIDIOSUS: PREDATORS OF PANONYCHUS ULMI

Introduction

The European red mite, Panonychus ulmi (Koch) is a perennial pest of apple trees in Virginia (Cagle 1946). A preliminary survey of the predaceous fauna associated with this mite in central Virginia apple orchards (Parrella et al. 1978) revealed that the most abundant predator was Leptothrips mali (Fitch) and that other predators, particularly Stethorus punctum LeConte and Orius insidiosus (Say), were present in large numbers. All these predators were commonly found on the same mite infested apple tree. Before a control program for P. ulmi could be developed utilizing L. mali as the major predator supplemented with S. punctum and O. insidiosus, it was necessary to determine if these predators were compatible. Laboratory studies were designed to investigate the control potential of combinations of L. mali and these two predators for biological control of P. ulmi.

Materials and Methods

Interaction arenas (Fig. 24) were prepared by placing 3 apple leaves (ca. area of 50 cm² each) adaxial side down on a 0.5 cm layer of water-saturated cotton in plastic petri dishes (15 cm d x 2 cm deep). Each leaf was carefully cleaned with damp cheesecloth before placement on the cotton. The leaves were arranged so that they overlapped and formed a circle. An apple leaf was cut into 1 x 3 cm sections and glued (Elmer's Glue-all^R) on the points of overlap to

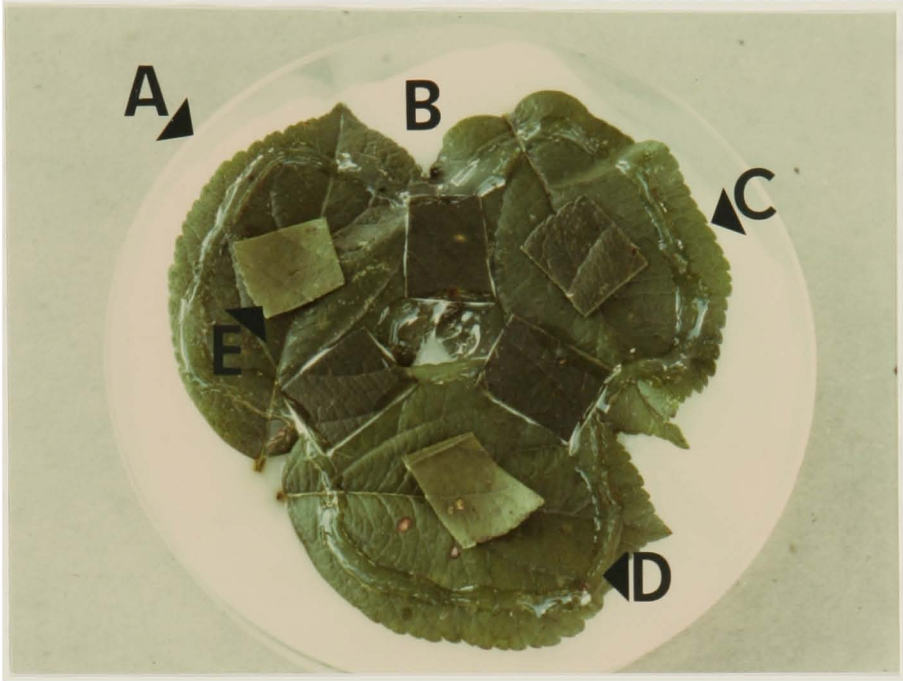


Fig. 24 - Interaction arena: a) plastic petri dish, b) water saturated cotton, c) apple leaves, d) Stikem barrier, e) leaf section fastened with a minuten.

provide a bridge between leaves. Stikem Special^R was applied to the inner and outer perimeter of the leaves with a fine artist's brush to keep predators and mites on the leaves. The area available to the mites and predators remained constant between replicates and treatments. A small section of apple leaf was placed in the center of each leaf and held with a minuten pin. This served as refuge for the predators. Adult female P. ulmi were transferred to the leaves at the rates of 15 and 45/arena with replicates including L. mali and S. punctum and 45 and 90/arena with L. mali and O. insidiosus. Mites were allowed to acclimate for 2 h before predators were added. L. mali were reared in the laboratory on all stages of the European red mite (Parrella and Horsburgh 1979) and S. punctum and O. insidiosus were collected in apple orchards infested with high populations of P. ulmi. The field collected predators were provided with a diet of P. ulmi for at least 8 h in the laboratory before each test. Four day old 2nd stage larvae of L. mali, 3rd and 4th stage larvae of S. punctum and 5th stage nymphs of O. insidiosus were used. Predator combinations (predator ratio 1:1) were made by transferring 1 L. mali and either 1 S. punctum or O. insidiosus to opposite leaves in the arena. The L. mali-S. punctum and L. mali-O. insidiosus combinations were replicated 6 and 4 times, respectively, at the 2 mite densities. Controls were established with mites only (predator ratio 0:0) and with each predator alone (predator ratios 0:1, 1:0). Controls were replicated 5 and 4 times for the L. mali-S. punctum and L. mali-O. insidiosus combinations, respectively, at the 2 mite densities.

Before the predators were added, a microscopic examination of the

leaves was made for mites caught in the Stikem. The trapped mites were removed and new mites added to the arena.

Observations, made 24 h after predators were introduced into the arenas, included the number of mites killed, those caught in the Stikem, the number of uneaten mite eggs and the condition of the predators. The petri dishes were kept in a Sherer-Gillette^R environmental chamber at 23.9°C, RH between 80-100%, and a 14 h photoperiod.

A. Statistical Analyses

Analysis of variance and the Student-Newman-Kuels Test were used to determine significant differences between treatments for the mean number of mites killed and uneaten mite eggs present. The F max test (Sokal and Rohlf 1969) was employed to determine homogeneity along the variances. Only the mite egg data from the L. mali-S. punctum interaction at the initial mite density of 15/arena required a transformation ($\text{Log}(X + 1)$) before analysis.

Results

No significant differences ($p > 0.05$) were detected in the number of mites killed between the combination of L. mali and S. punctum (1:1) and each predator individually (1:0, 0:1) at a density of 15 mites/arena (Table 9). All petri dishes with predators (1:1, 1:0, 0:1) had significantly more ($p < 0.05$) mites killed than the control (0:0). The number of uneaten mite eggs did not differ significantly ($p > 0.05$) between the combination of predators (1:1) versus L. mali alone (1:0) but differed significantly ($p < 0.05$) when compared to

Table 9. Effects of Predation by L. mali and S. punctum Individually and in Combination on P. ulmi in Leaf Arenas.

Initial Mite Density	Ratio of <u>L. mali</u> : <u>S. punctum</u> ^a	\bar{x} No. ^b	
		Mites Killed	Uneaten Mite Eggs
15/arena	(1:1)	14.1 a	0.3 c
	(1:0)	11.0 a	2.1 bc
	(0:1)	13.0 a	3.1 b
	(0:0)	2.3 b	18.5 a
45/arena	(1:1)	34.5 a	13.8 b
	(1:0)	21.1 b	36.3 a
	(0:1)	23.8 ab	51.3 a
	(0:0)	6.8 c	45.2 a

^a 1:1 replicated 6 times; 1:0, 0:0, 0:0 replicated 5 times.

^b Recorded after 24 h; means within each initial mite density in the same column followed by the same letter are not significantly different ($p > 0.05$), Student-Newman-Kuels Test. At initial mite density of 45/arena, 1:1 and 0:1 differ significantly ($p < 0.10$) in the no. of mites killed.

S. punctum alone (0:1). The control (0:0) had significantly more ($p < 0.05$) eggs than all arenas with predators (1:1, 1:0, 0:1); the number of uneaten mite eggs in arenas with solitary predators (1:0, 0:1) did not differ significantly ($p > 0.05$).

At the higher mite density of 45/arena (Table 9), the number of mites killed by the predator combination (1:1) was significantly greater than L. mali (1:0) and S. punctum (0:1) alone ($p < 0.05$ and $p < 0.10$, respectively). There was no difference ($p > 0.05$) in the number of mites killed between individual predators (1:0, 0:1) and all arenas with predators (1:1, 1:0, 0:1) differed significantly ($p < 0.05$) from the control. Arenas with individual predators (1:0, 0:1) and the control (0:0) had significantly more ($p < 0.05$) uneaten eggs present after 24 h than arenas with the predator combination (1:1). No adverse effects on the condition of the predators were observed after 24 h in replicates of L. mali and S. punctum individually (1:0, 0:1) or combined (1:1). Interference between L. mali and S. punctum may have occurred; the total number of mites killed by the individual predators exceeded that killed by the predators combined.

The only significant differences ($p < 0.05$) in the number of mites killed with the L. mali-O. insidiosus interactions (Table 10) were between arenas with predators (1:1, 1:0, 0:1) and the control (0:0) at both initial mite densities. In 75% of the replicates where L. mali and O. insidiosus were combined (1:1) at both mite densities, L. mali was killed and fed upon by O. insidiosus (Fig. 25). Fewer mite eggs were present in treatments with predators (1:1, 1:0, 0:1) compared to controls; differences were not significant ($p > 0.05$).



Fig. 25 - O. insidiosus (5th stage nymph) feeding on L. mali (2nd stage larva).

Table 10. Effects of Predation by L. mali and O. insidiosus Individually and in Combination on P. ulmi in Leaf Arenas.

Initial Mite Density	Ratio of <u>L. mali</u> : <u>O. insidiosus</u> ^a	\bar{X} No. ^b	
		Mites Killed	Uneaten Mite Eggs
45/arena	(1:1)	25.3 a	31.5 a
	(1:0)	19.0 a	40.0 a
	(0:1)	18.3 a	42.8 a
	(0:0)	6.0 b	45.8 a
90/arena	(1:1)	44.8 a	27.0 a
	(1:0)	30.5 a	45.3 a
	(0:1)	39.3 a	50.8 a
	(0:0)	14.8 b	75.3 a

^aEach combination replicated 4 times.

^bRecorded after 24 h; means within each initial mite density in the same column followed by the same letter are not significantly different ($p > 0.05$), Student-Newman-Kuels Test.

After 24 h, mites caught in the Stikem ranged from 0-8% of the total/arena; most of the arenas had no trapped mites. Mites avoided direct contact with the Stikem; those found trapped in the barrier became entangled due to the initial excitement caused by transferring them to the arena or by movement in response to the predators.

Discussion

The interaction studies with L. mali and S. punctum show that at the higher initial mite density (45) the combination of these predators kill more P. ulmi than individual L. mali or S. punctum. At the lower mite density (15/arena), there was no difference because the individual predators consumed most all the mites in the arena; 73 and 86% of the mites were killed with L. mali and S. punctum alone, respectively, and 93% with the combination. With 45 mites/arena the maximum consumption rate of L. mali was almost reached (Section V) and therefore the added predation by S. punctum caused significantly more mite mortality; 46 and 52% of the mites were killed with individual L. mali and S. punctum, respectively, and 76% by the combination. The feeding rates determined for S. punctum are less than has been reported previously (Colburn and Asquith 1971), and may be related to the larger feeding arenas used in this study. L. mali and S. punctum had similar feeding rates at each mite density.

There were fewer mite eggs remaining in the arena with L. mali alone than with the solitary S. punctum, even though there were fewer mites alive after 24 h in the latter. This may indicate a feeding preference for the egg stage by the thrips.

The interaction studies between L. mali and O. insidiosus indicated that these two predators were not compatible; in 75% of the replicates Orius killed and fed on Leptothrips. This was expected since members of the genus Orius (Wolff) are natural enemies of the Thysanoptera (Lewis 1973). However, despite Orius feeding on Leptothrips, there were more mites killed where these predators were combined than when they were tested individually (differences were not significant). Observations indicated that the first encounter between these predators would usually evoke an attack by Orius, but the first attack usually did not produce a successful capture. The success of the attack was dependent on whether the approach was from the front, side or rear of the thrips. L. mali produces a drop of liquid from its anal area which is forced onto an attacker with whip-like motions of its abdomen. Contact with this liquid (usually around the head), causes Orius to cease attack and begin cleaning itself. Due to this defense mechanism an attack from the rear of L. mali was rarely successful. In the interaction arena these predators were closely confined together and repeated Leptothrips-Orius confrontations occurred with Orius eventually feeding on Leptothrips. In a field situation the predator-predator contact might stimulate movement to other leaves which would reduce thrips mortality and possibly promote more efficient control at low prey densities (McMurtry et al. 1970).

Information on how these predators segregate the apple tree into their respective niches and further studies on the defensive and avoidance behavior exhibited by L. mali towards O. insidiosus would aid our understanding of the complex interspecific interactions of

these predators and the consequences of such interactions as they relate to P. ulmi.

VIII. COMPARISON OF TWO SAMPLING METHODS FOR LEPTOTHRIPS MALI IN VIRGINIA APPLE ORCHARDS

Introduction

Predaceous thrips have been sampled from deciduous fruit trees by beating limbs over a cloth covered tray (Putman 1965; Parent 1967; Horsburgh and Asquith 1968; Holdsworth 1968) and by visual examination of the foliage for timed periods (Clancy and Pollard 1952). Problems associated with the limb-beating method are the amount of time required, damaged limbs and dislodged fruit. Visual searching of the foliage for L. mali is practical because the adults are black and 2nd stage larvae are reddish-brown which allows these stages to be observed against the green foliage. Unfortunately, this technique greatly under-estimates the thrips' population on the tree because these predators are not always on the leaves where they can be observed.

To circumvent these problems, regression analyses were used to determine the relationship between the practical, non-destructive visual search and the efficient, but destructive limb beating technique.

Materials and Methods

In 1977, the study area was a 1.6 ha block of Golden Delicious, Red Delicious, Jonathan, Winesap and Rome apple trees. Only the latter two cultivars were sampled. The entire orchard was relatively homogeneous with seven year old trees approximately 4-5 m in height.

Cultivars were planted in double rows of 30 trees. Cover sprays were applied at reduced rates (Horsburgh 1977) to alternate rows to permit the buildup of prey and their associated predators. Sampling was in the early afternoon at weekly intervals from the middle of July through August. Four trees equally spaced down a row were sampled from each cultivar. A visual count of thrips on the foliage was made for three minutes while walking around one-half of a tree. The natural position of any part of the tree was not disturbed during the inspection. The visually searched area was then beaten vigorously with a rubber-coated stick over a 1 m^2 muslin cloth covered tray. When fruit were present, the limbs were lightly tapped and this was supplemented with a thorough hand-brushing of the foliage. L. mali falling on the tray were collected and counted. Trees were tagged so the same tree was not sampled twice.

An abandoned apple orchard that was not sprayed for ca. 10 years was used as a study area in 1978. Red and Golden Delicious, Jonathan and Stayman cultivars made up the 3.2 ha orchard. The trees were 15 years old and ca. 4 m in height. Golden Delicious trees were sampled as described, except that the number of trees was increased to six/sampling date. Sampling was done every two weeks for ten weeks starting in mid-June.

Regression analyses were calculated using the General Linear Model (GLM) procedure (Barr et al. 1976) with the limb-tapping and visual data as independent and dependent variables, respectively.

Results and Discussion

Thrips observed on the trees were adults and 2nd stage larvae. Preliminary studies have indicated limb-beating to be 85-90% efficient for sampling these stages of L. mali. In 1977, the largest number of thrips observed and limb-tapped/tree was 2 and 7, respectively and in 1978, 5 and 26, respectively. Significant ($p < 0.05$) R square values relating the mean number of thrips observed to those shaken off the searched area were obtained for the cultivars Rome (0.67) and Winesap (0.84) in 1977 and Golden Delicious (0.76) in 1978. The hypothesis that the regression lines for the Winesap and Rome cultivars are the same was not rejected ($p > 0.05$) so they are combined, giving the equation $Y = 0.033 + 0.124x$ and an R square value of 0.76. No attempt was made to statistically compare the 1977 data to the data in 1978 due to the large differences in the L. mali populations on the cultivars which would require questionable extrapolation. The 1978 data are presented graphically (Fig. 26).

The 2 regression equations obtained for the cultivars Winesap and Rome and Golden Delicious can be utilized to give a better approximation of the population of L. mali in a visually searched area. The combined equation for Rome and Winesap trees is limited in use to situations where L. mali populations are ≤ 2.0 /visual search; the equation for Golden Delicious is limited to L. mali populations ≤ 5.0 /visual search.

Thus the accuracy of a simple non-destructive sampling technique (visual search) was improved by defining its relationship to a time-consuming, destructive, but efficient sampling technique (limb-tap).

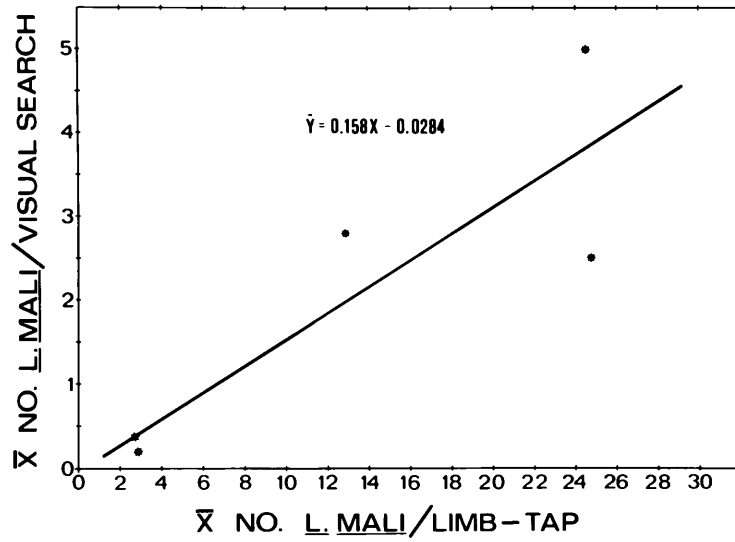


Fig. 26 - Relationship between the number of L. mali limb-tapped and observed from 6 Golden Delicious trees on 5 sampling dates, 1978 ($R^2 = 0.76$).

It is important that this relationship be determined for each cultivar and type of tree (dwarf, spur, etc.) over a range of population densities. With knowledge of the distribution of L. mali within and between apple trees, this sampling method can be used to obtain accurate population estimates.

SUMMARY

Research was conducted in central Virginia apple orchards in an effort to form the base of a pest management program. The beneficial arthropods with the most potential to control Virginia's major orchard pests were identified, and one of these beneficial arthropods, Leptothrips mali, was evaluated for its ability to regulate pest populations. Studies were designed to elucidate: 1) the bionomics of L. mali, 2) the functional and numerical responses of L. mali to densities of Panonychus ulmi, 3) the toxicity of commonly used orchard pesticides to L. mali, 4) the compatibility of L. mali with other predators abundant in Virginia's apple orchards and 5) a practical sampling method for L. mali.

Population dynamics of selected pests in Virginia apple orchards (P. ulmi, Aculus schlechtendali, Aphis citricola, Dysaphis plantaginea, Platynota spp.) and predators (L. mali, Haplothrips subtilissimus, Orius insidiosus, Stethorus punctum, Deraeocoris nebulosus, Chrysopa spp.) were monitored during 1977-1978 under 3 reduced pesticide programs. The pesticide program with Phosalone and Dilar^R as its major components allowed the largest number of predators to remain in the orchard and controlled most pests. Platynota spp. caused economic damage during August and September regardless of the pesticides used or the number of predators in the orchards. L. mali and H. subtilissimus were the most abundant predators and appeared to respond numerically to densities of A. schlechtendali. The presence of this mite species may aid the development of large numbers of

thrips within an apple orchard. O. insidiosus and D. nebulosus usually increased too late in the season to reduce aphid populations, but aphids may be important in attracting these general predators into the orchard. S. punctum's response to densities of P. ulmi was inconsistent but together with other predators may have had an important role in reducing European red mite populations. Chrysopa spp. remained at consistently low levels throughout the study under all pesticide programs.

The pesticides azinphosmethyl, phosmet, phosalone, Dikar and cyhexatin were evaluated for their relative toxicity to L. mali. Of the insecticides, phosalone was the least toxic compared to phosmet and azinphosmethyl. The fungicide-miticide combination Dikar was moderately toxic to L. mali; it caused higher mortality than the miticide cyhexatin. Benomyl can probably be substituted for Dikar in order to lessen mortality of A. schlechtendali in the field.

L. mali was studied in the laboratory to determine aspects of its development, biology and prey relationships. Length and width of eggs were determined as was the overall body length and ratio of head-capsule length:width for other stages. Mean development time (days) for each stage at 23.9°C was: egg, 7.5; 1st larva, 5.7; 2nd larva, 5.4; prepupa, 1.0; pupa I, 1.5; pupa II, 4.0 and total (egg-adult), 25.6. An inverse linear relationship was found with temperature and development for the egg, 1st and 2nd stage larvae, pupa II and total (egg-adult). The mean preoviposition period (range = 5-7 days) of mated and unmated field collected (FC) and laboratory reared (LR) females did not differ. A large difference in fecundity was found

between FC and LR females which probably reflects the nutritional history of the larvae. Mean no. eggs/LR and FC females were: mated - LR, 13.0; FC, 28.0 and unmated - LR, 11.7; FC, 45.1. No consistent difference was found between fecundity of mated and unmated females. Mean longevity of unmated females (LR, 50.1 and FC, 54.2 days, respectively) was greater than that for males and mated females; differences were not significant. L. mali completed development on Golden Delicious apple pollen in 23 days (1st stage larva - adult) which was slower than on diets containing various stages of P. ulmi. The most rapid development was obtained with P. ulmi eggs plus pollen. L. mali fed on the following orchard pests: A. schlechtendali, Tetranychus urticae, Lecanium corni and on the eggs of Laspeyresia pomonella and P. flavedana. No feeding was observed on the mite predator, S. punctum, but L. mali fed on the phytoseiid mite, Proprioseius oudemansi, when it was the only food source provided.

The functional response of all feeding stages of L. mali to densities of P. ulmi were determined at 18.3, 23.9 and 29.4 \pm 1 °C and the numerical response of adult female L. mali to this mite species was investigated. The functional response of 1st stage larvae when provided eggs of P. ulmi was slightly affected by increasing temperature. Maximum consumption rates at 18.3, 23.9 and 29.4°C were ca. 10, 15 and 17 eggs/larva/24 h. No functional response was observed when 1st stage larvae were provided with adult female P. ulmi. Increasing temperature affected the functional response of L. mali 2nd stage larvae and adult females when provided adult female P. ulmi; this effect was most pronounced with adult females at 23.9°C. Maximum

consumption capacity of L. mali is greater than most phytoseiid mites but less than S. punctum and O. insidiosus. L. mali may switch its feeding from A. schlechtendali to P. ulmi in the field thus producing stabilizing mortality on the P. ulmi population. The numerical response of L. mali reached a maximum of ca. 0.70 eggs/female/48 h which is less than many phytoseiid mites. The aggregation response of L. mali in the apple orchard should be determined before the overall numerical and functional response is evaluated for P. ulmi control.

The individual or joint potential impact of L. mali with S. punctum or O. insidiosus on the European red mite, P. ulmi, was evaluated in the laboratory. At a mite density of 45/arena, L. mali with S. punctum killed significantly more P. ulmi than L. mali or S. punctum alone. No difference was observed in total mites killed when the combination of L. mali or O. insidiosus was compared with individual L. mali and O. insidiosus. In 75% of replicates where L. mali was combined with O. insidiosus, the latter killed and consumed the thrips.

A simple, non-destructive, but inefficient visual sampling method for L. mali on apple foliage was compared to a destructive, time-consuming, efficient limb-tap sampling technique. Regression analysis of the numbers of L. mali limb-tapped from the searched area versus those observed in a visual search yielded significant R square values in 1977 for the cultivars Rome (0.67) and Winesap (0.84) and in 1978 for Golden Delicious (0.76). With these comparisons the usefulness of the visual sampling method was improved, thus increasing the potential of this sampling technique.

LITERATURE CITED

- Adkisson, P. L. 1971. Objective uses of insecticides in agriculture. P. 43-51 in J. E. Swift (ed.) Agricultural chemicals-harmony or discord for food, people, environment. Proc. Sym. Univ. Calif. Div. Agric. Sci., Sacramento, Calif. 151 pp. (cited in Metcalf, R. L. 1980. Changing role of insecticides in crop protection. Ann. Rev. Entomol. 25:219-256)
- Ananthakrishnan, T. N. 1976. The distribution and host ranges of predatory thrips. Ind. J. Plant Prot. 4:67-78.
- _____. 1979. Biosystematics of Thysanoptera. Ann. Rev. Entomol. 24:159-183.
- Asquith, D. and R. Colburn. 1971. Integrated pest management in Pennsylvania apple orchards. Bull. Entomol. Soc. Am. 17:89-91.
- Atival, A. S. and S. L. Sethi. 1963. Predation by Coccinella septempunctata L. on the cabbage aphid, Liphaphis erysimi (Kalt.) in India. J. Anim. Ecol. 32:481-488.
- Bailey, S. F. 1939. The six-spotted thrips, Scolothrips sexmaculatus (Perg.). J. Econ. Entomol. 32:43-47.
- _____. 1940. The black hunter, Leptothrips mali (Fitch). Ibid. 33:539-544.
- Barney, R. J., S. J. Roberts, R. D. Pausch and E. J. Armbrust. 1979. Impact of prey age and temperature on predation by the eastern flower thrips, Frankliniella tritici on eggs of the alfalfa weevil. Environ. Entomol. 8:814-815.
- Barr, A. J., J. H. Goodnight, J. P. Sail and J. T. Helwig. 1976. A user's guide to SAS 76. SAS Inst. Inc., Raleigh, N. C. 329 pp.
- Bartlett, B. R. 1958. Laboratory studies on selected aphicides favoring natural enemies of the spotted alfalfa aphid. J. Econ. Entomol. 51:374-378.
- Batiste, W. C., A. Berlowitz, W. H. Olson, J. E. DeTar and J. L. Joos. 1973. Codling moth: estimated time of first egg hatch in the field - a supplement to sex-attractant traps in integrated control. Environ. Entomol. 2:387-391.
- Beddington, J. R., M. P. Hassell and J. H. Lawton. 1976. The components of arthropod predation. II. The predator rate of increase. J. Anim. Ecol. 45:165-185.

- Berryman, A. A. and L. V. Pienaar. 1974. Simulation: A powerful method of investigating the dynamics and management of insect populations. *Environ. Entomol.* 3:199-207.
- Blair, W. H., R. L. Cross, D. D. Ingold, C. P. Whitman, J. H. Goodnight, J. P. Sall, L. B. Harrell, D. M. Delong, W. S. Sarle, H. J. Kirk, M. B. Nichols, J. T. Helwig, K. A. Council, P. S. Reinhardt. 1979. SAS User's Guide, 79 Edition, SAS Inst. Inc., Raleigh, N.C. 494 pp.
- Bourmier, A., A. Lacasa and Y. Pivot. 1978. Biologie d'un thrips predateur Aeolothrips intermedius (Thys.: Aeolothripidae). *Entomophaga* 23:403-410. (in French).
- Briggs, J. B. and D. J. Avery. 1968. Effects of infestation with fruit tree red spider mite, Panonychus ulmi, on the growth and cropping of young fruit trees. *Ann. Appl. Biol.* 61:269-276.
- Cagle, L. R. 1946. Life history of the European red mite. *Va. Agric. Exp. Stn. Tech. Bull.* 87. 19 pp.
- Chant, D. A. 1961. The effect of prey density on prey consumption and oviposition in adults of Typhlodromus (T.) occidentalis Nesbitt (Acarina: Phytoseiidae) in the laboratory. *Can. J. Zool.* 39:311-315.
- Childers, C. C. and W. R. Enns. 1975. Predaceous arthropods associated with spider mites in Missouri apple orchards. *J. Kansas Entomol. Soc.* 48:453-471.
- Clancy, D. W. and H. J. McAlister. 1956. Effects of spray practices on apple mites and their predators in West Virginia. *Proc. Tenth Intern. Congr. Entomol.* 4:597-610 (1958).
- Clancy, D. W. and H. N. Pollard. 1948. Effect of DDT on several apple pests and their natural enemies. *J. Econ. Entomol.* 41:507-508.
- _____. 1952. The effect on DDT on mite and predator populations in apple orchards. *Ibid.* 45:108-114.
- Colburn, R. and D. Asquith. 1971. Observations on the morphology and biology of the ladybird beetle, Stethorus punctum. *Ann. Entomol. Soc. Am.* 64:1217-21.
- Cott, H. E. 1956. Systematics of the suborder Tubilifera (Thysanoptera) in California. *Univ. of Calif. Pub. in Entomol.* Vol. 13. Univ. of Calif. Press, Berkeley and Los Angeles. 216 pp.

- Coulson, J. R. 1977. Biological control of alligatorweed. 1959-1972. A review and evaluation. USDA, ARS, Tech. Bull. No. 1547. 98 pp.
- Coville, P. L. and W. W. Allen. 1976. Life table and feeding habits of Scolothrips sexmaculatus (Thysanoptera: Thripidae). Ann. Entomol. Soc. Am. 70:11-16.
- Croft, B. A. 1975a. Tree fruit pest management. P. 471-506. In R. L. Metcalf and W. H. Luckman (eds.) Introduction to insect pest management. John Wiley and Sons, N. Y. 587 pp.
- _____. 1975b. Integrated control of apple mites. Coop. Ext. Serv., Michigan State Univ., Ext. Bull. E-825, 12 pp.
- Croft, B. A. and S. A. Hoying. 1977. Competitive displacement of Panonychus ulmi (Acarina: Tetranychidae) by Aculus schlechtendali (Acarina: Eriophyidae) in apple orchards. Can. Entomol. 109:1025-1034.
- Davies, R. G. 1969. The skeletal musculature and its metamorphosis in Limothrips cerealium Haliday (Thysanoptera: Thripidae). Trans. R. Entomol. Soc. Lond. 121:167-233.
- de Gryse, J. J. and R. C. Treherne. 1924. The male genital armature of the Thysanoptera. Can. Entomol. 56:177-182.
- Dempster, J. P. 1975. Animal population ecology. Academic Press, New York. 155 pp.
- Dover, M. J., B. A. Croft, S. M. Welch and R. L. Tummala. 1979. Biological control of Panonychus ulmi (Acarina: Tetranychidae) by Amblyseius fallacis (Acarina: Phytoseiidae) on apple: a predator-prey model. Environ. Entomol. 8:282-292.
- Dowell, R. F. and G. E. Fitzpatrick. 1978. Effects of temperature on the growth and survivorship of the citrus blackfly (Homoptera: Aleyrodidae). Can. Entomol. 110:1347-1350.
- Everson, P. 1980. The relative activity and functional response of Phytoseiulus persimilis (Acarina: Phytoseiidae) and Tetranychus urticae (Acarina: Tetranychidae): the effect of temperature. Can. Entomol. 112:17-24.
- Fernald, C. H. 1892. Report on insects. Hatch Exp. Stn., Mass Agric. Coll. Bull. No. 19:102-143.
- Fitch, A. 1855. Entomological survey. Insects infesting fruit trees. Trans. N. Y. State Agric. Soc. Vol. 14 (1854) pp. 700-881.

- Gilstrap, F. E. and E. R. Oatman. 1976. The bionomics of Scolothrips sexmaculatus (pergande) (Thysanoptera: Thripidae) an insect predator of spider mites. *Hilgardia* 44:27-59.
- Glass, N. R. 1970. A comparison of two models of the functional response with emphasis on parameter estimation procedures. *Can. Entomol.* 102:1094-1101.
- Hamilton, W. D. 1967. Extraordinary sex ratios. *Science* 156:447-488.
- Hassell, M. P. 1966. Evaluation of parasite or predator responses. *J. Anim. Ecol.* 35:65-75.
- _____. 1975. Density dependence in single species populations. *Ibid.* 44:283-295.
- _____. 1978. The dynamics of arthropod predator-prey systems. *Monographs in Population Biol.* 13. Princeton Univ. Pewaa, Princeton, N. J. 237 pp.
- Hassell, M. P. and R. M. May. 1973. Stability in insect host parasite models. *J. Anim. Ecol.* 42:693-736.
- Hassell, M. P., J. H. Lawton and J. R. Beddington. 1976. The components of arthropod predation. I. The prey death rate. *J. Anim. Ecol.* 45:135-164.
- _____. 1977. Sigmoid functional responses in invertebrate predators and parasitoids. *Ibid.* 46:249-262.
- Healy, M. J. R. 1952. A table of Abbott's correction for natural mortality. *Ann. Appl. Biol.* 39:211-12.
- Heming, B. S. 1969. A modified technique for mounting Thysanoptera in Canada balsam. *Entomol. News* 80:323-328.
- _____. 1970. Postembryonic development of the male reproductive system in Frankliniella fusca (Thripidae) and Haplothrips verbasci (Phlaeothripidae) (Thysanoptera). *Misc. Pub. Entomol. Soc. Am.* 7:237-272.
- _____. 1971. Functional morphology of the thysanopteran pretarsus. *Can. J. Zool.* 49:91-108.
- _____. 1978. Structure and function of the mouthparts in larvae of Haplothrips verbasci (Osborn) (Thysanoptera, Tubilifera, Phlaeothripidae). *J. Morph.* 156:1-20.

- Henderson, C. F. and H. V. McBurnie. 1943. Sampling technique for determining populations of the citrus red mite and its predators. USDA Circ. 671:1-11.
- Hill, C. J. and L. J. Cobb. 1979. Apple, timed leafroller treatments. Proc. 55th Cumberland Shenandoah Fruit Workers Conf. No. 43. 5 p.
- Hinds, W. E. 1902. Contribution to a monograph of the insects of the order Thysanoptera inhabiting North America. Proc. U. S. Nat. Mus. 26:79-242.
- Holdsworth, R. P., Jr. 1968. Integrated control: effect on European red mite and its more important predators. J. Econ. Entomol. 61:1602-1607.
- Holdsworth R. P. 1972a. European red mite and its major predators: effects of sulphur. Ibid. 65:1098-1099.
- _____. 1972b. Major predators of the European red mite on apple in Ohio. Ohio Res. Circ. 192, OARDC, Wooster, 18 pp.
- Holling, C. S. 1959a. The components of predation as revealed by a study of small mammal predation of the European pine sawfly. Can. Entomol. 91:293-320.
- _____. 1959b. Some characteristics of simple types of predation and parasitism. Can. Entomol. 91:385-398.
- _____. 1961. Principles of insect predation. Ann. Rev. Entomol. 6:163-182.
- _____. 1965. The functional response of predators to prey density and its role in mimicry and population regulation. Mem. Entomol. Soc. Can. 45:3-60.
- _____. 1966. The functional response of invertebrate predators to prey density. Mem. Entomol. Soc. Can. 48: 1-86.
- Hood, J. D. 1909. A new genus and a new species of North American Phloeothripidae (Thysanoptera). Entomol. News 20:249-250.
- _____. 1914. Studies in Tubiliferous Thysanoptera. Proc. Biol. Soc. Wash. 27:162-164.
- _____. 1917. An annotated list of the Thysanoptera of Plummers Island, Md. Insecutor Inscitiae Menstruus Nos. 4-6:53-65.
- _____. 1927. On the synonymy of some Thysanoptera occurring in California. Pan-Pacific Entomol. 3:173-178.

- Horsburgh, R. L. 1977. Integrated pest management for apples, 1977. Ext. Div. VPI and SU, Blacksburg, Va. 14 pp.
- _____. 1979. Reduced pesticide and integrated pest management program for apples. Publ. 830, Ext. Div. VPI and SU, Blacksburg, Va. 15 pp.
- Horsburgh, R. L. and D. Asquith. 1968. Initial survey of arthropod predators of the European red mite in south-central Pennsylvania. J. Econ. Entomol. 61:1752-1754.
- Hoyt, C. C. and L. E. Caltagirone. 1971. The developing programs of integrated control of pests of apples in Washington and peaches in California. P. 395-421. In C. B. Huffaker (ed.) Biological Control, Plenum Press, N. Y. 511 pp.
- Hull, L. A. 1979. Reduced pesticide and integrated pest management program for apples. P. 51-62. In 1979 Tree Fruit Production Guide, Penn. State Univ. CES, Univ. Park, Pa. 94 pp.
- Hull, L. A., D. Asquith and P. D. Mowery. 1977a. The functional responses of Stethorus punctum to densities of the European red mite. Environ. Entomol. 6:85-90.
- _____. 1977b. The mite searching ability of Stethorus punctum within an apple orchard. Ibid. 6:684-688.
- Jaynes, H. A. and P. E. Marucci. 1947. Effect of artificial control practices on the parasites and predators of the codling moth. J. Econ. Entomol. 40:9-26.
- Jeppson, L. R., J. A. McMurtry, D. W. Mead, M. J. Jesser and H. G. Johnson. 1975. Toxicity of citrus pesticides to some predaceous phytoseiid mites. Ibid. 68:707-710.
- Knisely, C. B. and F. C. Swift. 1972. Qualitative study of mite fauna associated with apple foliage in New Jersey. Ibid. 65:445-448.
- Laing, J. E. and C. B. Huffaker. 1969. Comparative studies of predation by Phytoseiulus persimilis Athias-Henriot and Metaseiulus occidentalis (Nesbitt) (Acarina:Tetranychidae). Res. Pop. Ecol. 11:105-126.
- Laing, J. E. and J. A. L. Osborn. 1974. The effect of prey density on the functional and numerical responses of 3 species of predatory mites. Entomophaga 19:267-77.
- Lewis, F. H. and K. D. Hickey. 1967. Methods of using large airblast sprayers on apples. Pa. Fruit News 46:47-53.

- Lewis, T. 1973. Thrips. Their biology, ecology and economic importance. Academic Press, London and N. Y. 349 pp.
- Lingren, P. D. and R. L. Ridgway. 1967. Toxicity of five insecticides to several insect predators. J. Econ. Entomol. 60:1639-1641.
- Livdahl, T. P. 1979. Evolution of handling time: the functional response of a predator to the density of sympatric and allopatric strains of prey. Evolution 33:765-768.
- Loan, C. and F. G. Holdaway. 1955. Biology of the red clover thrips, Haplothrips niger (Osborn) (Thysanoptera:Phloeothripidae). Can. Entomol. 87:210-219.
- Lord, F. T. 1949. The influence of spray programs on the fauna of apple orchards in Nova Scotia. III. Mites and their predators. Ibid. 81:202-214, 217-230.
- _____. 1956. The influence of spray programs on the fauna of apple orchards in Nova Scotia. IX. Studies of means of altering predator populations. Ibid. 88:129-137.
- Luckman, W. H. and R. L. Metcalf. 1975. The pest-management concept. P. 3-35. In R. L. Metcalf and W. H. Luckman (eds.) Introduction to insect pest management. John Wiley and Sons, N. Y. 587 pp.
- MacPhee, A. W. 1953. The influence of spray programs on the fauna of apple orchards in Nova Scotia. V. The predaceous thrips Haplothrips faurei Hood. Can. Entomol. 85:33-40.
- MacPhee, A. W. and K. H. Sanford. 1954. The influence of spray programs on the fauna of apple orchards in Nova Scotia. VII. Effects on some beneficial arthropods. Ibid. 86:128-135.
- _____. 1956. The influence of spray programs on the fauna of apple orchards in Nova Scotia. X. Supplement to VII. Effects on some beneficial arthropods. Ibid. 88:631-634.
- _____. 1961. The influence of spray programs on the fauna of apple orchards in Nova Scotia. XII. Second supplement to VII. Effects on beneficial arthropods. Ibid. 93:671-673.
- Madsen, H. F. and K. Williams. 1968. Effectiveness and persistence of low dosages of azinphos methyl for control of codling moth. J. Econ. Entomol. 61:878-879.

- Macquardt, D. W. 1963. An algorithm for least squares estimation of nonlinear parameters. *J. Soc. Indust. Appl. Math.* 11:431-441.
- Marsham, T. 1796. Observations on the insects that infested corn in the year 1795. *Trans. Linn. Soc. Lond.* 3:242-251.
- McCaffrey, J. P. 1978. Spiders associated with apple trees in Virginia with notes on their importance in controlling orchard insect pests. M. S. Thesis. Virginia Polytechnic Institute and State University. 108 pp.
- McCaffrey, J. P. and R. L. Horsburgh. 1980a. Relative toxicity of orchard pesticides to Orius insidiosus (Say). *Insect. Acaricide Tests, Entomol. Soc. Am.* (In press).
- _____. 1980b. The spider fauna of apple trees in central Virginia. *Environ. Entomol.* (In press).
- McMurtry, J. A., C. B. Huffaker and M. van de Vrie. 1970. Ecology of tetranychid mites and their natural enemies: a review. I. Tetranychid enemies: their biological characters and the impact of spray practices. *Hilgardia* 40:331-390.
- Metcalf, R. L. 1980. Changing role of insecticides in crop protection. *Ann. Rev. Entomol.* 25:219-256.
- Meyer, R. H. 1974. Management of phytophagous and predatory mites in Illinois. *Environ. Entomol.* 3:333-340.
- Mori, H. and D. A. Chant. 1966. The influence of prey density, relative humidity and starvation on the predaceous behavior of Phytoseiulus persimilis Athias-Henriot (Acarina:Phytoseiidae). *Can. J. Zool.* 44:483-491.
- Mound, L. A. 1971. The feeding apparatus of thrips. *Bull. Entomol. Res.* 60:547-548.
- Mound, L. A. and K. O'Neill. 1974. Taxonomy of the Merothripidae with ecological and phylogenetic consideration. *J. Nat. Hist.* 8:481-509.
- Mowery, P. D., D. Asquith and W. M. Bode. 1975. Computer simulation for predicting the number of Stethorus punctum needed to control the European red mite in Pennsylvania apple trees. *J. Econ. Entomol.* 68:250-54.
- Murdoch, W. W. 1969. Switching in general predators: experiments on predator specificity and stability of prey population. *Ecol. Monogr.* 39:335-354.

- Murdoch, W. W. 1972. The functional response of predators. Quantitative evaluation of natural enemy effectiveness. 14th Intern. Congr. Entomol. 335-341.
- Murdoch, W. W. and R. J. Marks. 1973. Predation by coccinellid beetles: experiments on switching. Ecology. 54:160-167.
- Murdoch, W. W. and A. Oaten. 1975. Predation and population stability. Adv. Ecol. Res. 9:1-131.
- Newsome, L. D. 1978. Progress in integrated pest management of soybean pests. P. 157-179. In R. F. Smith and D. Pimentel (eds.), Pest control strategies. Academic Press, N. Y. 344 pp.
- Parent, B. 1967. Population studies of phytophagous mites and predators on apple in southwestern Quebec. Can. Entomol. 99:771-778.
- Parent, B. J. P. H. 1973. Natural population densities of the European red mite on apple in Quebec. Environ. Entomol. 2: 1064-1068.
- Parrella, M. P. and R. L. Horsburgh. 1978. Laboratory rearing of Leptothrips mali (Fitch). J. N. Y. Entomol. Soc. 86:312-13. (Abstract).
-
- _____. 1979. Biology of Leptothrips mali (Fitch) (Thysanoptera:Phlaeothripidae): a predator of orchard mites. Ibid. (In press) (Abstract).
- Parrella, M. P., J. P. McCaffrey and R. L. Horsburgh. 1978. Population dynamics of some predators and their prey in Virginia apple orchards. Va. J. Sci. 29:44. (Abstract).
-
- _____. 1980. Compatibility of Leptothrips mali with Stethorus punctum and Orius insidiosus: predators of Panonychus ulmi. Environ. Entomol.. (In press).
- Pickett, A. D. 1949. A critique on insect chemical control methods. Can. Entomol. 81:67-76.
- Pimentel, D., E. C. Terhune, W. Dritschilo, D. Gallahan, N. Kinner, D. Nafus, R. Peterson, N. Zareh, J. Mitsiti and O. Haber-Schaim. 1977. Pesticides, insects in foods, and cosmetic standards. BioSci. 27:178-185.
- Pitkin, B. R. 1978. Lectotype designations of certain species of thrips described by J. D. Hood and notes on his collection (Thysanoptera). Proc. Entomol. Soc. Wash. 80:264-295.

- Pittman, H. A. 1927. Spotted wilt of tomatoes. Preliminary note concerning the transmission of the "spotted wilt" of tomatoes by an insect vector (Thrips tabaci (Lind.)). J. Coun. Scient. Ind. Res. Aust. 1:74-77.
- Poole, R. W. 1974. An introduction to quantitative ecology. McGraw-Hill, Inc. 532 pp.
- Priesner, H. 1964. A monograph of Thysanoptera of the Egyptian deserts. Pub. Inst. Deserte Egypte 13. 549 pp.
- Putman, W. L. 1942. Notes on the predaceous thrips Haplothrips subtilissimus Hal. and Aeolothrips melaleucus Hal. Can. Entomol. 74:37-43.
- _____. 1965. The predaceous thrips, Haplothrips faurei Hood, in Ontario peach orchards. Ibid. 97:1208-21.
- Real, L. A. 1979. Ecological determinants of functional response. Ecology 60:481-485.
- Reynolds, H. T., P. L. Adkisson and R. F. Smith. 1975. Cotton insect pest management. P. 379-443. In R. L. Metcalf and W. H. Luckman (eds.) Introduction to insect pest management. John Wiley and Sons, N. Y. 587 pp.
- Reidl, H., B. A. Croft and H. J. Howitt. 1976. Forecasting codling moth phenology based on pheromone trap catches and physiological time models. Can. Entomol. 108:449-460.
- Ripper, W. E. 1956. Effect of pesticides on balance of arthropod populations. Ann. Rev. Entomol. 1:403-408.
- Rock, G. C. 1972. Integrated control of mites. Agric. Ext. Serv. Fruit Insect Note A-1, N. C. State Univ. Publ. 18 pp.
- Rogers, D. J. 1972. Random search and insect population models. J. Anim. Ecol. 41:369-383.
- Royama, T. 1971. A comparative study of models for predation and parasitism. Res. Pop. Ecol. Suppl. 1:1-91.
- Sandness, J. N. and J. A. McMurtry. 1970. Functional response of three species of phytoseiidae (Acarina) to prey density. Can. Entomol. 102:692-704.
- Santos, M. 1976a. Evaluation of Zetzellia mali as a predator of Panonychus ulmi and Aculus schlechtendali. Environ. Entomol. 5:187-191.

- Santos, M. 1976b. Prey selectivity and switching response of Zetzellia mali. Ecology 57:390-394.
- Shaw, H. B. 1914. Thrips as pollinators of beet flowers. USDA Bull. 104:112.
- Simmonds, H. W. 1933. The biological control of the weed Clidemia hirta, D. Don., in Fiji. Bull. Entomol. Res. 24:345-348.
- Sokal, R. R. and F. J. Rohlf. 1969. Biometry. The principles and practice of statistics in biological research. W. H. Freeman and Co., San Francisco. 776 pp.
- Solomon, M. E. 1949. The natural control of animal populations. J. Anim. Ecol. 18:1-35.
- Stannard, L. J. 1957. The phylogeny and classification of the North American genera of the suborder Tubilifera. Ill. Biol. Monogr. 25. 200 pp.
- _____. 1968. The thrips of Thysanoptera of Illinois. Ill. Nat. Hist. Surv. Bull. 29. 552 pp.
- Stern, V. M., R. F. Smith, R. Van den Bosch and K. S. Hagen. 1959. The integration of chemical and biological control of the spotted alfalfa aphid. Hilgardia 29:811-54.
- Stern, V. M., R. Van den Bosch and H. T. Reynolds. 1960. Effects of Dylox and other insecticides on entomophagous insects attacking field crop pests in California. J. Econ. Entomol. 53:67-72.
- Tamaki, G., J. U. McGuire and J. E. Turner. 1974. Predator power and efficacy: a model to evaluate their impact. Environ. Entomol. 3:625-630.
- Tamaki, G. and G. E. Long. 1978. Predator complex of the green peach aphid on sugarbeets: expansion of the predator power and efficacy model. Environ. Entomol. 7:835-842.
- Tette, J. P., E. H. Glass, D. Bruno and D. Way. 1979. New York tree fruit pest management project 1973-1978. N. Y. Food and Life Sci. Bull. 81. 10 pp.
- Thomas, J. H. 1976. Biology and control of a leafroller, Platynota flavedana Clemens (Lepidoptera: Tortricidae) in Virginia apple orchards. M. S. Thesis, Virginia Polytechnic Institute and State University. 103 pp.
- _____. 1979. An evaluation of Bacillus thuringiensis for leafroller control in Virginia apple orchards. Ph.D. Dissertation, Virginia Polytechnic Institute and State University. 94 pp.

- Thomas, H. A., H. B. Specht and B. F. Driggers. 1959. Arthropod fauna found during the first season trial of a selective spray schedule in a New Jersey apple orchard. *J. Econ. Entomol.* 52: 819-821.
- Vance, T. C. 1974. Larvae of the Sericothripini (Thysanoptera: Thripidae), with reference to other larvae of the Terebrantia, of Illinois. *Ill. Nat. His. Sur. Bull.* 31. 208 pp.
- Van den Bosch, R., H. T. Reynolds and J. E. Dietrick. 1956. Toxicity of widely used insecticides to beneficial insects in California cotton and alfalfa fields. *J. Econ. Entomol.* 49:359-363.
- Van den Bosch, R. and V. M. Stern. 1962. The integration of chemical and biological control in arthropod pests. *Ann. Rev. Entomol.* 7:367-386.
- Walsh, B. D. 1864. On the insects, coleopterous, hymenopterous and dipterous inhabiting the galls of certain species of willow. *Proc. Entomol. Soc. Phila.* 2:19.
- Watson, J. R. 1918. Thysanoptera of Florida. *Fla. Buggist* 2:53-55, 65-77.
- _____. 1923. Synopsis and catalog of the Thysanoptera of North America. *Univ. Fla. Ext. Stn. Bull.* 168. 100 pp.

VITA

The author was born the son of Rocco and Anne Parrella on December 1, 1951, in Elizabeth, N. J. He attended grammar and junior high school in Rahway, N. J. and entered Roselle Catholic High School, Roselle, N. J. in 1966. Upon graduation in 1970 he entered Cook College, Rutgers University, New Brunswick, N. J., as an Animal Science major. He was employed by the Entomology Department of Cook College during his Junior year as a Research Technician working with biting flies on the New Jersey salt marsh. He graduated with a B.S. in Animal Science in 1974, and began working as a Graduate Research Assistant at VPI and SU on the laboratory propagation and field evaluation of two exotic weevils imported for thistle (Carduus) control. Research towards a Master's Degree in Entomology was started in September, 1974. The M.S. involved the evaluation of two Lepidoptera as potential biological control agents of bindweed (Convolvulus). He was awarded the M.S. Degree in Entomology in June, 1977 and immediately began work towards the Doctoral Degree at VPI and SU. The area of research for the Ph.D was shifted to the management of apple pests and this work was conducted at the Shenandoah Valley Research Station, 100 miles north of Blacksburg. During the course of the Ph.D he accepted the only full time teaching assistantship offered by the Entomology Department, and subsequently directed a number of courses from 1977-79. In 1978 he was awarded the Virginia State Pesticide Association Education Scholarship and in 1979 the Outstanding Graduate Student Award from the Eastern Branch of the Entomological Society of America.

Michael Parrella

LEPTOTHRIPS MALI (FITCH): A POTENTIALLY
IMPORTANT PREDATOR IN VIRGINIA APPLE ORCHARDS

by

Michael Peter Parrella

(ABSTRACT)

Population dynamics of selected pests (Panonychus ulmi, Aculus schlechtendali, Aphis citricola, Dysaphis plantaginea spp.) in Virginia apple orchards and predators (Leptothrips mali, Haplothrips subtilissimus, Orius insidiosus, Stethorus punctum, Dereacoris nebulosus, Chrysopa spp.) were monitored during 1977-78 under 3 reduced pesticide programs. The pesticide program with phosalone and Dikar^R as its principal components allowed the largest number of predators to remain in the orchard and controlled most pests. L. mali and H. subtilissimus were the most abundant predators and appeared to respond numerically to densities of A. schlechtendali. O. insidiosus and D. nebulosus usually increased late in the season and S. punctum responded to densities of P. ulmi inconsistently but together with thrips may have had an important role in reducing P. ulmi populations. Chrysopa spp. remained at consistently low levels throughout the study.

Laboratory studies indicated that phosalone and Dikar were the least toxic to L. mali among the pesticides tested. Benomyl can probably be substituted for Dikar in order to lessen mortality of A. schlechtendali in the field.

L. mali was studied in the laboratory to determine aspects of its development, biology and prey relationships. Mean development time

(days) for each stage at 23.9°C was: egg, 7.5; 1st larva, 5.7; 2nd larva, 5.4; prepupa, 1.0; pupa I, 1.5; pupa II, 4.0 and total (egg-adult), 25.6. The preoviposition period ranged 5-7 days and the mean no. eggs/lab-reared (LR) and field collected (FC) females were: mated - LR, 13.0; FC, 28.0 and unmated - LR, 11.7; FC, 45.1. Mean longevity (days) of unmated females (LR, 50.1 and FC, 54.2, respectively) was greater than that for males and mated females. L. mali completed development on Golden Delicious apple pollen in 23 days (1st stage larva - adult). This thrips fed on the following orchard pests: A. schlechtendali, Tetranychus urticae, Lecanium corni, and on the eggs of Laspeyresia pomonella and Platynota flavedana. No feeding was observed on S. punctum, but L. mali fed on the phytoseiid mite, Proprioseius oudemansi.

The functional response of all feeding stages of L. mali to densities of P. ulmi was determined at 18.3, 23.9, and 29.4°C and the numerical response of adult female L. mali to this mite species was investigated. The greatest effect of temperature on the functional response curve was observed with field collected adult female L. mali. The numerical response of L. mali reached a maximum of 0.70 eggs/female/48 h.

The individual or joint potential impact of L. mali with S. punctum or O. insidiosus on P. ulmi was evaluated in the laboratory. At a mite density of 45/arena, L. mali with S. punctum killed significantly more P. ulmi than L. mali or S. punctum alone. In 75% of the replicates where L. mali was combined with O. insidiosus, the latter killed and consumed the thrips.

A simple, non-destructive, but inefficient visual sampling method for L. mali on apple foliage was compared to a destructive, time-consuming, efficient limb-tapping sampling technique. With this comparison the usefulness of the visual sampling method was improved, thus increasing the potential of this sampling technique.