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POPULATION DYNAMICS OF THE ONION THRIPS, THRIPS TABACI LIND., ON ONIONS

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POPULATION DYNAMICS OF THE ONION THRIPS, *THRIPS TABACI* LIND., ON ONIONS

By

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ABSTRACT

POPULATION DYNAMICS OF THE ONION THRIPS,
THRIPS TABACI ON ONION

By

Solomon Quatekwei Quartey

Onion thrips, *Thrips tabaci* Lindeman, a cosmopolitan species, is a major pest of onions in Michigan. The objectives were to obtain more detailed information on the ecology and biology of the thrips in a near pristine environment, identify and understand the factors affecting field population densities and to understand the pest-crop interaction and the role of the onion thrips in the onion agro-ecosystem.

Adult thrips colonized the onions when the latter were 3-5 weeks old. The thrips distribution was random at the beginning of the season, but became clumped later. The population rose exponentially and peaked at or soon before harvest. Infestations reached as high as 121 thrips/plant. Adults and second instar thrips fed on onion leaf tissue at the rate of 4.93 and 4.51 $mm^2 \times thrips^{-1} \times day^{-1}$, respectively. The lower temperature developmental threshold was established as 7.4°C. At high densities, thrips killed young onion plants, but no loss in bulb weight occurred if feeding occurred in the late season.

Heavy rainfall was a major mortality factor. Coccinellids were the most abundant natural enemies. Although the coccinellid *Coleomegilla maculata* DeGeer consumed 3-400 thrips per day in the laboratory, the temporal and spatial

occurrence of this predator and the thrips were not properly synchronized in the field. Adult C. maculata density peaked in early season and before the prey. The coccinellids stayed in grasses and cereals and showed a bimodal diel flight into the onion field to feed. By manipulating the environment, this predator can be made more effective.

The results of this study provide pertinent information for developing pest management strategies for onion thrips in the onion agro-ecosystem.

To my parents, Emmanuel and Mary, my wife, Ama, and children, Nii Kwate, Naa Kwale and Nana Ama Aboagyawa Kwakor.

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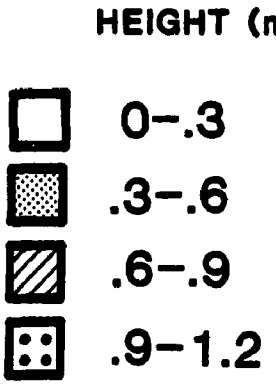


ACTUAL NUMBERS TRAPPED ARE SHOWN

1. INTRODUCTION

The onion thrips, Thrips tabaci Lindeman, is cosmopolitan; it occurrs in almost every part of the world, in temperate, tropical and subtropical areas, and at altitudes ranging from sea level to 2,000 m (Lewis, 1973). It is polyphagous and is reported as a pest of many crops (Lewis, 1973; Stannard, 1968; Metcalf et al, 1962). Its origin is not known for certain. However, through the study of the mode of reprodution and the sex ratio in different parts of the world, O'Neill (1960) and Mound (1973) concluded that it originated from the eastern Mediterranean.

Damage done by the onion thrips to onions, cotton and other crops makes it economically important (Sakimura, 1932; Harris et al, 1936; Richardson, 1957; Metcalf et al, 1962; Abdel-Gawaad and Shazli, 1970; etc.), and hence there is an accumulation of literature on this insect. However, most of these works have been directed towards the use of insecticides for control and not much information on the detailed biology and ecology is available. Where the biology and ecology have been treated, they lack important information needed for an onion pest management program.

In Michigan, onions are grown on 7,500 acres and the crop is worth over $18.5 million (Anon., 1981). The crop is attacked by a complex of diseases and insect which separately and together affect the growth and yield of the crop. As a first phase in designing a pest management program, it is necessary to understand how each pest component

interacts with and affects the crop. Having obtained this information, it then becomes pertinent to put together all the pieces into one whole that will simulate the real world situation. On its own, however, the onion thrips are estimated to cause an annual yield loss of 11% in Texas (Richardson, 1953). Being parthenogenetic and with a life cycle of under 20 days, onion thrips are capable of developing very high population densities in a short period when the weather is favorable, leading to severe crop losses.

The choice of this topic for the dissertation research afforded me the chance to work on an insect pest that is also a problem of my home country of Ghana, West Africa. In Ghana, onion and shallots form an important part of the agri-business in the north-eastern and south-eastern regions, respectively. Thrips tabaci have been reported to be an important pest of these crops, particularly in the Keta (south-eastern) region (Halteren, 1970). An understanding of the biology and ecology would be a useful basis in designing management programs, even though the environmental conditions in Ghana are different.

The aim of this study was to obtain information on the biology and ecology of the onion thrips, to identify and understand the factors that are responsible for changes in the field populations, to understand the pest-crop interaction and the role of the onion thrips in the onion agro-ecosystem. Information from these studies will hopefully form the basis for developing a management program of onion thrips in an ecologically compatible and economically feasible onion pest management system.

2. REVIEW OF RELEVANT LITERATURE

The taxonomy of the onion thrips, Thrips tabaci Lindeman (1888) (Thysanoptera: Thripidae), has been changed many times, but all previous names have been synonymized by Priesner (1925). Stannard (1968) revised the taxonomy of the order Thysanoptera and provided keys to identifying the various species that occur in Illinois. Thrips tabaci has been referred to by the following common names: onion or potato thrips (Lewis, 1973), and the tobacco thrips (Federov, 1930), but onion thrips is the most popular in the literature.

2.1 Economic Impact of Onion Thrips

Thrips tabaci is polyphagous (Lewis, 1973; Stannard, 1968; Metcalf et al, 1962), the latter stating that it attacks nearly all garden plants, including cauliflower, bean, melons, tomato, cucumber, and also many weeds and some field crops. The onion thrips is a pest of many crops, the most important being onion (Harding, 1961; Lall and Singh, 1968; Richardson, 1953), cotton (El-Saadany et al, 1975; Shoeib and Hosny, 1973; Hosny, 1964) and tobacco (Tutel, 1963; Federov, 1930). The preferred host plant is onion (Stannard, 1968).

Reports of the effect of onion thrips on onion yields are very conflicting and seem to indicate that there is a host of other factors involved in the yield obtained. These factors include onion varieties, cultural practices, soil types and environmental conditions. Horsfall (1921) reported 75% yield reduction compared to previous years

that had practically no thrips infestation. The loss was directly attributed to onion thrips since surrounding fields which had no thrips produced 400 bushels/acre compared to 60 bushels/acre for the thrips infested field. Maughan (1933, 1934), Hibbs and Ewart (1946) and Sleesman (1946) all showed increased onion yield by suppressing thrips infestations with insecticides. Richardson (1953, 1954) reported 11% and 21% yield reduction respectively when comparing the best yield from insecticide-treated plots with untreated plots. Wilcox and Howland (1948) reported yield increases from thrips control, but not in every test as reported by the preceeding authors. Sleesman (1943) and Douglas and Shirck (1949) showed little yield differences using thrips-resistant varieties. Harding (1961) used a Parathion and Dieldrin mixture and obtained drastically reduced levels of thrips infestation, but yields were not significantly different: the best insecticide treated plants averaged about 3 thrips/plant over the entire season compared to 80 thrips/plant for the untreated plants. Shirck and Douglas (1956) showed that onion thrips did not reduce yield unless the population was very high, particularly if the severe infestations occurred early during the growing season. There is no information in the literature on the economic threshold and what thrips numbers mean in terms of their quantitative effects on onion plant growth and yield, although high numbers will kill young plants.

Apart from feeding on and interfering with the normal physiological functioning of the leaves, Thrips tabaci have also been reported to cause sterility in onions (Pearson, 1930). They have been reported to be vectors of the tomato spotted wilt virus (Sakimura, 1963), but there is no report of their serving as vectors of any disease in onions. The wounds created by its feeding could become secondarily infected.

2.2 Sex Ratios and Reproductive Biology

The field populations of most species of thrips are bisexual but often the females predominate and in some species the males are rare or reproduction is wholly parthenogenetic (Lewis, 1973). In some cosmopolitan species, the sex ratios differ in different regions. Thrips tabaci have a sex ratio of about 1:1 in the eastern Mediterranean and Iran (Mound, 1973), but in most other areas the males are rare. The sex ratio is 1:1000 females in Hawaii (Sakimura, 1932), 0:3000 in Sudan (MacGill, 1927), and no males found in Illinois (Stannard, 1968). Shull (1914) collected 2 males and 226 females in Michigan giving a sex ratio of 1:113. The reason for the vast disparity in sex ratio is not clear. In the latter case, since the 2 males were collected in September, it was concluded that the species is wholly parthenogenetic but that the appearance of males might have been caused by cooler climate conditions. Morrison (1957) also suggested that the difference in sex ratios from place-to-place may be dependent on the temperature and observed that in England,

males of Thrips tabaci were found in the fields where it was cooler but not in the artificially warm sub-tropical climate of the greenhouse where reproduction was always parthenogenetic.

O'Neill (1960) suggested a different reason for this difference in sex ratios over the range of distributions of the species. He believes that the scarcity of males, and hence parthenogenesis, is common in introduced species because the parthenogenetic forms are more easily spread than the sexual forms. Thus in the area in which the species originated, the sex ratio may be equal or close to 1:1, but males will be rare or absent in other areas.

Thrips tabaci lays its eggs indiscriminately in leaves, cotyledons, petals, sepals and glumes. The eggs are kidney-shaped and measure 0.26 x 0.12 mm (Ghabn, 1948). The eggs may be laid singly into the underlying tissue (Ghabn, 1948), or in clusters (Lall and Singh, 1968) or may sometimes be laid in rows (Lewis, 1973). The total number of eggs laid by most plant thrips range from 30 to 300 depending on the species, the individual, and the amount and quality of food available (Lewis, 1973). For some species (e.g., Thrips imaginis) the availability of protein is very critical. Practically no eggs are laid if the females are reared on a protein deficient diet (an average of 20 eggs/female when fed on stamens with anthers removed), but when this diet is supplemented with protein they lay an average of 209 eggs (Andrewartha, 1935). Loan and Holdaway (1955) reported that

although pollen is the preferred diet of Haplothrips leucanthemi the females are able to lay fertile eggs without it. There is no mention of the requirement of protein for oviposition of Thrips tabaci in the literature and the species reproduces effectively without any observable protein source. Evidence of the possible effect of food constitution on oviposition is given by Abdel-Gawaad and Shazli (1970) who reported that more eggs were laid and the duration in the various stages were shorter if onion thrips were fed on green leaves of stored onion bulbs, and on caster oil seedlings compared to a food source of stored onion bulbs, new onion bulbs or garlic bulbs. Lall and Singh (1960) also noticed a change in the developmental durations with respect to the age of the onion plant and attributed this to changes in nutritive constitution of the plant. Reported fecundity of the onion thrips ranges from 4.5 to 80 eggs per female (Table 1). It is not surprising that this range occurs since the data reported are for different host plant species. Even on the same host plant, fecundity changes with host nutrient constitution. Ghabn (1948) reported that only 73% of females that were observed laid any eggs.

Temperature probably does not affect total egg production of Thrips imaginis once the threshold for laying has been exceeded (Andrewartha, 1935), although the rate of oviposition depends on it. Lewis (1973) reported that Thrips tabaci lay more eggs at higher temperatures. The lower threshold temperature for oviposition has been determined as 8.5^{o}C for

Table 1. Egg production of Thrips tabaci.

Temp.°C	Average # egg/female	Range	Host	Reference
18-33	4.5	2-22	cotton	Ghabn (1948)
---	14.5	?-46	cotton	Eddy & Clarke (1930)
29	37.4	0-109	Emelia sagittata	Sakimura (1932)
18	80	---	Onion?	Sakimura (1937)
---	28.7±3.2	13-54	cotton	Abdel-Gawaad & Shazli (1971)
15.8	49.8	---	Onion	Lall & Singh (1968)
18.0	51.7	---	Onion	Lall & Singh (1968)
23.4	55.0	---	Onion	Lall & Singh (1968)
30.8	28.2	---	Onion	Lall & Singh (1968)

Table 2. Duration of Thrips tabaci in various stages in days.

T°C	RH°	E	L_1	L_2	P_p	P	PreA	Ov.A	Post.A	Σ A	Host	Reference
-	-	4.7	2.3	2.8	1.4	3.2	3.8 (1-7)	8.6 (1-26)	2.7 (0-6)	14.5 (4-28)	Cotton	Eddy & Clarke (1930)
-	-	4.6 (2-9)	2.0 (1-4)	2.8 (1-6)	1.0 (1-4)	2.7 (1-5)	3.1 (1-5)	-	-	18.3	Cotton	Watts (1934)
25	-	6.0	6.1		1.2	2.8	-	-	-	-	Onion	Harris et al (1936)
30	-	4.0	4.2		1.0	2.0	-	-	-	19.9	Onion	Harris et al (1936)
21	-						3	50	6		Onion?	Sakimura (1937)
18-33	-	-	2.3 (1-4)		1.5 (1-2)	2.1 (1-3)	6.9	-	-	14.5 (1-30)	Cotton	Ghabn (1948)
22	65-70	4.9 ± 0.7	-	-	-	-	2.1±0.3	12.9±5.5	3.7±0.4	18.7±3.6	Cotton	Abdel-Gawaad & Shazli (1971)
30.8 Mean	47.6	4.8	5.9		1.4	2.4	-	-	-	20.2	Onion	Lall & Singh (1968)
23.4	54.4	6.0	5.5		1.7	2.8	-	-	-	20.1	Onion	ibid
18.0	61.8	7.9	6.2		2.0	3.5	-	-	-	19.6	Onion	ibid
15.8	78.5	8.5		6.5	2.0	4.0	-	-	-	18.8	Onion	ibid

E = Egg
L = Larva
P_P = Prepupa
P = Pupa

PreA = Pre-oviposition Adult
Ov.A = Ovipositing Adult
Post.A = Post-ovipositing Adult
Σ A = Sum for Adult

Thrips imaginis by Andrewartha (1935) and 12.5°C for Heliothrips haemorthoidalis by Rivnay (1935). Thrips imaginis laid similar numbers of eggs at 12.5°C, 15°C, 20°C and 23°C (Andrewartha, 1935). No threshold temperature for oviposition has been found in the literature for Thrips tabaci.

2.3 Developmental Biology

The life cycle of the onion thrips involves the following stages: egg, two larval instars, prepupa, pupa and adult. The duration of development from egg to adult is dependent on temperature but generally falls within 12-16 days.

Egg. Incubation lasts 4.8 days at 30.8°C (Lall and Singh, 1968), but ranges from 4.0-8.5 days depending on the temperature (Table 2). The rate of successful hatching is also affected by temperature. At 24°C, the hatchability of eggs is about 41%, it drops sharply at lower temperatures, and averages 38% for 18-33°C (Ghabn, 1948) (Figure 1). These data compare with 30-40% hatchability for Anaphothrips obscurus (Muell.) (Hinds, 1903).

Larvae. The two larval instars are similar in appearance and, except for the period soon after the emergence of the first instar, the use of size to distinguish the two stages is unreliable. Both instars are pale yellow in color. The main distinguishing feature in these two stages is the shape of the third antennal segment. The first instar has a short, top-shaped third antennal segment which is as long as it is wide and a pointed terminal (6th) segment. The second instar has a slender third antennal segment that is longer than

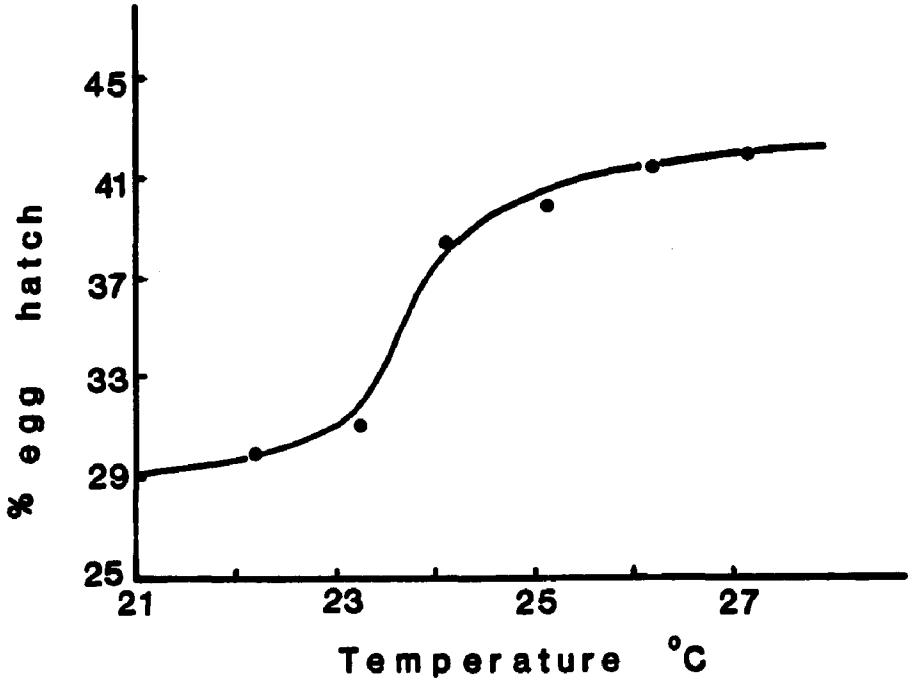


Figure 1. The relationship between egg mortality and temperature for Thrips tabaci (after Ghabn, 1948).

it is wide and a more rounded terminal segment (Ghabn, 1948). Each stage lasts between 2-3 days (Table 2). The developmental duration varies with the age of the onion plant (Lall and Singh, 1968) and with the food source (Abdel-Gawaad and Shazli, 1970). No larval developmental temperature threshold has been determined for Thrips tabaci, but Ewald and Bust (1959) reported the lower threshold temperature of 8°C for Taenothrips laricivorus Kratochvil. The mature second instar onion thrips stops feeding and migrates 3-5 cm or more into the soil (Ghabn, 1948) where it molts into the prepupa.

Prepupa and Pupa. The prepupa and the pupa are both pale yellow but can be easily distinguished from the larvae by the presence of wing buds. The prepupa has short wing buds which hardly exceed the length of the head and the prothorax together. The antennae are folded back in the head, as in the pupa, but are shorter and scarcely reach the anterior margin of the prothorax. The wing buds of the pupa are much longer than the head and thorax together. They usually extend beyond the anterior half of the abdomen. The antennae are also long and cover about half the length of the prothorax. The prepupa and the pupa last a little over 1 or 2 days, respectively (Lall and Singh, 1968) (Table 2).

Adult. The adults vary in color from pale brown when they first emerge to dark grey brown and measure 0.8 mm (segments contracted) to 1-2 mm (segments extended). Antennal segment I is light brown but the other segments are light

brown except the bases of segments III-V which are somewhat paler (Stannard, 1968). Occellar pigment is grey to yellowish grey as opposed to red pigments found in most other species. The forewings usually have 4 or more apical bristles on the fore vein instead of 3 or fewer as in other species.

The longevity of the adult has been recorded as 30 days (Shepard, 1925). Table 2 gives the mean durations reported by various authors.

2.4 Natural Enemies

Lewis (1973, Appendix 3a, 3b) recorded the parasitoids and predators of various species of thrips. The onion thrips, Thrips tabaci, is attacked by 6 different parasitoid species of which 2 are found in the U.S.A. -- Dasyscapus parvipennis Gah.(Eulophidae: Hym.) and Thripoctenus russelli Crwf. (Eulophidae: Hym.). He also listed 8 species of predators in the U.S. Sakimura (1937b) found a density dependent relationship between Thrips tabaci and Thripoctenus brui Vuil in Japan and recorded 20-80% parasitism. Saxena (1971) found another eulophid, Ceranisus sp., parasitizing the onion thrips. The females of this parasitoid select and ovipost on the second instar onion thrips and the adult parasitoid emerges from either the prepupa or the pupa.

Bourne and Shaw (1934) recorded a fungus, Entomophthora sphaerosperma Fres., attacking onion thrips in Massachusetts. Carl (1975) found another Entomophthora sp. which attacks and kills both adults and immatures in 3-6 days, but doubted if this was the same species reported in Massachusetts. Incidence

of the latter Entomophthora sp. was found to be density-dependent. It causes high host mortality but is not an effective control agent, since it does not become abundant in the field until late in the season when most of the damage has already been done by the pest.

2.5 Population Dynamics

To understand how the numbers of a particular pest species change within and between seasons, one needs to know how the initial population becomes established, how the numbers build up and change through the season, and whether there is migration during the season or at the end of the season.

Overwintering and sources of infestation. Thrips tabaci overwinter principally in the adult stage (Boyce and Miller, 1954; Ghabn, 1948). Vinson (1929) reported that this insect overwinters as pupae inside onion pulps. Ghabn (1948) also reported seeing larval onion thrips in late December and early March but noted that such larvae were found in periods preceded by warm weather and that the larvae died when the temperature fell again. Dimitrov (1975) reported that adults overwintered in the soil. This was contrary to the findings of Boyce and Miller (1954) that the adults overwintered in fields of clover and alfalfa and that grass sod bordering onion fields, onion culls and muck soils did not appear as suitable overwintering sites.

Irrespective of the stage and site of overwintering, it is the adult onion thrips that colonize available suitable plants at the onset of warm weather. The overwintered adults

start reproducing and building up their numbers on weeds and forage crops including lucerne (Banham, 1968; Boyce and Miller, 1954), alfalfa and set onions (Horsfall, 1921) and then later migrate into fields of seeded onions. Boyce and Miller (1953) reported that the initial infestation was by adults that dispersed from nearby crops and that further population increases in onions could be associated with the cutting of adjacent hay crops. Horsfall (1921) observed the spread of Thrips tabaci from an adjacent alfalfa field into seeded onion fields. The spread was initiated by cutting of the alfalfa and by prevailing winds that blew from the alfalfa to the onion field. Banham (1968) found a similar increase of thrip populations on asparagus spears following the cutting of bordering forage crops.

Developmental rates. A close relationship exists between the rate of development of insects and other animals and the temperature. This relationship has been reviewed by various authors (Crozier, 1926; Shelford, 1929; Belhradek, 1930; Uvarov, 1931; Janisch, 1932; Hoskins and Craig, 1935; Huffaker, 1944; Davidson, 1944; Fry, 1947; Wigglesworth, 1953; Andrewartha and Birch, 1954; Messenger and Flitters, 1958). The rate of development at different constant temperatures does not increase proportionately with increasing temperature throughout the range suitable for development. The rate is slower at the lower temperatures, faster in the median range and slower at the upper temperatures. This relationship is best described by a logistic curve, the equation

for which was first formulated by Pearl and Reed (1920) using the Pearl and Reed equation:

$$\frac{1}{Y} = \frac{K}{1 + e^{a-bx}}$$

where: Y = the time required for complete development of a particular stage at a given constant temperature X,

and K, a, b = constants.

When 1/Y is plotted on the ordinate against temperature, X, on the abscissa, K is the upper asymptote of the resulting velocity curve which is typically sigmoid or S-shaped. a is the parameter which indicated the relative position of the origin of the curve on the abscissa and b represents the degree of acceleration of development of the stage in relation to temperature and hence determines the slope and course of the curve. Davidson (1942) gave reasons why the data on the rate of development at temperatures above the peak should not be included in calculating the formula for the temperature-velocity curve. Commonly the reciprocal of the time required for development of each stage, 1/Y, is multiplied by 100 so it becomes 100/Y, the percent development per unit time (Davidson, 1944; Andrewartha and Birch, 1954). Davidson (1944) claims the temperature-velocity curve represents the trend of the speed of development of insects for 85-90% of the complete range of temperature at which development can occur. According to Matteson and Decker (1965) the point where the velocity line crosses, or is extrapolated to cross,

the temperature axis is theoretically the threshold of development of that particular stage. The number of day degrees it takes to complete development can be calculated using the developmental threshold temperature:

$$\text{Day degree} = \sum \left[\frac{(\text{Max.} + \text{Min.})}{2}^{\circ} - \text{threshold temperature} \right]$$

Baskerville and Emin (1969) have developed another method for calculating degree days using a modified sine curve. Day degrees is one of the simplest thermal heat units used in measuring development and gives a more useful measure of the duration of development than simple time units.

3. METHODS AND MATERIALS

3.1 Sampling Methods for Onion Thrips

The various sampling methods used by different authors to estimate relative population densities of thrips on vegetation have been discussed by Lewis (1973). The choice of a particular method depends on the sampling accuracy desired, the physical characteristics of the plant and the behavior of the thrips.

Sampling techniques that have been used in this study and also cited in the literature for the onion thrips, have been restricted to the larvae and adults only. The eggs of the onion thrips are laid embedded in the plant tissue and since the onion leaves are thick, they need to be chemically treated to see the eggs. The prepupal and pupal stages are spent in the soil and are consequently not sampled, since soil extractions could be cumbersome.

The larvae and adults of the onion thrips tend to be cryptic and usually hide in the narrow spaces between the bases of the onion leaves. They do not ordinarily crawl down deep into these spaces and hence can be easily seen when the leaves are slightly pulled apart. However, both these stages will crawl deeper down the leaf-bases if the plant is grossly disturbed. The adults may fly away with such disturbance.

3.1.1 Passive or Liquid Extraction

The type of leaf surface is particularly critical for this method since the thrips are killed by the liquid and must

be washed out. Seventy percent ethyl alcohol (Le Pelley, 1942; Ota, 1968), petrol (Bullock, 1963) or detergent (Taylor and Smith, 1955; Ota, 1968) have been used with good recovery for flat leaves, e.g., coffee and rose leaves.

This method was not found suitable in this study for the reasons given below:

1) whole onion plants need to be uprooted for the extraction,
2) during the process of uprooting the plant, adult thrips fly away,
3) alcohol-killed thrips get caught in their hiding places, and
4) the process is cumbersome, requiring one to carry cylinders of alcohol from plant to plant, and spend long periods of washing and counting the thrips.

At very high densities of thrips, however, this method was used in some parts of this study. The plants were cut immediately above the soil surface with a pair of scissors if they were not too thick, dipped in 70% alcohol and then each leaf was pulled off and washed in the alcohol. Thrips were sieved through a fine nylon mesh and counted through a binocular microscope.

3.1.2 Dynamic Extraction

In this method, the thrips are made to move away from the plant surface to a collection point by expulsion with heat through the Berlese or Tullgren funnel (Schirck, 1948); or expulsion with turpentine (Taylor and Smith, 1955).

Drawbacks are:

1) and 2) as above, and

3) since extractions cannot be done immediately and in the field, thrips crawl away and are lost during transportation, or if they are held in plastic containers, they get trapped and die in moisture that condenses in the bags.

3.1.3 Knockdown Method

Sakimura (1937a) tapped onion plants over a black card and counted the dislodged thrips. Other authors have used felt and cotton lint cloth instead of card so the thrips are temporarily entangled in the fibres (Powell and Landis, 1965; Henderson and MacBurnie, 1943). This method is quick but has the following drawbacks:

1) and 2) as above, and

3) the method underestimates the numbers since the thrips, particularly the larvae, are not easily dislodged from their hiding places.

3.1.4 Direct Counting

This method is most suited for plants on which the thrips can be easily seen and for thrips species which remain still long enough to be counted. Estimates of density can be obtained on the field. No damage is done to the plants and no crop loss through uprooting occurs and hence larger samples can be taken, particularly at the low thrips densities, without cost to the grower. However, plants need to be handled with minimum agitation of leaves. For sampling thrips on onion plants, one has to get very close to the plant to count the larvae. The method

is laborious at high thrips densities.

This was the favored sampling method. Since the thrips are more active and crawl faster in warmer weather, all sampling was done before mid-day, if possible. Counting was done systematically, starting with the outer leaves and working towards the center. Since the adult thrips move away faster than the larvae when the plant is distributed, these were counted first. The leaves were pulled apart very gently to expose individuals hiding between the bases of the leaves. A small hand lens was occasionally used to identify the first instar larvae.

The following environmental factors were measured through the growing season: temperature, relative humidity and rainfall.

3.2 Preliminary Field Survey

3.2.1 Occurrence and Importance of Onion Thrips

A survey for the distribution and determination of pest status of the onion thrips in Michigan was carried out in the summer of 1978 at the following locations: East Lansing, Grant, Eaton Rapids, Decatur, Stockbridge and Newago (Fig. 2).

The survey was conducted at the early part of the season and again towards the end of the season. At each location, the opinion of the grower was sought on the pest status of the onion thrips in his field using a questionnaire (Table 3). Where the information desired was not yet available for the season being surveyed, the grower provided data from previous years.

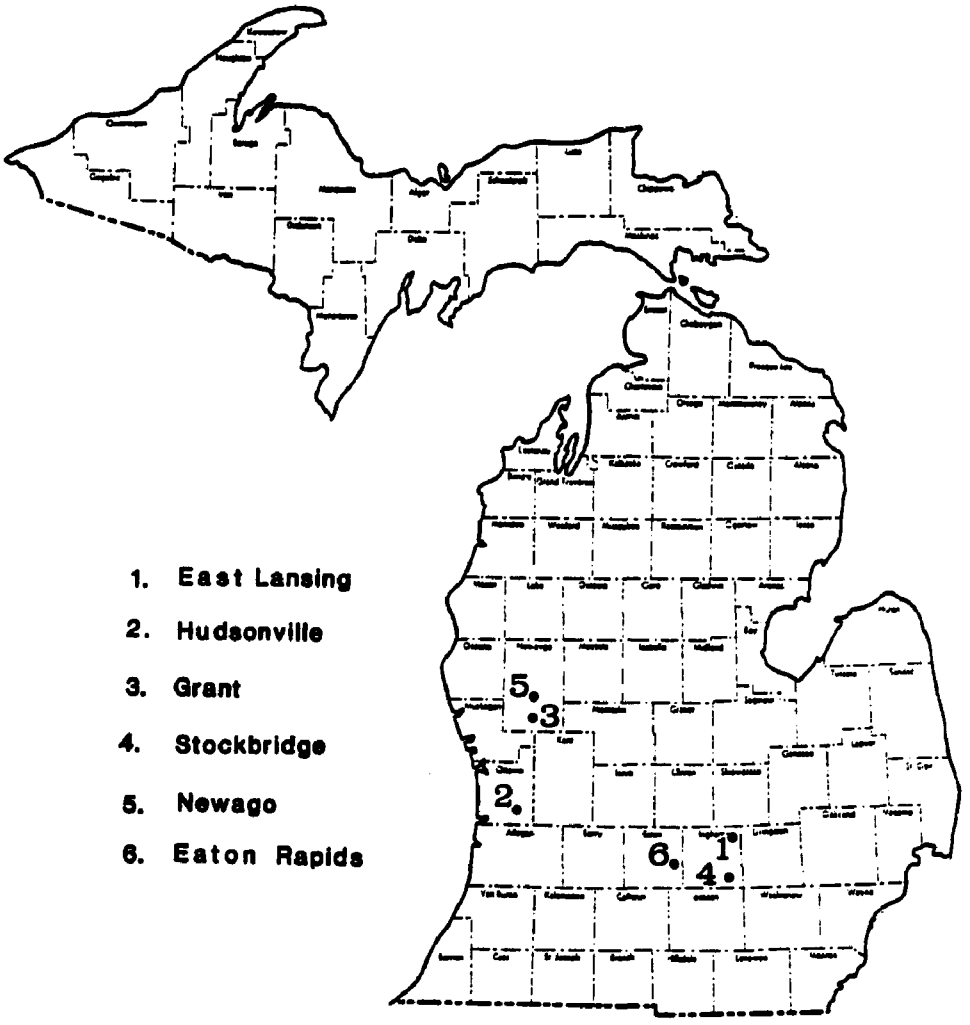


Figure 2. Michigan, Localities sampled for preliminary field survey.

Table 3. Questionnaire for Onion Thrips Survey.

Michigan State University
Department of Entomology
East Lansing, MI

THRIPS SURVEY

Location _____ Date _____

Onion Variety _____

Date Planted _____ Plant Age _____

Insecticide(s) Used _____

Rate of Application _____

Frequency _____

The direct counting method was used for the early season survey, but towards the end of the season, the extraction method was used in order to reduce the time spent at each location. One-hundred plants were sampled along each diagonal of the field in the direct counting method, but this size was halved for the extraction method.

3.2.2 Natural Enemies Survey

At each location mentioned above, a visual search was made for any predators that occurred in the fields. A search was made in the surrounding bushes for any predators. Large thrips larvae, presumed to be second instars, were brought back to the laboratory and reared on onion leaf sections in petri dishes to see if any were parasitized. Five-hundred larvae were reared from each location.

3.3 Population Dynamics of Onion Thrips

The survey of the onion-growing areas of Michigan showed there was only one grower that grows onions on a commercial scale that had a thrips problem most of the time. This grower, Dale Kunkel, grows onions and other crops (potatoes, carrots, soybeans, and some small grain) in the organic fashion and does not use any pesticides. The Dale Kunkel farm, located near Eaton Rapids (35 km SW of the M.S.U. campus), was thus chosen as the site for most of the field research through 1978, 1979 and 1980 growing seasons. Data were also collected from the M.S.U. Muck Farm at Laingsburg during the 1980 season.

Lewis (1973) reported that thrips are more abundant near the edge of the field than in the center and hence it was necessary to sample the end rows. With aphids, Sylvester and Cox (1961) reported that the distribution in the field during the initial phase of infestation is random, but later becomes contagious as each aphid reproduces. There is no detailed study of the field distribution of onion thrips in the literature, but it is doubtful if a large onion field will show a random distribution of thrips even at the early phase of infestation. The initial colonizers will most probably land near the edges of the field so that although the distribution in the early phase of infestation may approach random, there may be higher densities near the edges of the field at this time. The distribution may become further clumped as the thrips reproduce.

3.3.1 Field Data, 1978

Sampling done in 1978 at Eaton Rapids was considered as a preliminary study. Sampling was done bi-weekly from the time the plants were 5-7 weeks old, through harvest.

The onion field was about 300 x 50 m and was bordered on two sides by an edge row of trees and shrubs and potatoes and onions on the other sides. All the rows in the field were numbered. Starting from the middle row, a bi-weekly sampling scheme was designed so that one whole row was sampled on each visit, i.e. 2 rows were sampled each week. For each row, all plants within the first 1 m length were counted and carefully searched for larvae and adult thrips.

Several 1 m length samples were taken along the same row, separated by about 30-40 m (30 long strides), to provide about 500 plants/row and including a sampling of the last 1 m length of the row. On the next sampling date, one row was skipped and the next row sampled, thus reducing the chances of disturbing a row before sampling it. This order of row sampling was continued to the edge of the field and the direction reversed and worked to the other side of the field using the rows that were previously skipped.

3.3.2 Field Data, 1979

A different sampling scheme was used for the 1979 season. Along each row, small plots of 10 m in length were marked off and staked. Each plot was separated by 5 m of length of unmonitored onion plants. Only alternate rows of onions were used so as to reduce the chances of disturbing insects in adjacent plots while sampling another.

Data from the 1978 season for single plant entries of thrips were used to estimate the number of samples needed. Southwood (1978) gives the number of samples N as:

$$N = (s/E\bar{x})^2$$

where s = standard deviation,

E = predetermined standard error expressed as a decimal,

$\bar{x}$ = mean

Table 4 shows the ratio of the variance to the mean during 1978 (which give the measure of the degree of clumpedness) and also the number of samples needed for different times in the season. With the direct counting method, the

Table 4. Ratio of variance to mean number of thrips/plant and required sample size (1978 data)

Time	Mean Thrips/plant	Variance s^2	$s^2/\bar{x}$	Required sample size
Early season	1.3	1.8	1.4	106 (E = 10%) 26 (E = 20%)
Early season	1.7	4.9	2.9	169 (E = 10%) 42 (E = 20%)
Early season	1.4	5.6	4.0	289 (E = 10%) 71 (E = 20%)
Early season	3.3	23.1	7.0	212 (E = 10%) 53 (E = 20%)
Mid-season	14.7	522.0	35.5	242 (E = 10%) 60 (E = 20%)
Late season	34.8	1534.8	44.1	127 (E = 10%) 32 (E = 20%)

chances of seeing and counting all larvae are low and further become decreased at high thrips densities, thus, the error margin was set high, 10%, and increased towards the end of the season as the variance and degree of clumpness increased. If a larger error was not permitted, very large samples had to be taken. An error margin of 10% or better was decided on, so that about 200 plants could be sampled at the beginning of the season. An error margin of 20% or better, in the middle to the end of the season, allowed a sample size of about 100 plants mid-season, and 50 plants late season. Other authors, Hoerner (1947), Shirck (1948) and Faulkner (1954) have used a sample size of 10 plants and did not alter this size through the season.

3.3.3 Field Data, 1980

Onion sets, which were left in the field at Eaton Rapids at the end of the 1979 season, were monitored regularly from the first week of May, to determine when onion thrips began migrating into the field. Monitoring was done weekly until the numbers of thrips began to rise and the onions from the fields to be used for the regular sampling program were 6 weeks old.

The layout of the field at Eaton Rapids was such that the onions were adjacent to spring oat, winter wheat and alfalfa. (Figure 3). All onions and spring oat were planted between April 28 and May 4, 1980. The winter wheat and alfalfa were planted at the end of the 1979 season. The onion cultivar used for the study, 'Southport white globe', was the same cultivar that was used in the preceeding seasons

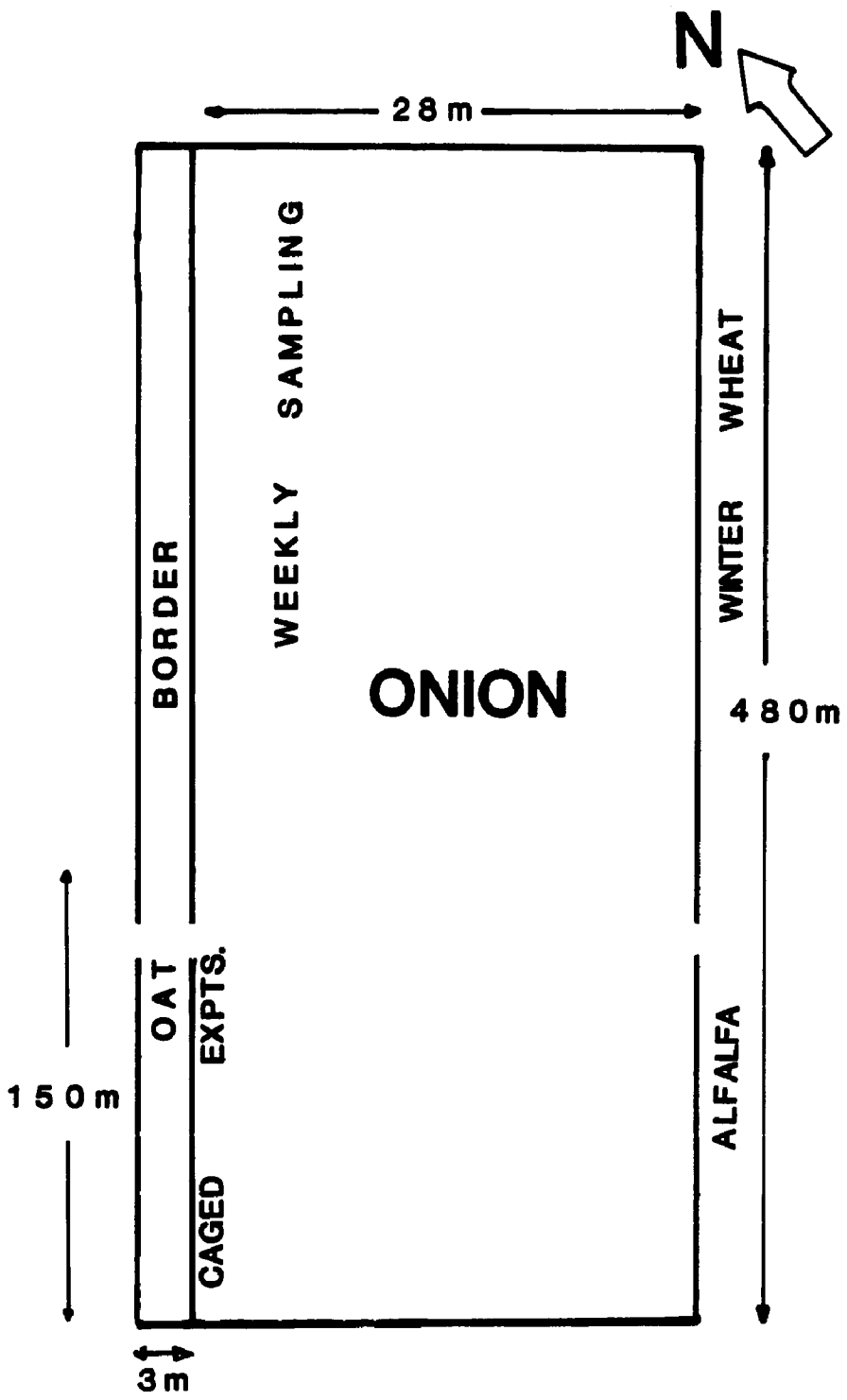


Figure 3. Layout of field at Eaton Rapids, 1980.

at Eaton Rapids. There were 15 rows of this variety bordered on one side by other varieties of onions. Alternate onion rows on the western half of the study area was divided into 10 m row-length plots and staked for the regular sampling. There were 20 plots per row. Each week, 5 plots (replicates) were randomly sampled, 60 plants were sampled per plot at the beginning of the season, 40 plants in mid-season and 30 towards harvest. Thus, a total of 300, 200, and 150 plants were sampled at early, mid and late season using a predetermined standard error margin of 10% or 20% of the mean (based on 1978 data).

At the Muck Farm, onions (cultivar: 'Ontario M') were planted on June 4, 1980. The thrips monitoring formed part of an insecticide control study. Plots were arranged in a randomized complete block design with three replications. Each plot was three row by 7.5 m (25ft.) long. The treatments and rates were as follows:

Treatment	Rate lb ai/A
Orthene 75 WP	0.5 lb
Orthene 75 WP	0.75 lb
Orthene 75 WP	1.0 lb
Diazinon AG 500	0.5 lb
Untreated	--

Treatments were applied with a tractor-mounted boom sprayer at 300 gpa on the following dates: July 14, 21; August 4, 11, 18, 25. Counts of numbers of thrips per plant were taken approximately weekly from 20 plants from the center row of each plot.

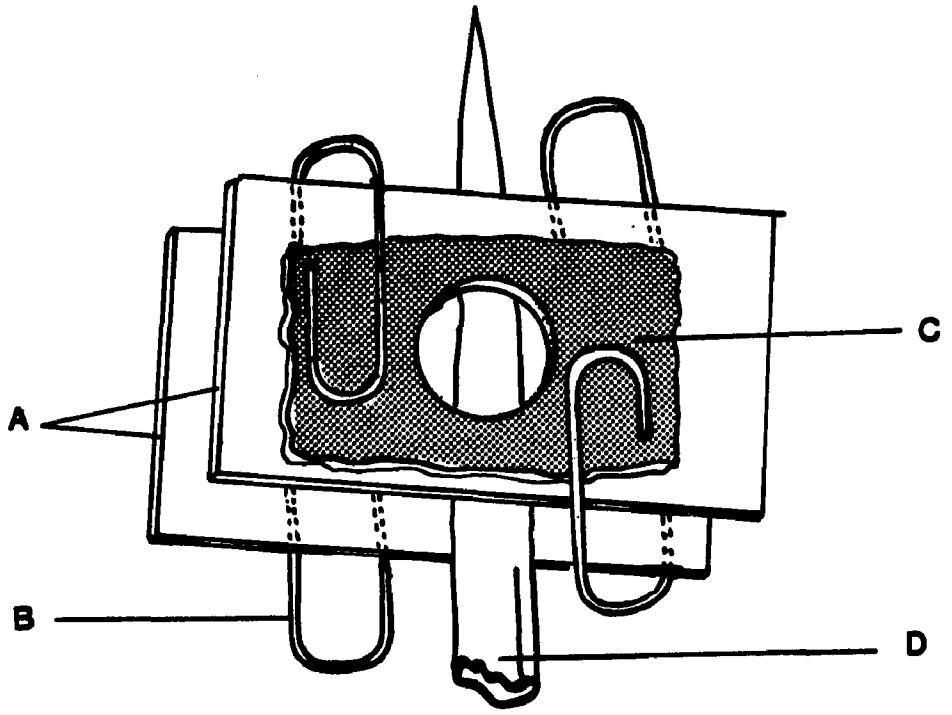
3.4 Developmental Biology

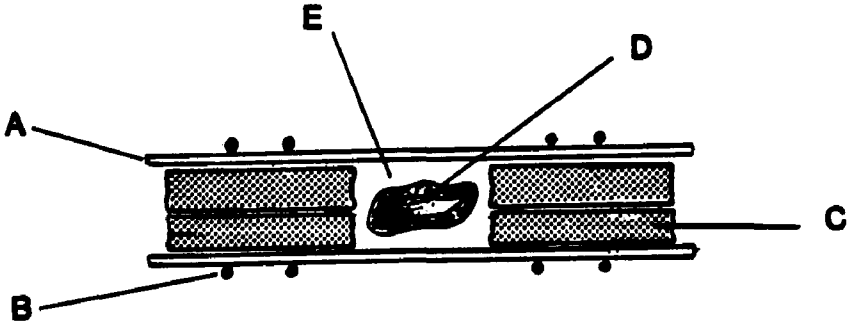
3.4.1 Design of Rearing Cells for Onion Thrips

The small size of the onion thrips, like most other thrips, demands that they be confined in a small space for some studies. The first instar larva of the onion thrips is seen as a pale yellow speck to the naked eye, and hence a lot of precision is required in constructing a rearing cell that will prevent their escape. However, air-tight containers are unsuitable, particularly for the adults whose wings get trapped in water vapor that condenses within the cell. Condensation of moisture is even more severe when moist food such as onion leaves are enclosed in the cell. A good rearing cell then should be one that has a tight fitting seal and at the same time allows the free flow of air. Preferably the container should be of clear sides so observations can be made without opening it and it should be possible to visually verify the goodness of the seals of the sides.

a. Felt rearing cell. Lewis (1973) described various small cells that could be used for individual rearing of thrips, of which the type consisting of rings of felt and transparent plastic was considered most suitable (Fig. 4). This cell consisted of 2 rings of thick felt placed above and below the leaf and then held together by big paper clips.

Although the above set-up allowed observations to be made into the cell, and no condensation occurred within the cell because there was free flow of air across the felt,





A = Transparent plastic
B = Paper clip
C = Thick felt
D = Onion leaf
E = Rearing cell

Figure 4. Felt rearing cage (after Lewis, 1973).

it was not possible to be certain of the tightness of the set-up and in fact thrips escaped from the cells on many occasions or they got trapped and died between the fibers of the felt.

b. Plastic clay cells. This new design consists of blue plastic clay (Plasticine^{R}) ring and 2 pieces of clear acetate (5 x 5 cm). The clay is first rolled into a cylinder of 0.7 cm thickness and cut into 5 cm pieces. The two ends are slightly flattened and joined together to make a ring. The curvature in the inner surface of the ring is then removed by carefully rolling a glass rod or a similar cylindrical object on this surface while holding the ring in one hand. The clay ring is then placed on a piece of clear acetate. A ventilation hole of 0.5 cm diameter is bored near the center of the acetate and covered by a very fine nylon mesh (62 microns) using Elmer's ^{R} glue. A drop of water is spread over the surface of another piece of acetate and the moist side is pressed down gently on the clay. The clay yields to the pressure and makes a firm bond with the first acetate (with the ventilation hole) but not with the moist acetate. The moistened acetate can be easily pulled away in the horizontal plane while still moist without deforming the clay. The areas of good bonding between the clay and the acetate appear wet and thus the tightness of the seal can always be verified. A check is made on the tightness of the "ventilation" acetate and the clay and then an onion leaf is rolled and placed inside the clay ring. The required

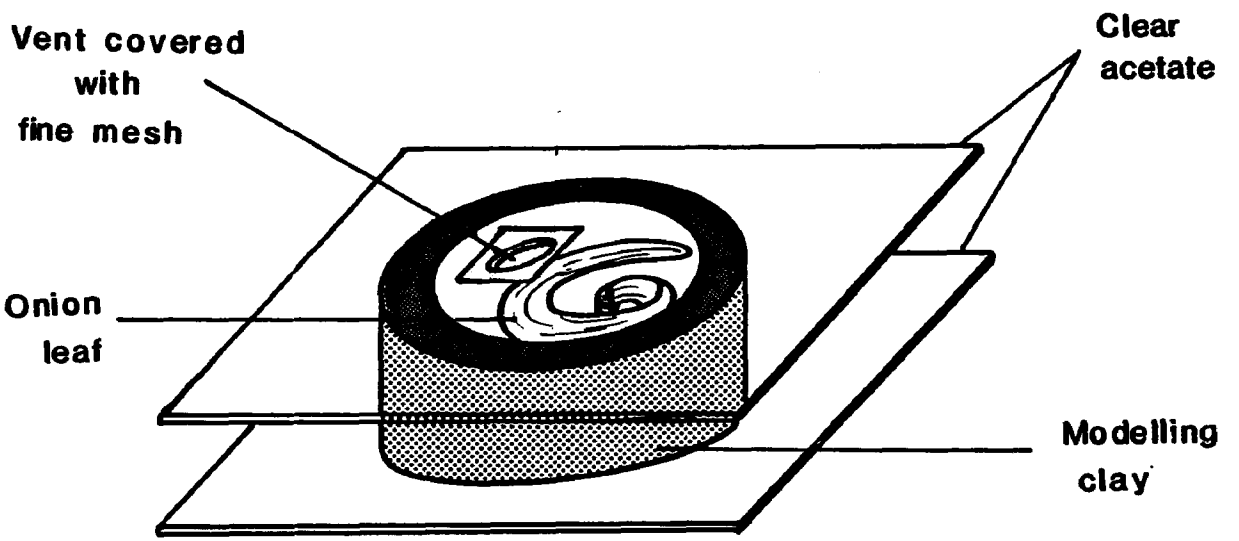


Figure 5. Plastic clay rearing cell.

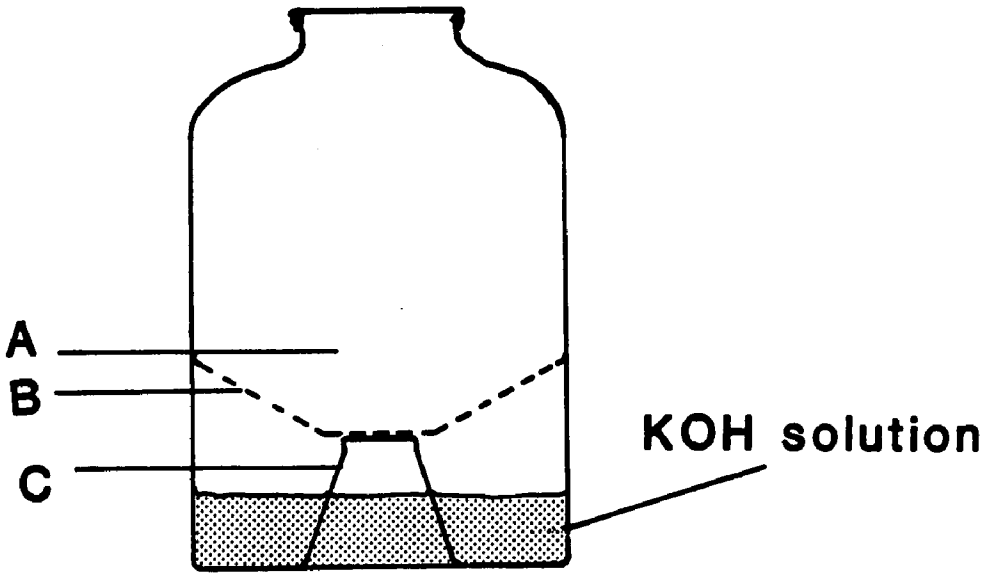
thrips stage is placed inside the cell using a fine moist sabel brush and the cell covered with a dry piece of acetate and pressed down gently until a perfect seal is obtained. The acetate and clay bond together firmly and no clips are required (Fig. 5).

The plastic clay gets slightly harder below room temperature and bonds even better but still remains pliable. It gets softer above room temperature and the bonding to the acetate becomes weaker and hence the two acetate pieces need to be picked up together to avoid separation and loss of material.

3.4.2 Developmental Biology of Onion Thrips

The developmental rates were measured for the larval, prepupal and pupal stages. The studies were conducted at the following constant temperatures: 5^{o}, 10^{o}, 17^{o}, 20^{o}, 23^{o}, 26^{o}, and 29^{o}C. MacGill (1931) reported the optimum relative humidity for the development of the onion thrips to be 75 to 85%. In this study, the thrips were reared at 70-80% relative humidity. Since fresh onion leaves were fed to the thrips and the thrips generally stayed on the leaf surface, the actual measurement of relative humidity of the air in which the thrips spent most of their time will be higher than that recorded for the general air space within the humidity chamber.

The relative humidity solutions were prepared using potassium hydroxide pellets dissolved in distilled water according to the concentration reported by Solomon (1951).



A = rearing chamber
B = hardware cloth
C = inverted flower pot

Figure 6. Constant humidity chamber.

The KOH solutions were equilibrated for 24 hours at the required temperatures in one gallon jars with tight fitting lids. Into each jar was placed an inverted flower pot with a hardware cloth glued to the bottom. The hardware cloth was cut to fit the inner diameter of the jar, creating a chamber above the KOH solution (Fig. 6). A small Eaton^{R} hygometer/thermometer by Airguide was introduced into the chamber and the jar placed in an environmental chamber previously set to the required temperature to equilibrate.

First instar larvae that were 0-12 hours old were obtained as follows: onion leaves that did not show excessive thrips damage were collected from the general onion thrips culture. (The thrips culture was maintained at about 22^{o}C and 50% RH on onion plants grown from bulbs.) The excised leaves were assumed to contain thrips eggs, and were carefully brushed with a soft brush to remove all thrips stages from the leaf surface. The leaves were inserted into a perforated plastic disc and the latter placed in a plastic cup. Enough water was poured into the cup to cover the plastic disc completely (Fig. 7). The tops of the leaves were held together by a rubber band to prevent any leaves from touching the cup. With this set-up, it was possible to recover all first instar larvae that emerged. The set-up was placed in the 20^{o}C environmental chamber and inspected after 12 hours for any first instar larvae.

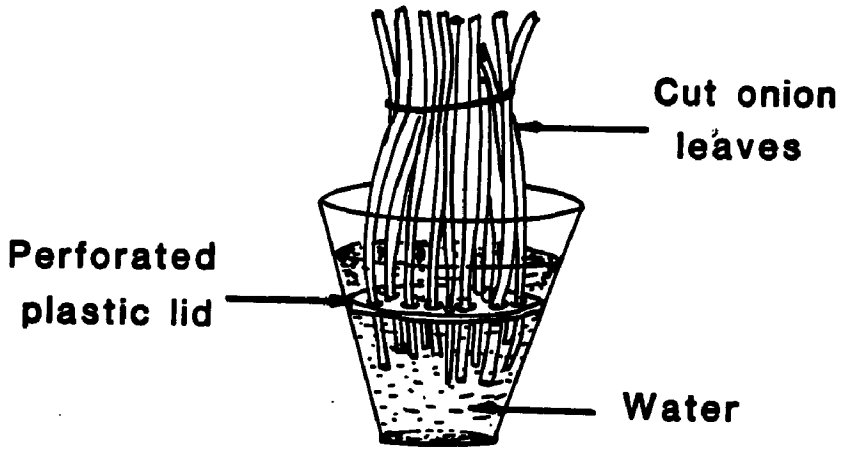


Figure 7. Set-up for collecting freshly hatched first instar thrips larvae.

The first instar larvae were placed individually in the rearing cells described previously with a segment of fresh onion leaf. The cells were introduced into the humidity chambers and the latter into the appropriate environmental chamber. Each cell was checked twice a day between 8:00-10:00 a.m. and 7:00-10:00 p.m. for any molts. The food was changed once every one or two days as needed. At the colder temperatures, the leaves stayed fresh longer and were changed less often.

The only positive identification of the first molt is by inspecting the shape of the third antennal segment under a binocular microscope. The first instar larva has a short top-shaped third antennal segment that is about as long as it is wide while the second instar has a more slender segment that is longer than is broad.

Observations were taken until the thrips molted into the prepupal stage when they were removed from the rearing cells and introduced separately into plastic cups. Each cup contained fine sand, 0.3-0.5 cm deep, that was moistened with tap water. Excess water was blotted off, the prepupa was placed on the sand and covered with a moist piece of paper thus providing an atmosphere of about 100° RH around the prepupa. The cup was then covered with tissue paper and a perforated lid. Since the prepupal and pupal stages do not feed, no food was provided. Each specimen was checked every 12 hours until it molted into a pupa and then into the adult.

3.4.3 Developmental Biology of Coleomegilla maculata

The life history of C. maculata was studied at 24°C and 50% RH. A general culture of coccinellids was maintained in glass globes on the English grain aphid, Macrosiphum avenae (Fabricius), with oat as the food host for the aphids (Fig. 8).

C. maculata eggs were obtained from the above culture soon after they were laid. The eggs are usually laid on the oat leaves but occasionally on the glass globe. If laid on the leaves, the leaf segments were cut and placed in plastic cups. Those laid on the glass globe were left there but the glass globe was removed and sealed on the open end with paper towel using Elmer's glue, and the culture provided with a new glass globe. After emerging, the first instar larvae were kept separately in dry plastic cups and provided with thrips larvae and adults on onion leaves. The onion leaves were changed every day and more thrips were provided as needed. The coccinellids were observed daily for molts and observed until the adult emerges.

3.5 Population Dynamics of the Coccinellid Complex

The 1978 survey showed that the most common insect predators in the onion fields were coccinellids. Since a few adult coccinellids were observed to feed on the thrips in the fields, a study was made on the seasonal abundance of these predators.

3.5.1 Coccinellid Population Estimates, 1979

Three methods, pit fall traps, flight interception traps, and sticky board traps, were used for this study

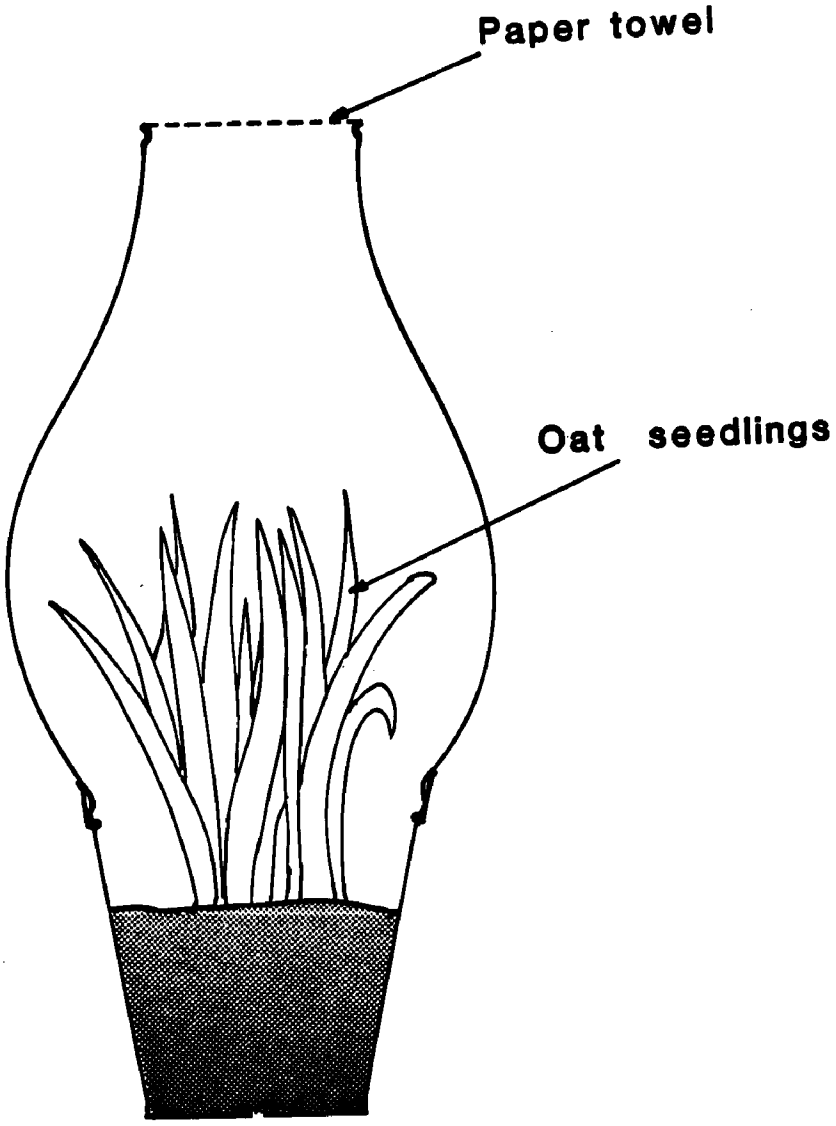


Figure 8. Glass globe for rearing coccinellids.

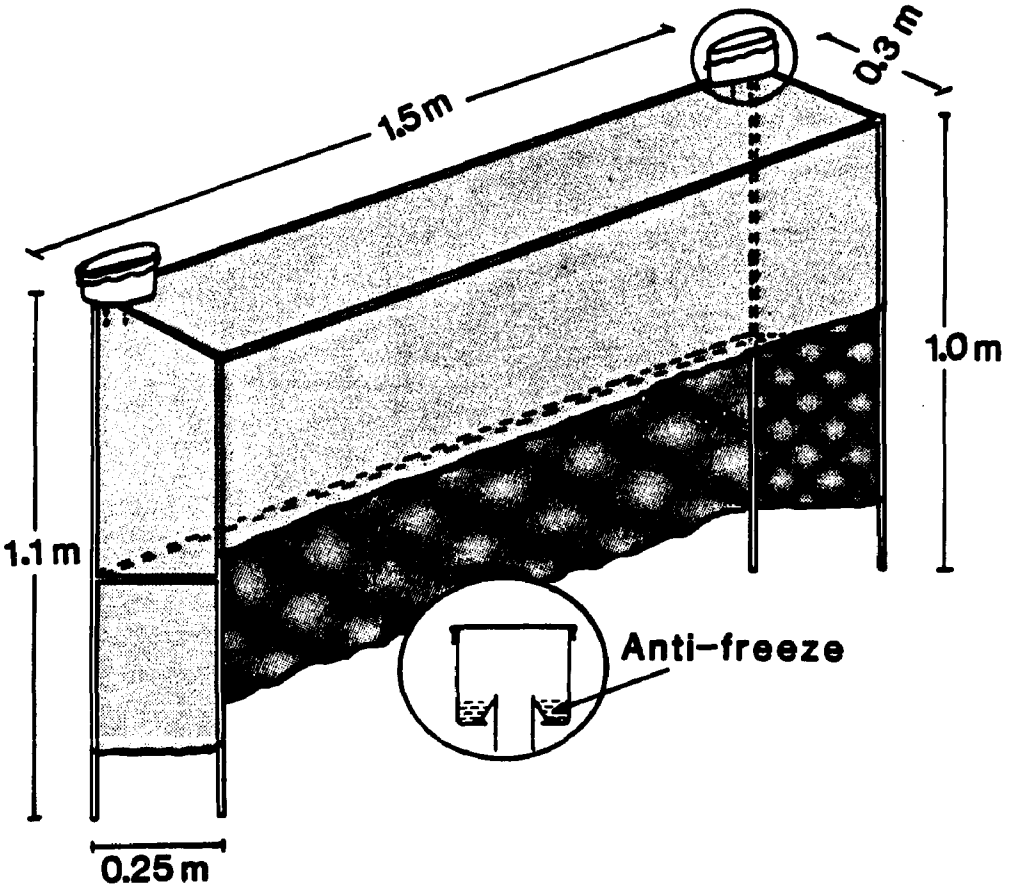


Figure 9. Flight interception trap.

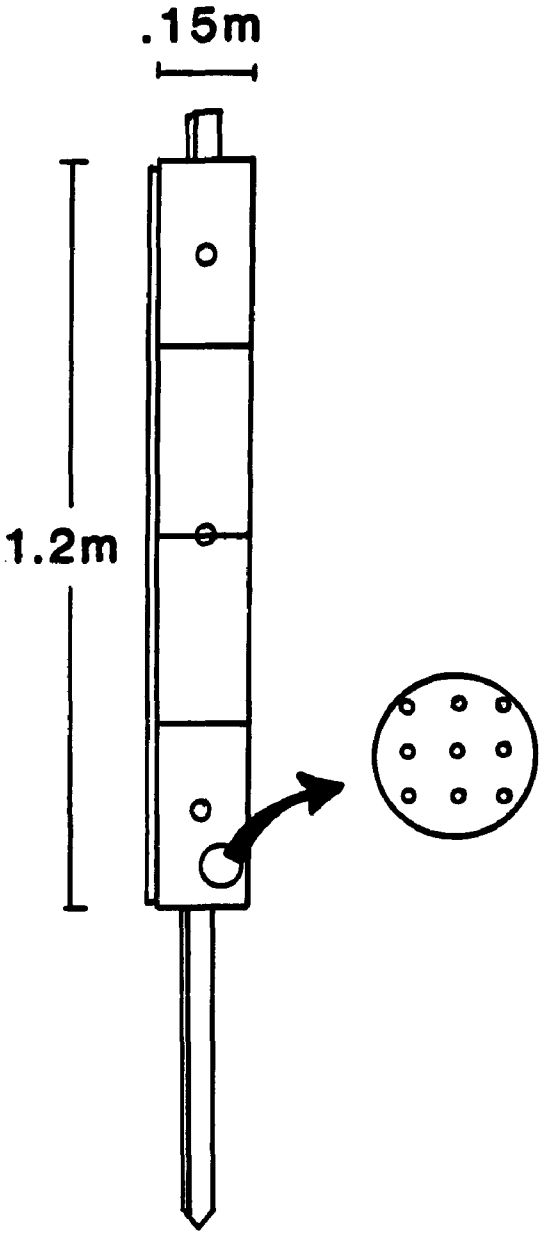


Figure 10. Stickyboard trap.

at Eaton Rapids. Sticky board traps alone were used on the Muck Farm.

a. Pit fall trap: one quart plastic bowls were used containing 20 ml of anti-freeze. Each bowl was sunk into a hole so the rim was level with the ground and the earth around the rim was smoothed to ensure a perfect level between the ground and the rim. Fifteen pit fall traps were used and the layout in the field was 3 rows by 5. Each bowl was emptied once a week and the coccinellids were counted. Trapping was started in the third week of July.

b. Flight interception traps: the trap used was a modified malaise trap (Fig. 9). Insects that were caught in the nylon netting crawled up and were collected in anti-freeze. Each trap was emptied once a week. Eight traps were used in the field and arranged along the edges and the middle of the field. The inlets of the traps were arranged to face opposite directions in an alternating order.

c. Sticky board traps: the traps were 122 cm (4 ft.) tall by 15.2 cm (6 in.) wide; consisting of 2 pieces of .32 cm (1/8 in.) thick tempered peg board bolted to a 183 cm (6 ft.) long stake so each trap had 2 surfaces (Fig. 10). The surfaces were painted with "irridescent yellow" exterior enamel latex paint (Silver Lead Co.). Tangle foot^{R} was used as the sticky substance and this was applied to the surfaces of the boards using a paint roller. Sixteen sticky board traps were used at Eaton Rapids and 29 at the Muck Farm. The traps were arranged in 4 rows, 2 rows in the middle and

a row each along the long edge of the field and at right angles to each other with their surfaces oriented into or away from the field, or along the length of the field. Each trap was pounded into the ground so that the sticky boards were about 15.2 cm (6 in.) above the ground. Recoating the surfaces with tangle foot was necessary when they became covered with dust particles. The trap surfaces were divided into 4 equal vertical areas to examine the vertical distribution of the coccinellids. The traps were inspected weekly and all coccinellids were removed and counted.

3.5.2 Coccinellid Population Estimates, 1980

Data from the 1979 season indicated that the sticky board traps caught the highest numbers of coccinellids at both Eaton Rapids and the Muck Farm. Visual observation during that season showed that even though fairly high numbers of adult coccinellids occurred in the grasses and adjacent cereals, only low numbers were caught in the traps. Trapping by sticky boards was the only method repeated from 1979. Data from 1979 also showed adult coccinellids started occurring in the fields very early in the season, in fact, even before the onions were planted and their numbers were high before and at the onset of the onion season and declined as the season progressed (Fig. 35). It was thus necessary to obtain some index of the population size at the onset of the season.

3.5.2.1 Visual Count on Ragweed

The visual count method was used to estimate the population size of adult coccinellids because this method was

not destructive compared to the trapping methods, and did not jeopardize other experiments that had been planned for the season by destroying the population. Adult coccinellids were counted on ragweed that occurred in the onion field and an adjacent field of spring oat. The census was taken on May 24, 1980, when the onions were just past the flag stage and the spring oat were 5 - 8 cm tall, (both onions and oat were planted April 28 - May 4, 1980). Since the onions and oat were very small at this time, no coccinellids occurred on them but rather on ragweed that were present all over the field at this time. The ragweed occurred between the rows of the crop and was up to 60 cm tall. Each ragweed was thoroughly checked for coccinellids. The census was divided into three blocks: spring cereal adjacent onion field, first four rows of onions, and rest of the onion field.

3.5.2.2 Quadrat Sampling

Quadrats ($1m^2$) were used to sample the coccinellids in the same spring oat field where the visual counting was done, and in an adjacent plot of winter wheat. Sampling began on June 12, 1980. The winter wheat was about 30-40 cm tall. Sampling was done randomly at the edges and middle of each field, and all coccinellids occurring on the plants and ground within the $1m^2$ area were counted but not removed.

3.5.2.3 Sticky Board Traps

Sticky board trapping, similar to that of the 1979 season, was started in July at Eaton Rapids and the Muck Farm. At the Muck Farm, the layout of traps was the same as

that for 1979. At Eaton Rapids the traps were placed along the middle of the spring oat and winter wheat fields and along the field border of bush which consisted predominatly of ragweed, but not in the onion field. The reason for setting the sticky board traps differently at Eaton Rapids was to avoid the possibility of trapping and destroying the population of coccinellids which might jeopardize other experiments in the general field area.

3.5.3 Arthropod Complex Associated with Coccinellids

Because the coccinellids occurred in large numbers on cereal, grasses and weeds, at the beginning of the season, when the onion plants were too small and often before the onions were planted, investigations were made to determine the types of small arthropods that occurred on these other host plants. Samples of cereals, grasses and ragweed were collected and washed in 70% ethyl alcohol. The arthropod complex thus collected was sorted and identified. This study was done only at Eaton Rapids.

3.5.4 Diel Activity Patterns of Coccinellids

The diel activity patterns of the coccinellids were studied by two methods at Eaton Rapids. This study was to provide the following information: i) whether the coccinellids moved in and out between the onion and the cereal in the fields; ii) whether there was any pattern of movement through the day, and iii) make observations on their flight height.

3.5.4.1 Visual Counts on Onion Plants

This was accomplished by walking along the space between 2 rows of onions and counting the coccinellids present on the

parts of the plants facing the inter-row space. Although two rows were checked at a time, this constituted one row of plants since only one-half of each plant was assessed at a time. Counts were taken every 2 hours, starting at 8:00 a.m., for 6 rows of 150 m each, 2 rows near the oat field, 2 in the middle of the general onion field and 2 near the alfalfa with oat field.

3.5.4.2 Flight Interception Method

Four flight interception traps were placed across the width of the onion field with their entrances directed towards or away from the oat field. The traps were checked hourly from 8:00 a.m. until dusk and any coccinellids found inside and on the outside of the traps were counted and released in the field. The air temperature was recorded every hour.

3.5.5 Predation by Coleomegilla maculata

The objectives here were to determine whether C. maculata is a predator of the onion thrips and, if so, how many thrips are eaten per day by the various stages of coccinellids and also, how many thrips will be required for the development of the coccinellids. To answer these questions, laboratory and field experiments were conducted.

3.5.5.1 Laboratory Predation Experiments

Cells similar to the thrips rearing cells (see sec. 3.4.1) were used for these experiments, except that one or two holes (0.3 cm diameter) were bored on the acetate in addition to the ventilation hole. Fresh onion leaves were passed through these holes so that the closed tips of the leaves projected

into the cell space. The leaves were chosen so that they fitted tightly in the holes and to further ensure that no leaves fell out, a ring of placticine was used to cement the leaf base to the acetate. Since the objective of the study was to measure the maximum number of thrips the coccinellids could eat in a day, it was necessary to ensure that the coccinellids did not complete eating the thrips available within the periods of determination. Also, all thrips provided had to be available for predation, i.e., the cell design should not provide narrow spaces into which the thrips could hide, making them inaccessible to the predators. Extra care was thus taken to smoothen and remove any curvature and crevices from the inner wall of the plasticine ring.

Second instar thrips larvae were used for the predation experiments except in the few cases when adult thrips were used to determine if the various instars of coccinellid will feed on adult thrips. Large larval thrips, assumed to be second instars, were selected and transferred onto the onion leaf in the rearing cell using a moist brush. Adult thrips were picked up using an aspirator and anaesthetised with CO_2 for 30-40 seconds, transferred quickly onto a white piece of paper for counting and quickly brushed into the cell. The appropriate stage of coccinellid was introduced into the cell and the latter closed. The cell with onion leaf, thrips and coccinellid was then placed on a rack beneath which were cups of water so that the cut tip of onion leaf was submerged

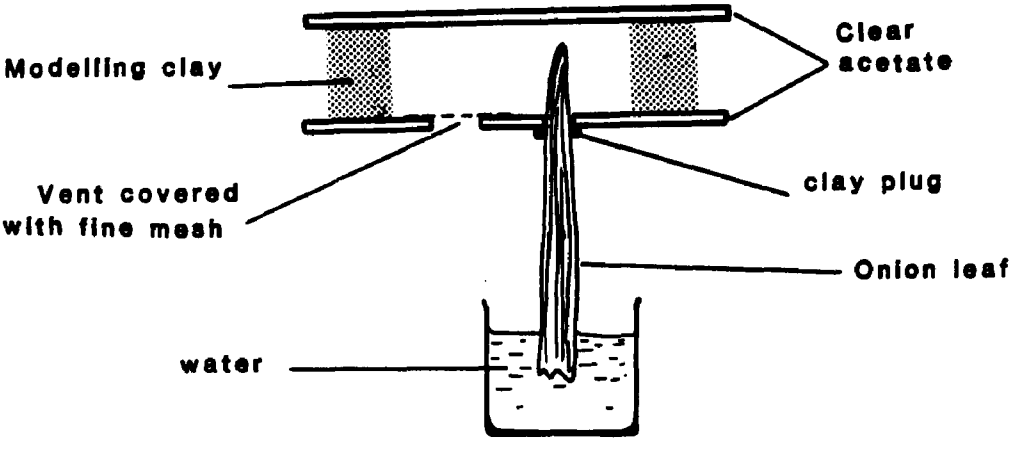


Figure 11. Set-up of coccinellid predation cell.

in water (Fig. 11). More thrips were added to each cell periodically and each time the duration of exposure to the predator and the number of prey eaten was recorded.

3.5.5.2 Field Predation Experiments

The field predation experiments were prompted by the observation in 1979 that the temporal and spatial occurrence of the coccinellids and the onion thrips did not precisely coincide in the field to make the coccinellids highly effective predators. The overwintered adult coccinellids were abundant in June and early July after which the numbers began to drop and remained low for the rest of the onion growing season. The onions thrips on the other hand did not appear in the onions until late June and the numbers started to build up in July reaching a peak in late August to September. Furthermore, the high numbers of coccinellids occurred in cereal crops (wheat, oat and barley) and in grasses which harbored a host of small arthropod-prey, and did not transfer into the onions when the latter began to show increasing thrips numbers in July. The experimental design was thus aimed at manipulating the onion-crop environment by making some cereal crop available next to the onions to attract and sustain the coccinellids until the thrips became available.

The general onion field was bordered by winter and spring cereal. The experimental plots consisted of three replicates of winter cereal (wheat), spring cereal (oat) and control (no cereal) planted next to onions. Each plot measured 1.5 x 1.5 m (5 x 5 ft) and had three rows of cereal and two

rows of onions. The oat was direct seeded with the rest of the oats border and at the same time the onions were planted. The winter wheat was transplanted in the middle of June when they were 30-45 cm high. The oat was about 15 cm tall at this time and the onions were at the 5 leaf stage (about 8 weeks old). Observations were made twice weekly on cereals to monitor the development of coccinellids and on the onions for thrips. In the second week of July, this being the period when the numbers of thrips began increasing, 1.8 x 1.8 x 1.8 m (6 x 6 x 6 ft) cages with plastic mesh were enclosed over the plants in the 9 plots. The cages were held down with nylon ropes to prevent their being blown away by the wind.

All cereals inside the cages were checked for coccinellids and onions for thrips, coccinellids and any other predators. Coccinellids and all predators within the cages were then removed. Five adult coccinellids and 10 third instar coccinellids were released into the cages with oats and wheat. Ten plants were randomly chosen in each cage and monitored for onion thrips and coccinellids at the end of the season.

3.6 Onion Thrips - Onion Plant Interaction

Experiments were conducted in the greenhouse at 21-24^{o}C (70-75^{o}F) and 70-80% R.H. to study the feeding rates of the different stages of the onion thrips on onion. These experiments were in 2 parts: 1) using onion leaf segments, and 2) using whole onion plants. The following assumptions were made to simplify the design and interpretation of the

results:

1. All individuals of the same stage are identical. By choosing appropriate time periods, no molting or reproduction could occur. Therefore, we can compute the average effect for a given stage.
2. All individuals feed continuously during the period measured and also feed at the same rate. Previous preliminary tests had shown that most adults and larvae die if they are starved for over 18 hours.
3. No deaths occur during the period. Any that are found dead are assumed to have died at the onset of the experiment through handling, e.g., death through anesthesia with CO_2.
4. CO_2 anesthesia and handling has no effect on the feeding rate and amount of leaf material consumed.
5. There are no positive or negative effects of individuals on each other in the closed cell.

3.6.1 Feeding Rate on Onion Leaf Segments

The set up for this experiment was similar to the predation experiments using the rearing cells. Various numbers of larvae or adults were introduced into rearing cells containing onion leaf tips and left to stand for measured time periods. Larvae were picked up with a moist brush, and adults were anethetised with CO_2. Only second instar larvae were used and these were sorted out from the thrips culture by size as before. As explained previously in section 2.3, size is an unreliable character for distinguishing the two

instars, but it was used to save the time that would be required for microscopic scrutiny.

At the end of the experimental period, the number of live individuals was counted, and the total leaf area consumed was measured under a binocular microscope using a grid. The leaf tips were assumed to be perfect cones and so the leaf areas were computed using the formula $\pi\gamma\ell$, where ℓ is the height of the cone (leaf tip) and γ the radius of the leaf.

3.6.2 Feeding Rate on Whole Onion Plants

Six week old potted onion plants were used for these experiments. These plants were completely free of any thrips attack until the onset of the experiments. Only adult onion thrips were used.

Old dying leaves were trimmed from the plants and the pots were placed in small plastic cups containing water so that the plants were continuously watered from below. The diameters of the leaves were measured at the widest point which usually occurs in the lower half of the length of the leaves. Since the leaves taper slightly towards the base, they are not perfect cones but were assumed so in order that the surface area could be estimated using the formula $\pi\gamma\ell$. The length of each leaf was measured from the tip to the point of attachment so that the surface area computed did not include the leaf sheath, since thrips do not generally feed on the sheaths.

Adult thrips were picked up from the general thrips culture with an aspirator and anesthesized in the same container with CO_2 for about 30 seconds. They were tapped onto

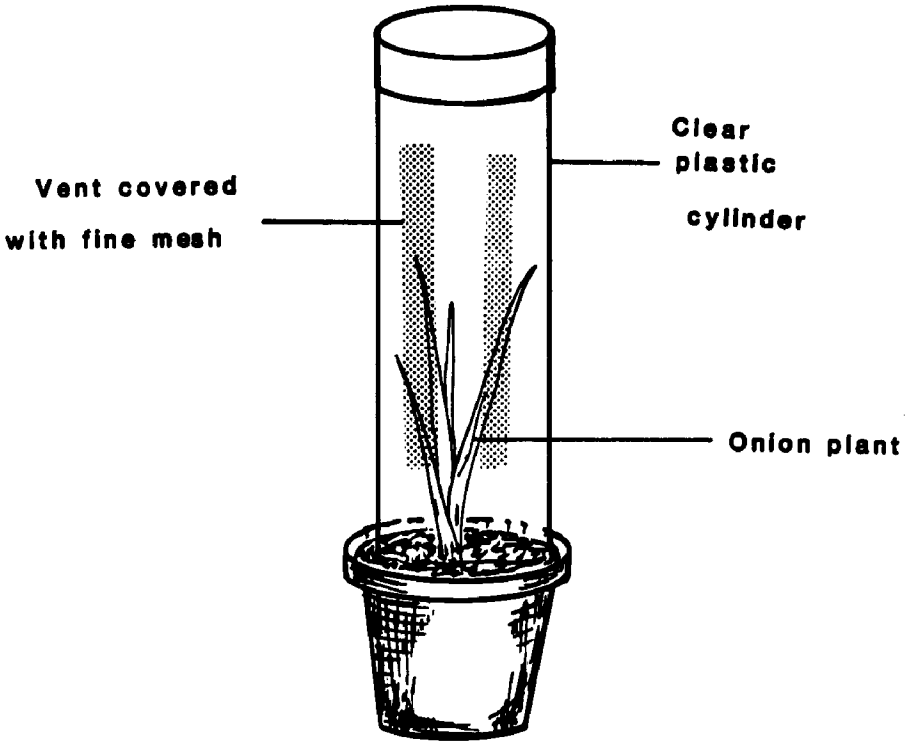


Figure 12. Set-up for measuring thrips feeding rate on whole onion plant.

a piece of paper (3 x 3 cm), any larvae were removed and the adults counted. The paper was placed at the base of the onion plant and the plant was enclosed with a 5 cm diameter clear plastic cylinder (Fig. 12). Each cylinder was 45 cm long, was sealed at the top and had two 2 x 30 cm vents along its side that were covered with a cloth. The open end of the cylinder was pushed into the soil until it held up firmly. The potted plants and thrips were provided with 18:16 hr light-dark photoperiod at 21-24^{o}C and 70-80% R.H. and observed daily until 25% of the total surface of all leaves had been destroyed. However, owing to the difficulty in estimating when this exact portion of the surface area had been damaged, the observations were continued until the total leaf surface had been destroyed.

4. RESULTS AND DISCUSSION

4.1 Preliminary Field Study

A summary of the results of this survey is shown in Table 5. All growers at the 8 locations sampled considered the onion thrips as a major pest. With the exception of one grower who farms his crops in organic fashion and hence does not use any chemicals, the other 7 sprayed regularly to keep the thrips numbers down and in an attempt to control onion maggots. Even though the numbers of thrips per plant at the organic farm (Eaton Rapids) was higher than all the other locations at both sampling dates, a comparison of means showed no significant difference between the sprayed and unsprayed areas.

All the growers that used insecticides reported satisfactory to good control of thrips and reported that it was necessary to stay on a 7-10 day spray schedule, using principally parathion.

Two species of adult Coccinellid predators, adult syrphid flies, and adults and eggs of Chrysopa Sp. were found at Eaton Rapids, but evidently these natural enemies were not keeping the thrips population down effectively. Fewer natural enemies (Coccinellids and Chrysopa) were found in and around these fields that were sprayed compared to the field at Eaton Rapids except one field at Grant where high numbers of Chrysopa sp. eggs were found.

Table 5. Summary of preliminary survey of some onion fields in Michigan, 1978.

Location	Insecticide	Mean Infestation Rate (# Thrips/Plant)			Grower Remarks
		Early Season	Late Season	Seasonal Mean[1]	
1. East Lansing	Yes	.22	14.6	7.41	Satisfactory Chemical Control
2. Hudsonville	Yes	.16	28.9	14.53	Satisfactory Chemical Control
3. Grant	Yes	.02	.08	.05	Good Chemical Control
4. Stockbridge	Yes	0.0	0.0	0.0	Good Chemical Control
5. Newago	Yes	.13	2.4	1.26	Satisfactory Chemical Control
6. Eaton Rapids	No	2.89	148.2	75.55	Problem

[1] Seasonal mean infestations followed by the same letter are not significantly different based on Student-Newman-Keuls multiple range test (P>.05).

No parasitoids were recovered from any of the larvae that were collected from all the surveyed fields (total n = 3000).

4.2 Population Dynamics of Onion Thrips

The population trend of onion thrips on onions through the growing season is summarized in Appendix Tables 1 a, b, c, d. Data were collected at Eaton Rapids in 1978, 1979 and 1980. In 1980, data were also successfully collected from the M.S.U. Muck Farm at Laingsburg for the first time during this study. In the two previous years, weeds had completely overrun the experimental field. No pesticides were used in this field and it was impossible to keep up manual weed control. The 1980 Muck Farm data were collected from another section of the farm (within the fence) where cultivation has been done yearly and also the weeds were under chemical control.

Figure 13, 1978, showed the mean number of adults per plant was either equal to or higher than that of the larvae at the beginning of the season but soon the predominant stage recorded was larvae. This is to be expected since the onions were planted from seeds which cannot harbour any larval thrips. The adults are the colonizers and they migrate into the field when the plant is only a few weeks old. As the adults reproduce, the numbers of larvae soon increased and these became the predominant stage. This phenomenon was shown even more clearly in 1979 (Fig. 14), where the thrips counted at the first date of sample was

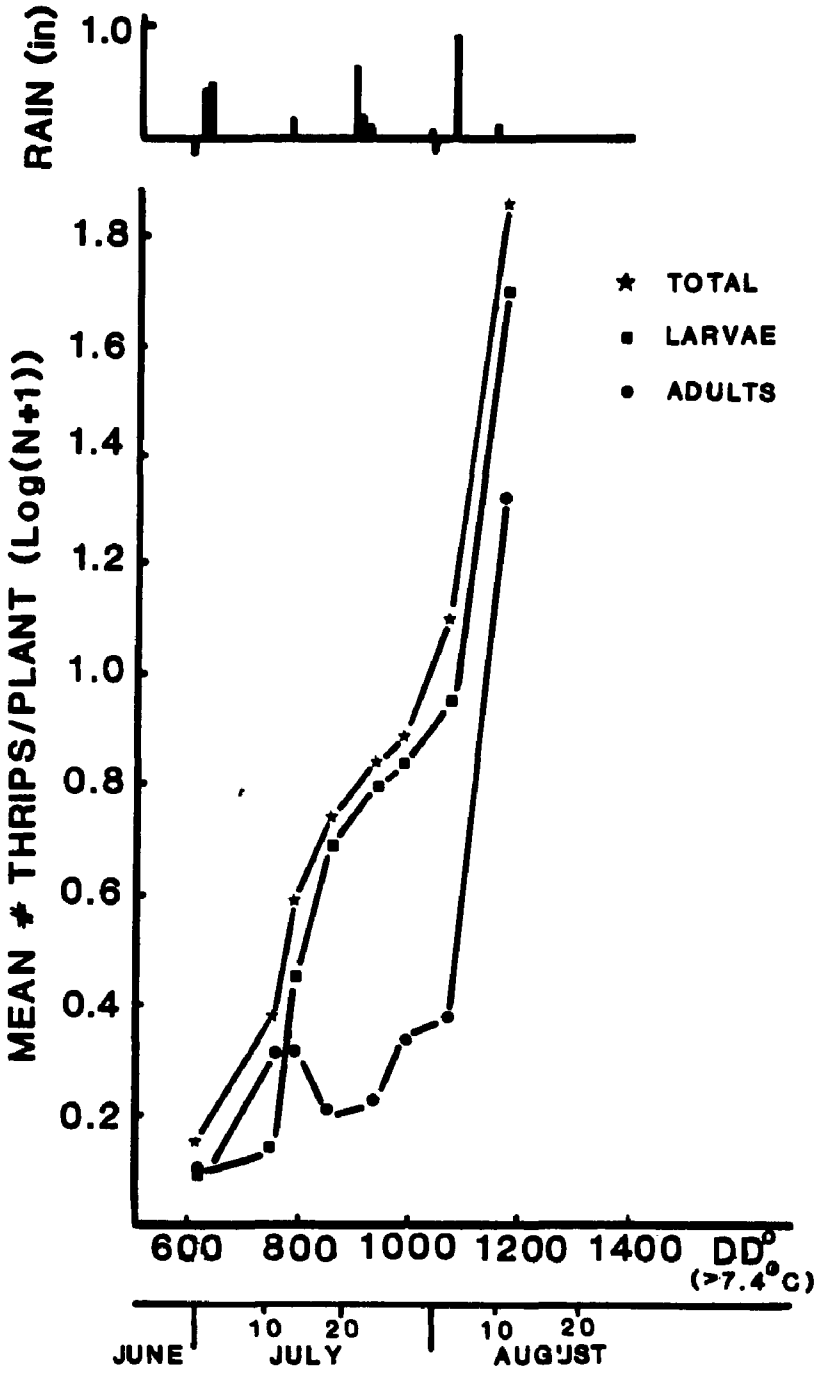


Figure 13. Population trend of onion thrips, Eaton Rapids, 1978.

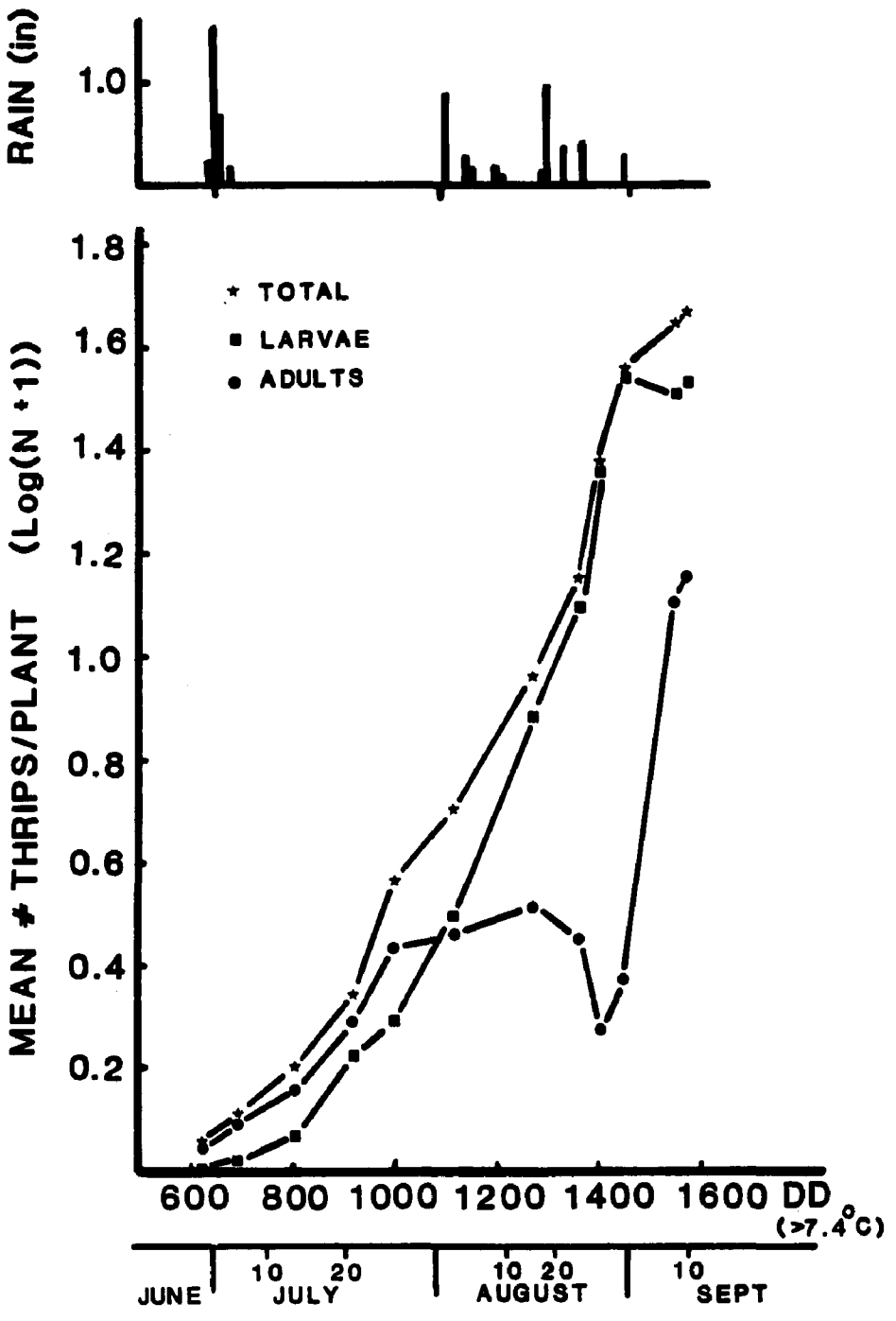


Figure 14. Population trend of onion thrips, Eaton Rapids, 1979.

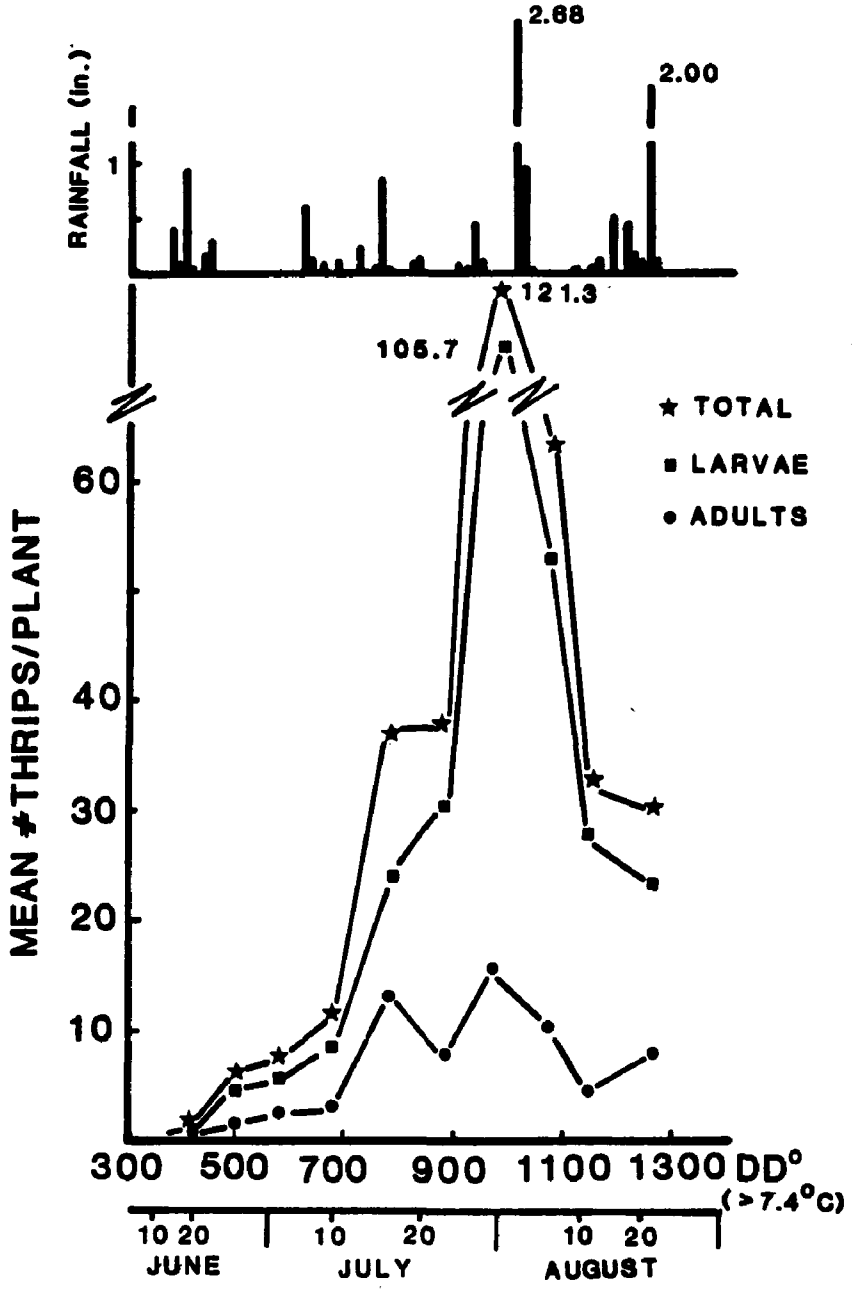


Figure 15. Population trend of onion thrips, Eaton Rapids, 1980.

comprised entirely of adults. It was necessary to transform the number of thrips per plant for some years to a log (N+1), since the numbers were extremely low at the beginning of the season compared to the number at the latter part of the season. This transformation spreads out the lower numbers relative to the larger numbers. The general pattern of the population buildup for the two stages combined, approached an exponential progression, particularly the 1979 data (Fig. 14), although this was not uniformly so. It is interesting to note that in both 1978 and 1979, the graphs for the adults show more perturbation than the larvae. The following reasons are suggested: a) a sudden rise in the adult numbers could be due to recent immigration into the field from adjacent onion fields or other crops e.g., alfalfa that has been cultivated, harvested, or disturbed in a manner that will cause resident thrips populations to emigrate. Larvae so disturbed cannot move beyond a few plants at best. b) since the adults occur more on the exposed parts of the leaves, they are more likely to be disturbed. The larvae, on the other hand, hide between the bases of the leaves and are thus protected until their numbers become high, in the middle to late season, when they can also be found on the exposed parts of the leaves.

The graph of the 1980 season (Fig. 15) showed a similar exponential rise in the numbers of thrips per plant (both stages together) until the end of July. The population crashed severely after this time due to heavy rainfall of

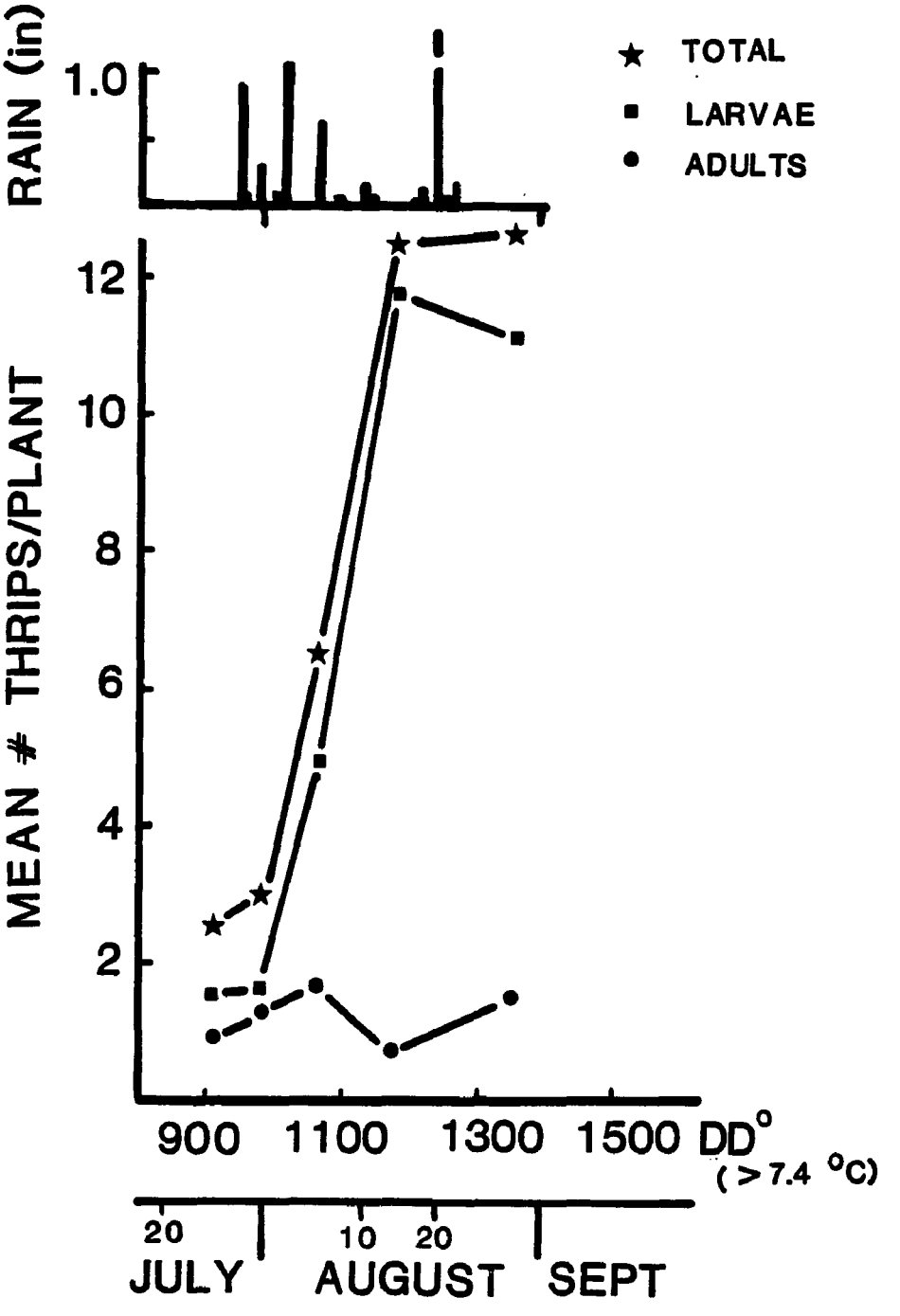


Figure 16. Population trend of onion thrips, M.S.U. Muck Farm, 1980.

Table 6. Chemical control of onion thrips, Thrips tabaci.

Treatment	lb ai/A	Harvest Data		Thrips count[1] (mean #/plant)				
		Yield (lb/10ft. row)	wt/bulb	7/25	7/31	8/7	8/14	8/28
Orthene 75WP	0.5	8.8	0.10	0.8b	1.4	1.8a	1.3a	0.7a
Orthene 75WP	0.75	9.4	0.10	0.7a	1.1	7.3b	11.4b	2.8ab
Orthene 75WP	1.0	9.0	0.11	1.0c	1.4	2.3a	1.6a	0.9a
Diazinon AG 500	0.5	8.2	0.11	1.3cd	1.6	12.8b	8.8ab	6.8ab
Untreated	---	9.1	0.10	1.5d	1.6	6.5b	12.4a	12.6b

[1]Means followed by the same letter are not significantly different (P>0.05, Student-Newman-Keuls, test of log transformed counts).

6.57 cm (2.68 in.) on August 2nd and 2.33 cm (.95 in.) the following day.

At the Muck Farm (1980), the population trend in the untreated onions again assumed an exponential pattern until mid-August and then flattened (Fig. 16). The mean number of thrips per plant in the untreated plots was significantly different from the treated plots on some dates (Table 6). This difference in numbers of thrips was not reflected in the bulb weights and there was no difference between treatments. Thrips infestation at the Muck Farm was generally low compared to Eaton Rapids where infestation at one point was over 120 thrips per plant.

4.2.1 Relationship between Thrips Infestations of Onions and Distance from Adjacent Field that is Chemically Protected

By the middle of the 1980 field season, it was noticed that the numbers of thrips per plant varied with the locations within the study area. The sampling design that was being used up to this time involved sampling a given number of randomly chosen plots on a particular date. The assignment of plots was done at the beginning of the season and the sampling scheme was not changed even though a pattern of uneven infestations was beginning to be noticed. Lower infestations seemed to occur in plots near an adjacent field where regular pesticide control was practiced. At the end of the season, the study area was divided into six parallel and equal blocks starting from one end of the field. Each block was 50 m long.

Table 7. Correlation coefficients of distance versus number of thrips.

Date	y-intercept	n	slope	r	sign. level
6-13-80	4.5	6	6.5	0.90	P > .01
6-19-80	34.7	5	10.1	0.46	P < .05
6-26-80	81.4	5	74.4	0.90	P > .01
7-2-80	-180.0	5	164.3	0.88	P > .01
7-10-80	-75.3	5	197.6	0.94	P > .01
7-16-80	380.0	5	1023.4	0.87	P < .01
7-23-80	1711.3	5	158.7	0.31	P < .05
8-6-80	2114.6	5	445.2	0.56	P < .05
8-13-80	2845.0	5	-349.5	-0.78	P < .01

For each date, regression analysis was conducted for distance away from this end versus the number of thrips found. Since the assignment of plots to the sampling dates was purely random, there was not a good control over plot distribution to each date. Fortunately, most dates had plots scattered over at least three blocks except July 30, 1980, so this date was deleted in the analysis. The correlation coefficients obtained showed a strong relationship between distance and infestation (Table 7).

The reason for this difference in rate of infestation with location along the length of the field may be due to the fact that to the northeastern side of the study area, just across the ditch and about 10 m away from the "zero end" of the field, is another grower's field where regular insecticide treatment is practiced. It is suggested here that insecticide drift from the adjacent field affords some protections to the onion plants near-by. However, the prevailing wind in the area originate from the south-westerly direction and could not account for the insecticide drift into the organically grown onions. A more thorough study will be needed to confirm and understand this uneven infestation rate within the study area.

4.2.2 Dispersion Pattern of Onion Thrips in the Field

The distribution of the onion thrips in the field gives an indication of how these insects occur in the habitat and hence how they should be sampled and is also important when considering the method to be used in analysing the data.

As stated earlier in the methods, the distribution may not be the same throughout the growing season and thus even though the early adult colonizers of the field may be assumed to be randomly distributed, this will be expected to change as the season progresses and the adults reproduce. To study this dispersion phenomenon, data from the early, middle and late season was analysed. The ratios of variance (s^2) to mean ($\bar{x}$), ($\bar{x}$ = number of thrips per plant, in this study), is less than unity for regular (or even) distribution, equals zero for random distributions, and greater than one for contagious distributions (Southwood, 1978). In the early part of the season, the variance/mean ratio was approximately equal to one, indicating a near random dispersion but became greater than one towards the middle and late seasons (Appendix Table 2). The population became even more clumped towards harvest. The non-random distribution of the onion thrips means some transformation of data is necessary for analysis.

In general, most statistical tools for analysing data require that the frequency distribution be normal which in turn means the variance should be independent of the mean, or better yet, the variance be homogenous. A normal distribution also means the individuals are randomly distributed in the field population. The following analysis was conducted on some of the 1980 data, using Taylor's Power Law (Southwood, 1978) to determine if the population was contagious and if so, what transformation was required for statistical analysis (Appendix Table 2). From this law, the relationship between

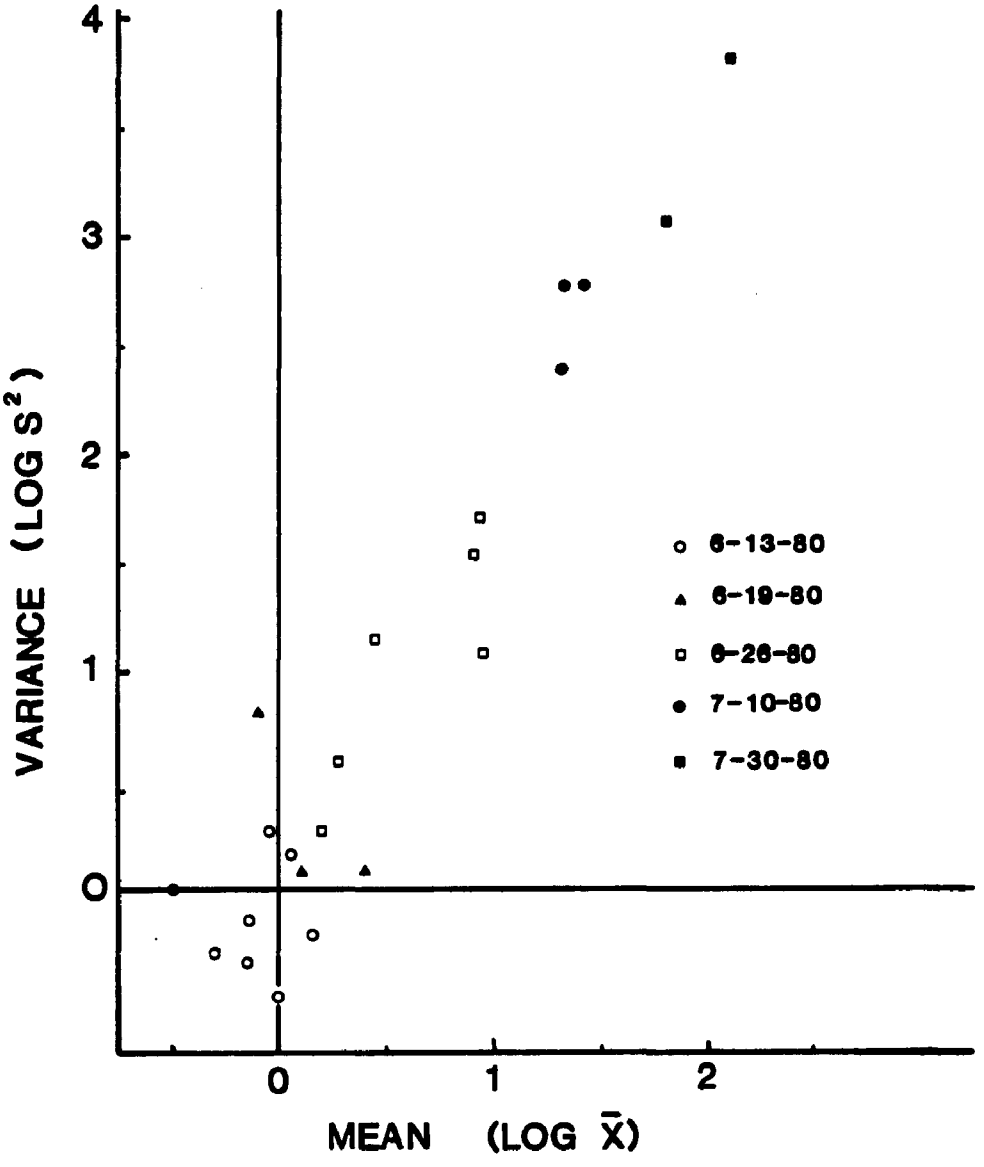


Figure 17. Relationship between variance and mean (number of thrips per plant) on log/log scale.

the variance, s^2 and the mean, $\bar{x}$ is given by

$$s^2 = a\,\bar{x}^b \text{ ----------(2)}$$

where a is largely a sampling factor and b is an index of aggregations characteristic of the species. The values of $\bar{x}$ and s^2 were plotted on a log/log scale (Fig. 17) and fitted to a straight line using linear regression. The log of equation (2)

$$\log s^2 = \log a + b \log \bar{x} \text{ ----------(3)}$$

is a straight line with "y-intercept" of 0.13, slope b of 1.68 and r of .97. The value of a in equation (3) is either read off on the s^2 axis at the point $\bar{x} = 1$ or calculated from the linear regression equation for $\bar{x} = 1$, remembering that the value for s^2 obtained at $\bar{x} = 1$ on the graph is the true intercept since log 1=0.0. Southwood (1978) gives the variance stabilizing transformation function,

$$f(\bar{x}) \text{ as } f(\bar{x}) = Q\int \bar{x} - {}^{b/2}\, d\bar{x} \text{ ---------(4)}$$

The transformation is obtained from the value of z in the equation:

$$z = x^p \text{ ----------(5)}$$

where x = the original (raw) number, z = the transformed value and $p = 1 - \frac{1}{2}b$. From the data used, $p = 1 - \frac{1}{2}(1.68) = 0.16$ and the transformed value, z is

$$z = x^{.16} \text{ ----------(6)}$$

Because of the contagiousness of the distribution of the onion thrips in the field, it would be necessary to transform the raw data obtained using equation (6) to adjust it to a normal distribution before making any statistical comparison.

4.3 Developmental Biology of *Thrips tabaci*

4.3.1 Relationship between Temperature and Rate of Development of *Thrips tabaci*

The results of rearing the larval, prepupal, and pupal stages of the onion thrips at various constant temperatures, are shown in Table 8. No complete development of any stage was observed at 5°C for up to 28 days except for one first instar that molted and died almost immediately after 25 days of observation. This suggests that 5°C is close to or below the lower developmental threshold for the immature stages. At 10°C, the development from first instar to the emergence of the adult took 62.9 days. The development for these same stages was much faster at 17°C and above. Thus only about 1.59% of the development occurs in one day at 10°C and 13.51% at 29°C (Table 8).

When the percent development per day (100/y) is plotted against temperature, a sigmoid-shaped temperature-velocity curve should be obtained, the middle portion of this curve being close to straight (Davidson, 1944). The plots for the first instar, second instar, prepupal and pupal stages are shown in Figures 18, 19, 20 and 21. Figure 22 is the temperature-velocity curve for the four immature stages together. It appears that the temperature range studied, 10°C to 29°C, falls within the middle straight line portion of the sigmoid curve. Addition of temperatures outside this range will provide the typical sigmoid curve which fits the equation:

$$\frac{1}{y} = \frac{K}{1+e^{a-bx}} \qquad \text{----------(1)}$$

Table 8. Mean developmental time and percent development per day (100/y) for the different stages of i.e. onion thrips at various constant temperatures.

Temp. °C	Larva 1		Larva 2		Prepupa		Pupa		Total	
X	y (± S.D)	100/y	y (± S.D)	100/y	y (± S.D)	100/y	y (± S.D)	100/y	y (± S.D)	100/y
5	No complete development after 28 days									
10	19.0±1.3	5.26	17.6±4.0	5.68	10.8±3.0	9.26	15.5±2.8	6.45	62.9±11.1	1.59
17	4.0±0	25.00	4.8±0.8	20.83	3.0±0.3	33.33	4.6±0.5	21.74	16.4±1.6	6.10
20	3.1±0.2	32.26	3.2±0.6	31.25	2.1±0.4	47.62	4.8±1.1	20.83	13.2±2.3	7.58
23	3.1±0.2	32.26	3.8±0.1	26.32	1.9±0.2	52.63	3.1±0.9	32.26	11.0±1.4	8.40
26	2.2±0.3	45.45	3.2±0.3	31.25	1.6±0.4	62.50	2.3±0.4	43.48	9.3±1.4	10.75
29	2.1±0.3	47.62	2.3±0.3	43.48	1.0±0	100.00	2.0±0	50.00	7.4±0.6	13.51

Table 9. Linear regression statistics for fitting temperature-velocity curve to straight line and K-values calculated from three equally spaced temperatures.

Stage	Regression statistic			P-value (=100/y) at			K
	y-intercept	slope	r	20°C	23°C	26°C	
1st instar	-15.07	2.23	.98	29.45	36.13	42.81	72.26
2nd instar	-10.19	1.76	.95	25.00	30.28	35.36	54.98
Prepupa	-38.09	4.27	.96	47.33	60.14	72.96	120.50
Pupa	-18.92	2.31	.98	27.20	34.12	41.04	68.24
Total	-4.40	0.59	.99	7.49	9.28	11.06	18.30

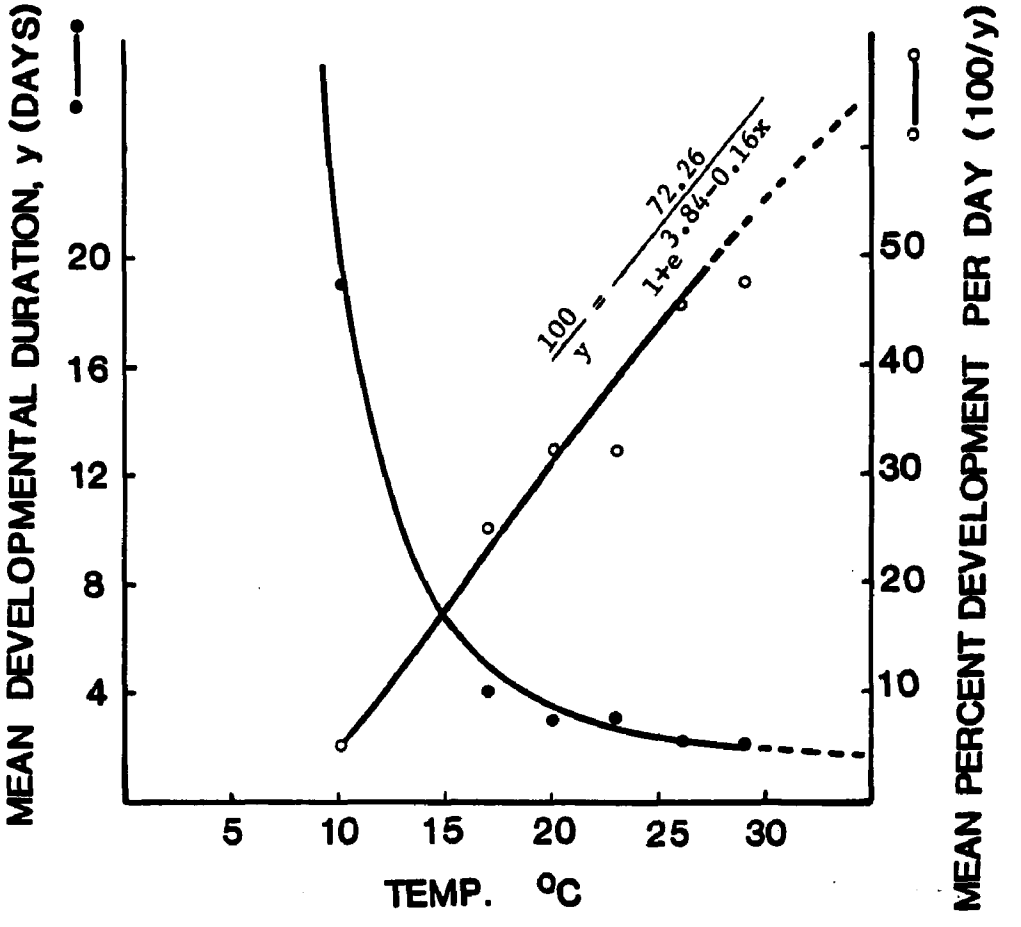


Figure 18. Temperature-velocity curve for first instar Thrips tabaci.

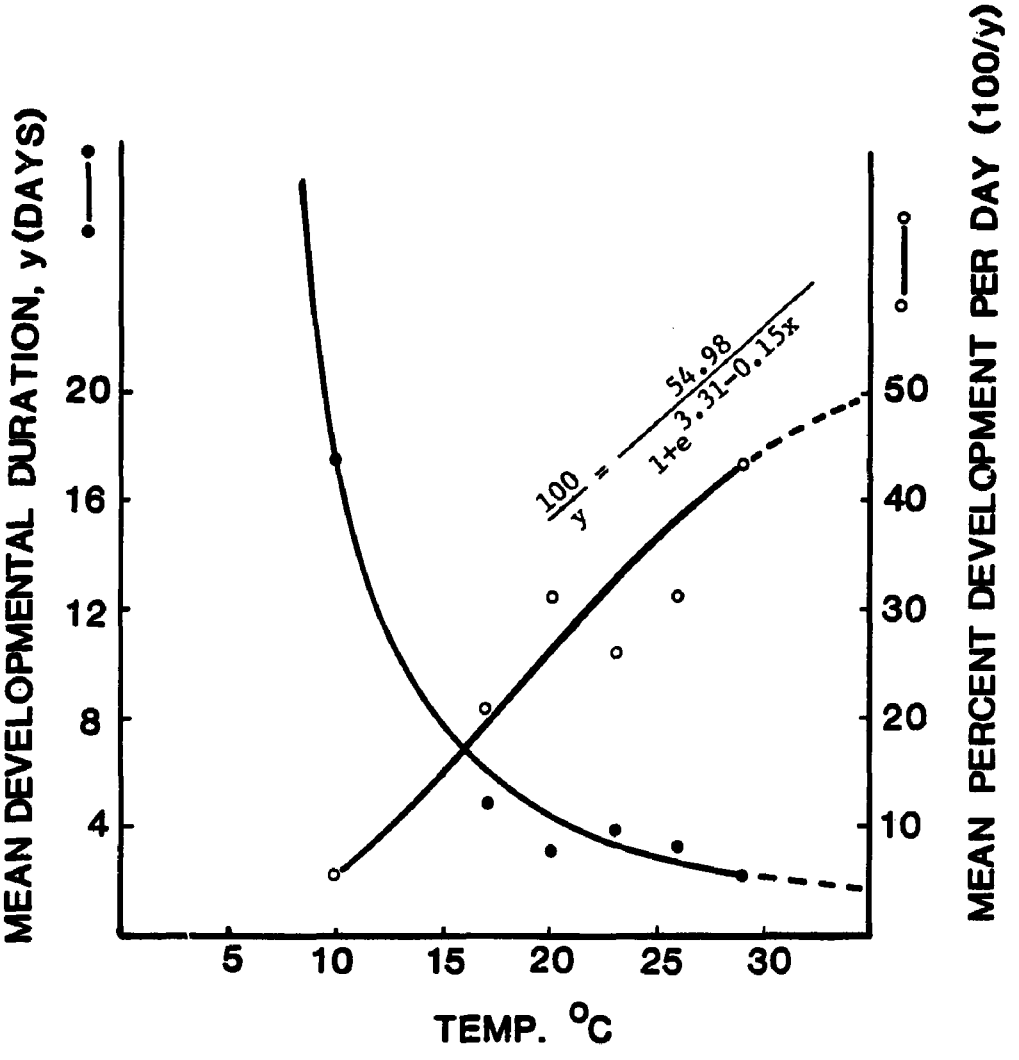


Figure 19. Temperature-velocity curve for second instar Thrips tabaci.

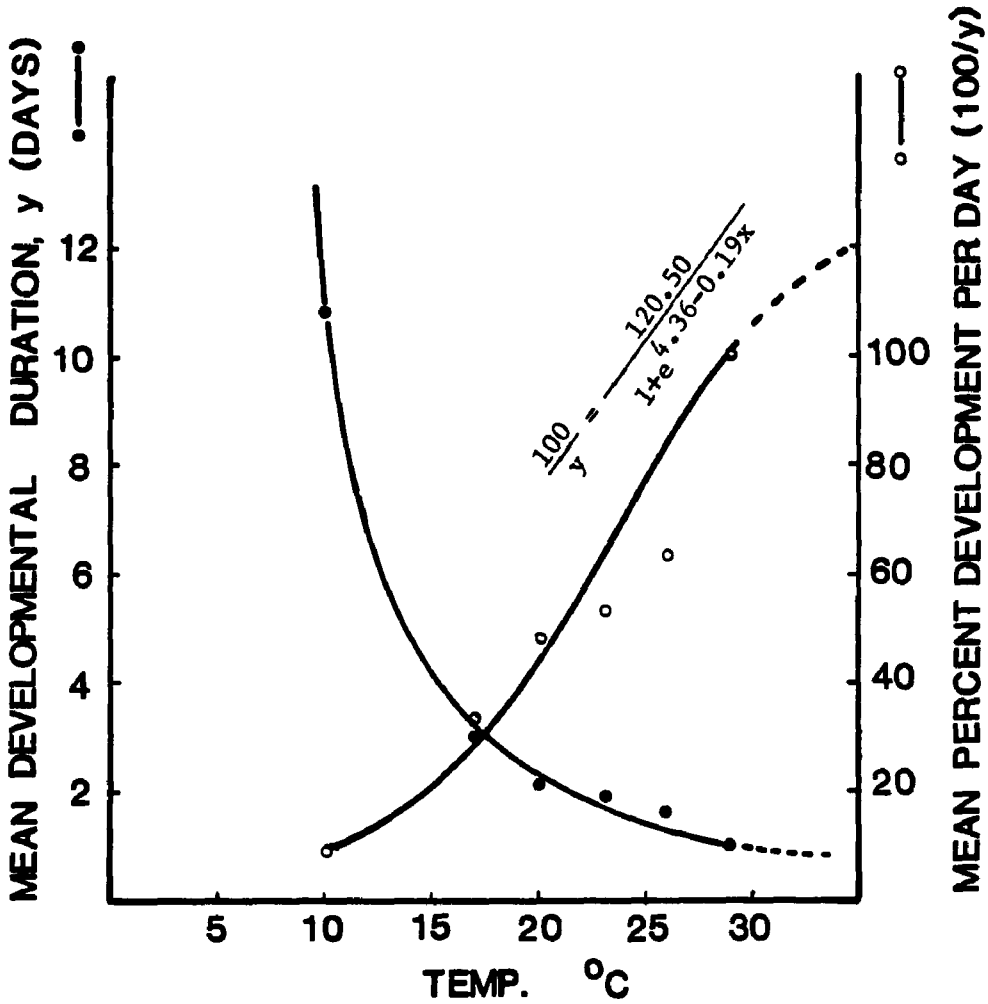


Figure 20. Temperature-velocity curve for prepupal stage of Thrips tabaci.

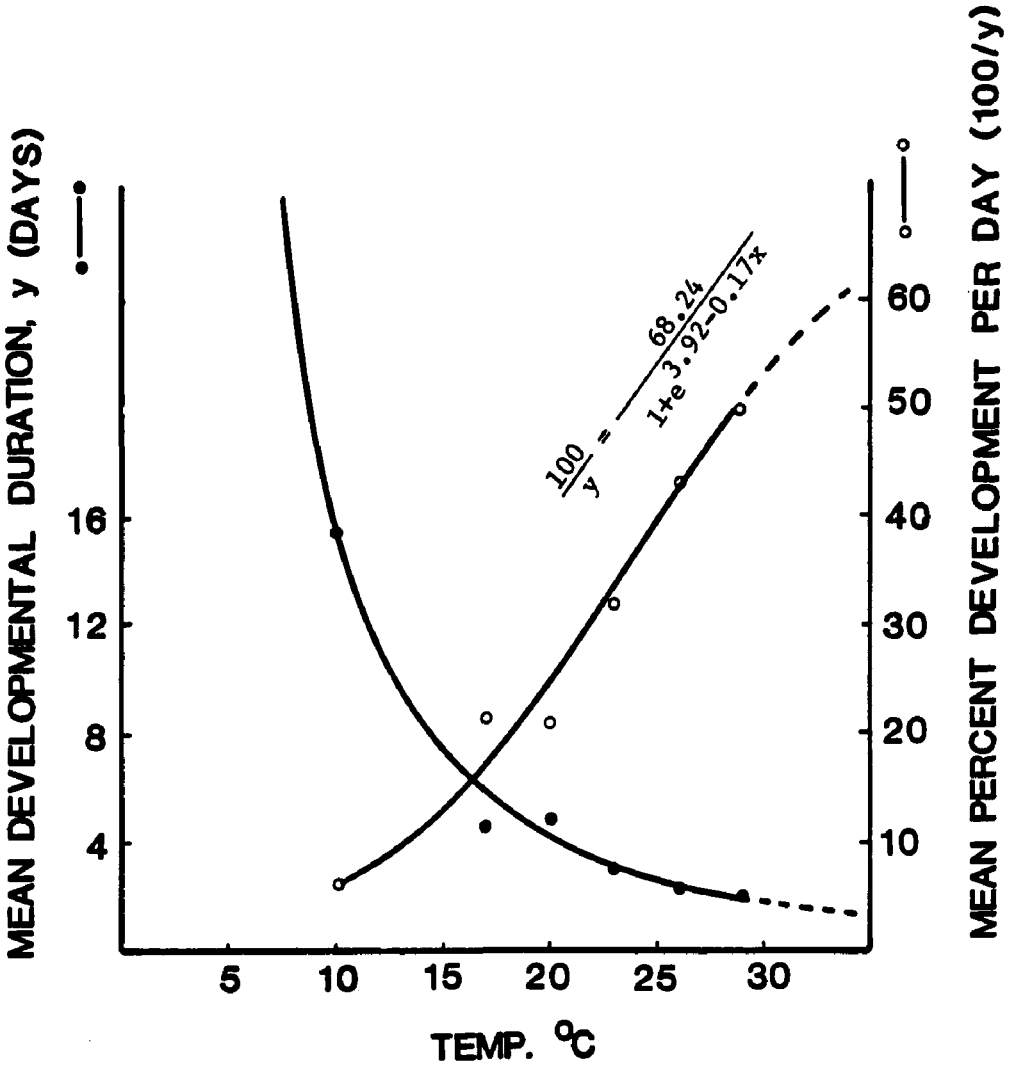


Figure 21. Temperature-velocity curve for pupal stage of Thrips tabaci.

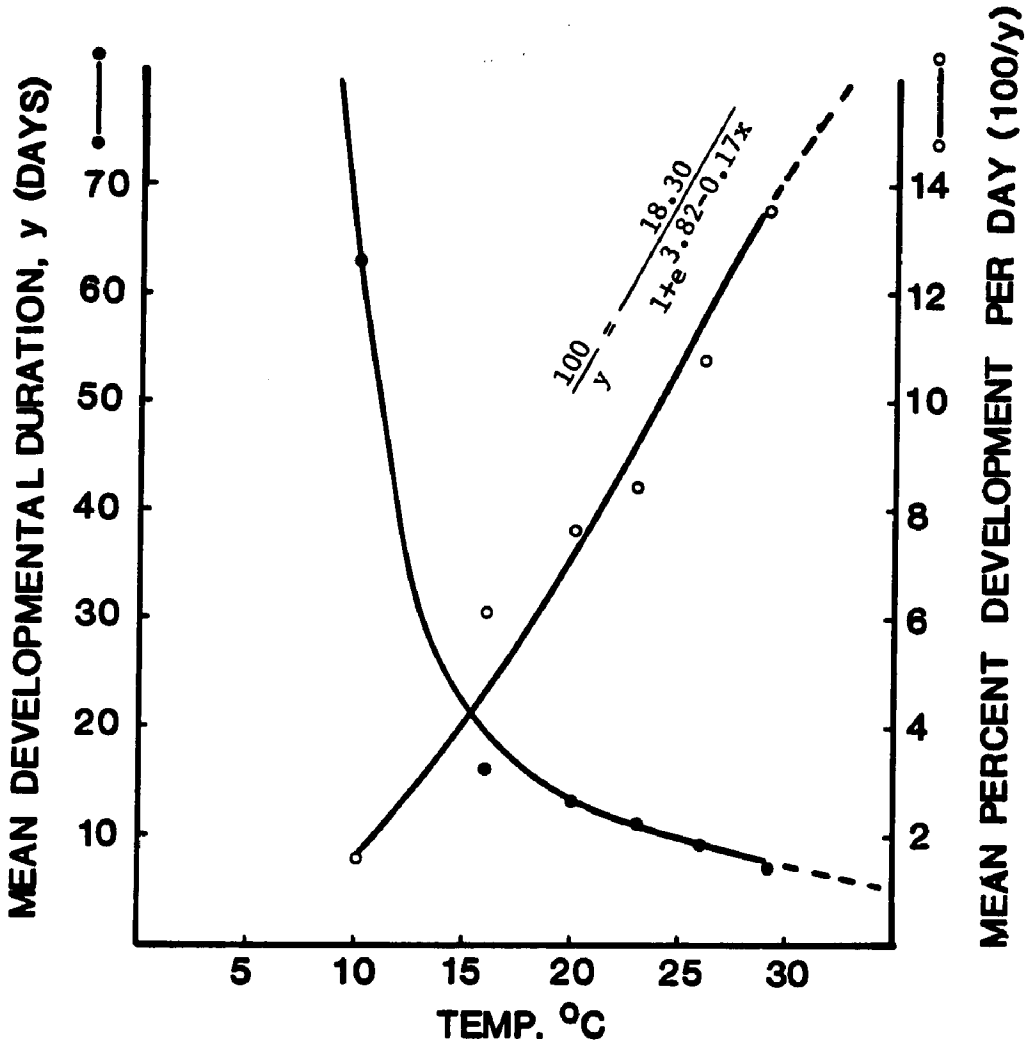


Figure 22. Temperature-velocity curve for four immature stages (1st and 2nd instar, prepupa and pupa) of Thrips tabaci.

where $\underline{y}$ is the developmental duration at a given temperature $\underline{x}$. The constants: K, $\underline{a}$ and $\underline{b}$ were explained previously. The parameter K, the upper asymptote could be assessed from the graph by inspection but because the temperature ranges studied did not include this asymptote, the following formula developed by Davidson (1944) was used to calculate K:

$$K = \frac{2P_1P_2P_3 - P_2^2 (P_1+P_3)}{P_1P_3 - P_2^2} \text{ ----------(2)}$$

where P_1, P_2 and P_3 are values for 100/y on the curve at three equally spaced temperatures. The percent development per day (100/y) for the various temperatures was fitted to a straight line by linear regression (Table 9) and the P_1, P_2 and P_3 for three equally spaced temperatures, 20^o, 23^o and 26^oC were obtained from the regression equation. Using Equation (2), K was calculated (Table 9).

To determine the parameters $\underline{a}$ and $\underline{b}$ from Equation (1), the value of (K-P)/P for each temperature was calculated for the straight line portions of the sigmoid curve (which for our data included the whole range studied). Fitting Equation (1) to a straight line yielded the parameters $\underline{a}$ and $\underline{b}$ as follows:

$$\frac{100}{y} = \frac{K}{1 + e^{a-bx}}$$

letting $P = \frac{100}{y}$, $\qquad P = \frac{K}{1 + e^{a-bx}}$

and hence $\qquad \frac{K-P}{P} = e^{a-bx}$

$$\text{Ln } \frac{K-P}{P} = a - bx \text{ ----------(3)}$$

Table 10. Straight line equations for ln[(K-P)/P] and the Logistic equations.

Stage	Straight line equations for $\ln[(K-P)/P] = a-bx$			Logistic equation: $\frac{100}{y} = \frac{K}{1+e^{a-bx}}$
	a	b	r	
1st instar	1.67	-0.07	-0.96	$\frac{100}{y} = \frac{72.26}{1+e^{3.84-0.16x}}$
2nd instar	1.44	-0.06	-0.91	$\frac{100}{y} = \frac{54.98}{1+e^{3.31-0.15x}}$
Prepupa	1.89	-0.08	-0.97	$\frac{100}{y} = \frac{120.50}{1+e^{4.36-0.19x}}$
Pupa	1.70	-0.07	-0.99	$\frac{100}{y} = \frac{68.24}{1+e^{3.92-0.17x}}$
Total	1.66	-0.07	-0.98	$\frac{100}{y} = \frac{18.30}{1+e^{3.82-0.17x}}$

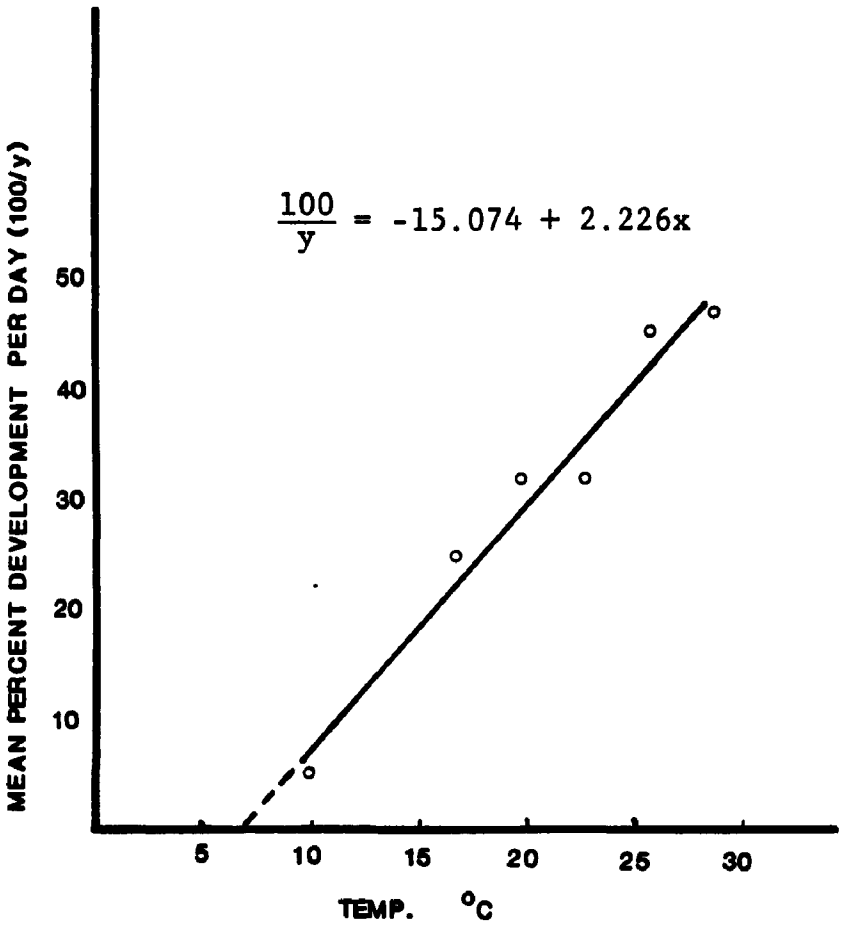


Figure 23. Lower temperature developmental threshold for first instar Thrips tabaci.

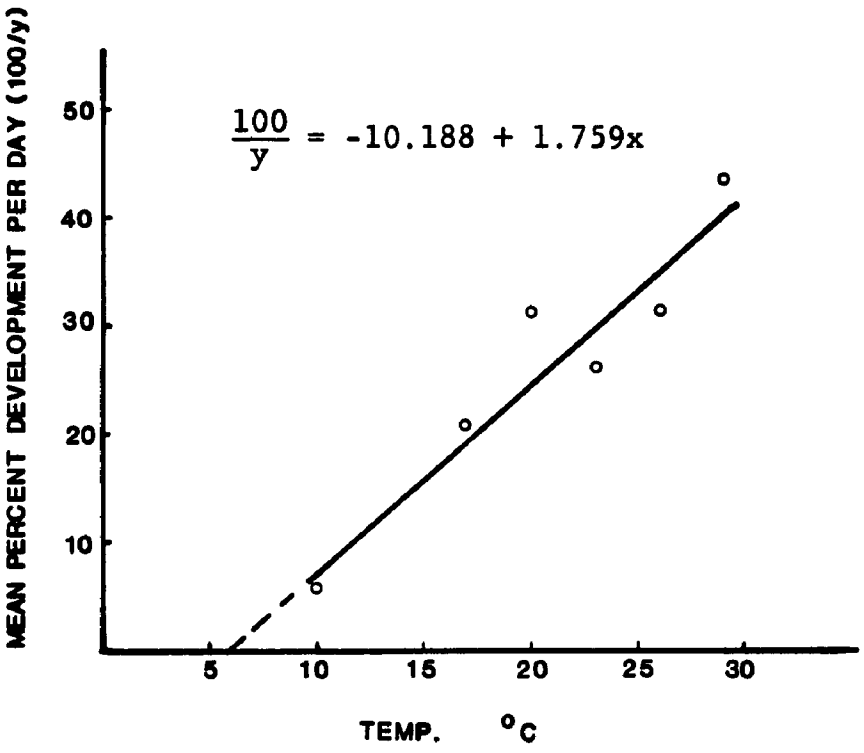


Figure 24. Lower temperature developmental threshold for second instar Thrips tabaci.

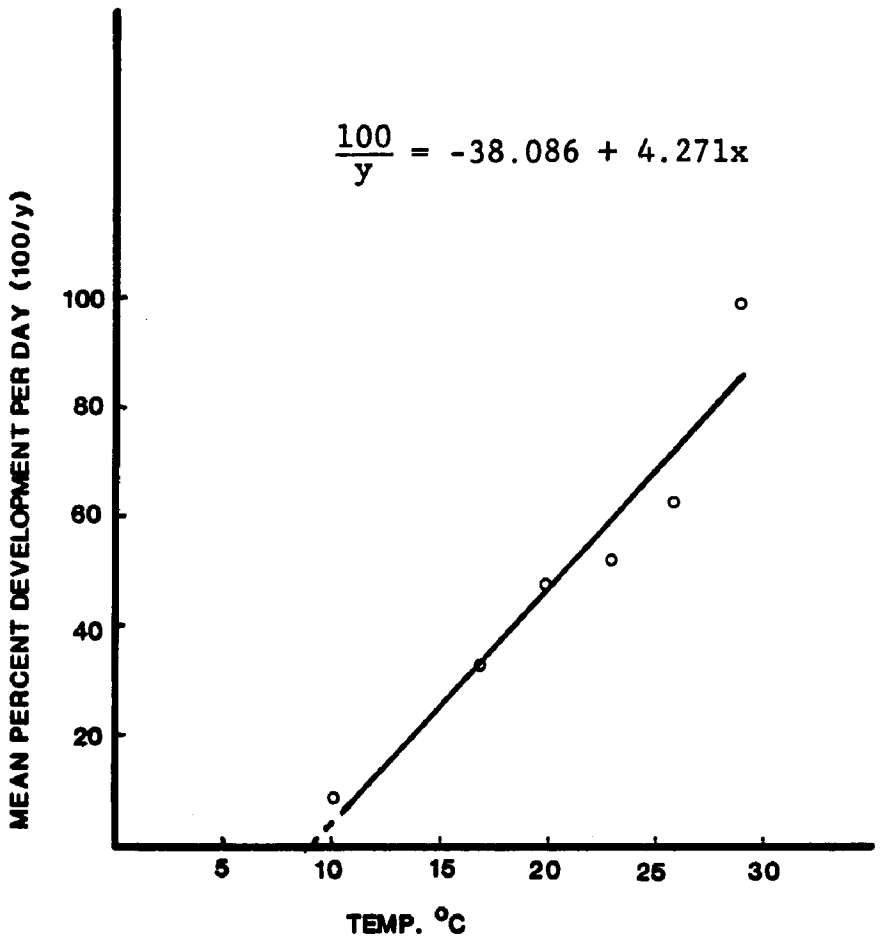


Figure 25. Lower temperature developmental threshold for prepupal stage of Thrips tabaci.

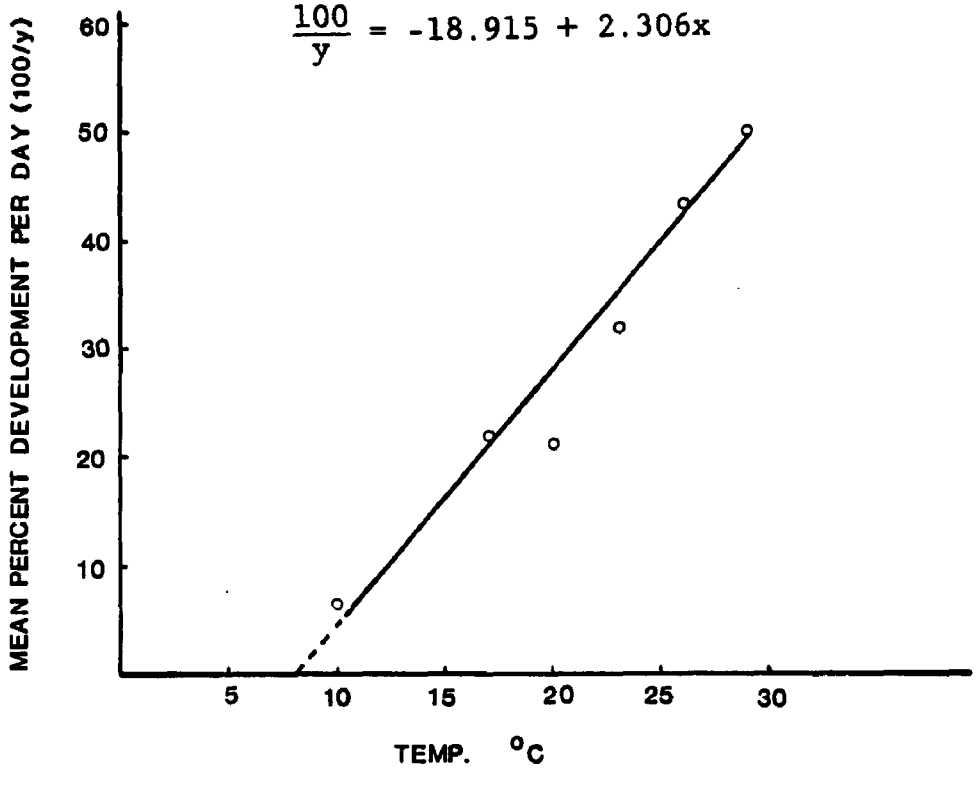


Figure 26. Lower temperature developmental threshold for pupal stage of Thrips tabaci.

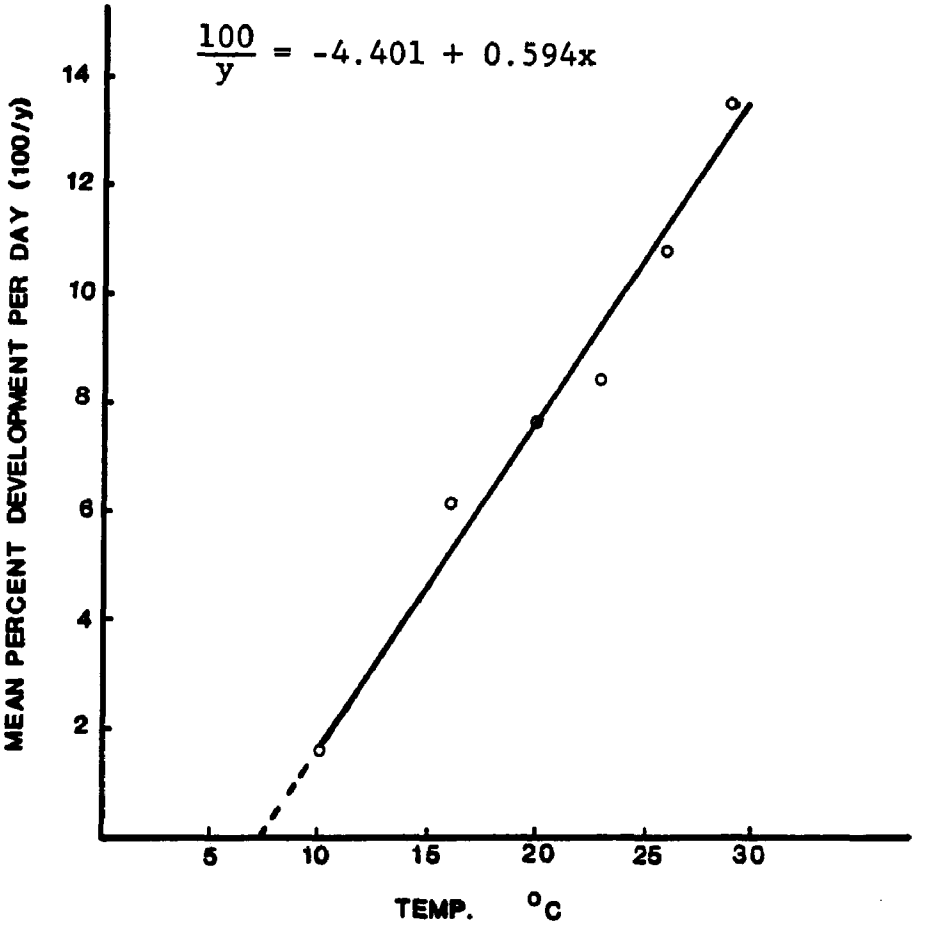


Figure 27. Lower temperature developmental threshold for immature stages of Thrips tabaci.

This is the form of the straight line, y - a-bx. The natural logarithms of (K-P)/P for the various values were fitted a straight line using linear regression (Table 10), from which the y-intercept and slopes were obtained.

4.3.2 Theoretical Lower Temperature Developmental Threshold of *Thrips tabaci*

The theoretical lower developmental threshold is the minimum temperature at which any development will occur. This is the point of interception of the linearised temperature-velocity curve and the temperature-axis or the extrapolated point of interception in this case. Table 11 gives the linear regression equation of the temperature-velocity curve which is of the form: $\frac{100}{y} = a-bx$

The lower developmental threshold is at the point y = 0 in the above equation. Figures 23, 24, 25, 26 and 27 show the graph for the different stages, and Table 11 shows, the calculated lower temperature development thresholds.

4.4 Developmental Biology of *Coleomegilla maculata*

The average developmental period through the four larval stages was found to be 22 days (Table 12). This was higher than what was observed in the continuous feeding predation experiment (see section 4.6) where it was insured that the larvae never ran out of onion thrips. In the predation experiment, the four larval stages together took an average of 13.9 days. The longer developmental period in the former experiment may be due to the fact that the larvae of *C. maculata* did not get enough thrips to eat.

Table 11. Theoretical lower temperature developmental thresholds, t, for various stages of *Thrips tabaci*.

Stage	Straight line equations $\frac{100}{y} = a - bx$	r	t°C
1st instar	$\frac{100}{y} = -15.074 + 2.226x$	.98	6.77°
2nd instar	$\frac{100}{y} = -10.188 + 1.759x$	.95	5.79°
Prepupa	$\frac{100}{y} = -38.086 + 4.271x$	.96	8.92°
Pupa	$\frac{100}{y} = -18.915 + 2.306x$	.98	8.20°
Total	$\frac{100}{y} = -4.401 + 0.594x$	.99	7.40°

Table 12. Developmental duration in days (mean ± S.D) of Coleomegilla maculata when reared under different conditions.

Temp. °C	24°	24°	24°	24°
R.H.	50%	50%	--	--
Food	Thrips tabaci	T. tabaci	Myzus persicae	Therioaphis maculata
Egg	4.5 ± 1.2	--	3.2 ± 0.1	2.8
1st instar	4.8 ± 0.6	3.83 ± 0.2	3.1 ± 0.1	3.0
2nd instar	3.9 ± 0.3	3.03 ± 0.6	2.0 ± 0.2	2.0
3rd instar	6.5 ± 0.8	3.63 ± 0.3	2.5 ± 0.1	2.3
4th instar	6.8 ± 1.1	3.42 ± 1.2	4.8 ± 0.3	3.5
Total larval	22.0	13.91	12.4	10.7
Pupa	5.2 ± 0.8	--	3.7 ± 0.3	6.7
Egg to Adults	31.7	--	19.3 ± 0.5	17.4
Reference	This study (Developmental biology)	This study (Predation experiments)	Obrycki and Tauber (1978)	Simpson and Burkhardt (1960)

Even though enough thrips were always present in the rearing containers, the thrips hid inside the hollow of the cut onion leaves and thus were not always accessible to the predators. The larval developmental period of 13.9 days (thrips-fed) is more comparable to 12.4 days obtained by Obrycki and Tauber (1978) using the green peach aphid, Myzus persicae (Sulzer) as host, and 10.7 days on the alfalfa aphid, Therioaphis maculata (Buck) (Simpson and Burkhardt, 1960) (Table 12). The experimental set up in both cases allowed the predator to easily obtain aphids coupled with the fact that the aphids are not very cryptic. The eggs from adult C. maculata that were fed onion thrips took longer, 4.5 days, to hatch compared to 3.2 days for those fed on green peach aphid (Obrycki and Tauber, 1978), and 2.8 days for those fed on the alfalfa aphid (Simpson and Burkhardt, 1960). No data from eggs of adult coccinellids that had been fed with thrips are available for comparison. Data was also not collected on the fecundity of the adult C. maculata.

The observations on the developmental duration of C. maculata that had been fed onion thrips shows that C. maculata can survive and reproduce on onion thrips but the cryptic nature of the onion thrips may affect the amount of food the predator can obtain and thus slow down developmental rate and possibly reduce its fecundity. In the field, Thrips tabaci are cryptic, particularly when they occur at low densities, so that the developmental rate C. maculata under field conditions may be even slower if the predator is to survive on only the onion thrips.

4.5 Population Studies on Coccinellids

4.5.1 Coccinellid Complex at Eaton Rapids and Laingsburg, 1979

The following species of coccinellids were trapped at both Eaton Rapids and the MSU Muck Farm at Laingsburg: Coleomegilla maculata DeGeer, Adalia bipunctata (Linnaeus), Coccinella transversoguttata Faldermann, Hippodamia tredecimpunctata tibialis (Say), H. parenthesis (Say), and Cycloneda munda (Say). Species identification was done by Daniel Young of M.S.U. Entomology department. Pitfall, flight interception, and sticky board traps were used at Eaton Rapids. Only sticky board traps were used at the Muck Farm. A summary of the catch of the various species is shown in Table 13. Because the specimens trapped were not identified immediately, all the adults caught at the beginning of the season were grouped together as "unidentified coccinellids".

C. maculata and H. tredecimpunctata were mistaken for two forms of the same species until late in the season when it was observed the proportion of the two "forms" had changed. A closer study of the two then confirmed that they were different species. The order of abundance of the coccinellids at Eaton Rapids was: C. maculata, H. tredecimpunctata, C. transversoguttata, with A. bipunctata, H. parenthesis and Cycloneda munda occurring in very low numbers. At the Muck Farm, C. maculata and H. tredecimpunctata were the most abundant, in that order, followed by A. bipunctata, C. munda,

Table 13. Numbers of adult coccinellids caught by three different trapping methods at Eaton Rapids and the Muck Farm, 1979.

Location	Trapping Method	CM+HT	AB	CT	HP	CMU	Undeterm.	TOTAL
Eaton Rapids	Pitfall (7/11 - 9/7/79)	66	0	11	3	0	25	105
	Flight Interception (6/25 - 9/7/79)	41	1	1	0	0	5	48
	Stickyboard (6/20 - 9/7/79)	136	4	25	4	3	516	688
	Total	243	5	37	7	3	546	841
	% Total Det. Sp.	82%	2%	13%	2%	1%		
Muck Farm	Sticky board	653	139	34	12	74	0	912
	% Total Det. Sp.	72%	15%	4%	1%	8%		

CM = Coleomegilla maculata
HT = Hippodamia Tredecimpunctata
AB = Adalia bipunctata
CT = Coccinella transversoguttata
HP = Hippodamia parenthesis
CMU= Cycloneda munda

C. transversoguttata and H. parenthesis. Besides occurring in low numbers and together accounting for 18% of the coccinellids trapped at Eaton Rapids and 28% at the Muck Farm, A. bipunctata, C. transversoguttata, H. parenthesis and C. munda appeared to prefer the grass and weed borders rather than the onion plants. Further studies will be needed to determine whether their low occurrence within the onion fields is because of the absence of the preferred food host or whether this environment is unsuitable for them. With regards to numbers and distribution, C. maculata and H. tredecimpunctata were considered as the two important coccinellid species in both Eaton Rapids and the Muck Farm.

To compare numbers occurring at the two locations studied, only the sticky board trap method was used since this was the only method common to both locations. The plot at the Muck Farm was designed not to receive any pesticide applications and all weeds were controlled mechanically. Unfortunately, data was collected here only up to the end of July 1979, when the plot was overrun by weeds. Even though the sticky board traps were not checked on the same days at both locations, the data from Eaton Rapids was grouped to obtain similar trapping dates and durations (taken from Table 13) as at the Muck Farm. The catch for each period was converted to catch X 100 traps $^{-1}$ X day $^{-1}$ (Table 14). Analysis of variance showed no significant difference between the two locations ($F = 5.548$, $p>0.05$).

Table 14. Comparison of the total stickyboard trap catch of coccinellids (catch x 100 traps^{-1} x day^{-1}) for similar periods and trapping durations at Eaton Rapids and thr Muck Farm, 1979.

EATON RAPIDS				MUCK FARM			
Date	Trapping Days	# of Traps	Catch x 100traps^{-1} x day^{-1}	Date	Trapping Days	# of Traps	Catch x 100traps^{-1} x day^{-1}
7-06-79	7	29	196	7-04-79	9	16	72
7-12-79	6	29	189	7-11-79	7	16	125
7-20-79	8	9	269	7-20-79	9	16	122
7-28-79	8	9	97	7-27-79	7	16	71

4.5.2 Vertical Distribution of Adult Coccinellids

The vertical flight distribution of the adult coccinellids was studied using sticky board traps. These were the same traps used for the population studies and were marked into 30 cm segments along their heights.

Muck Farm, 1979: In 1979, this study was conducted only at the Muck Farm. The traps were located within and along the borders of the onion plot. Trapping was done once a week in the month of July. The study period was short enough to allow the assumption that no appreciable increase in onion plant height occurred during this period. In general, onion plants do not grow tall enough during the season to grossly alter the flight behavior of any adult coccinellids that prefer to fly above the plant tops. This assumption becomes very crucial if the traps are located among plants whose height increase appreciably during the growing season. Only the three abundant species, C. maculata, H. tredecimpunctata and A. bipunctata were used, the first two being grouped together because of misidentification. The number of adults occurring at the four heights were converted to their percentage of the catch (Appendix Table 3), thus emphasizing the proportion of the species at that height even though the procedure overemphasized low catches. This was necessary because the number of traps dropped from 29 to 9 after the second monitoring owing to a shortage of tanglefoot. These results are shown in Figure 28. A comparison of the percentage occurrence of the adults at the different

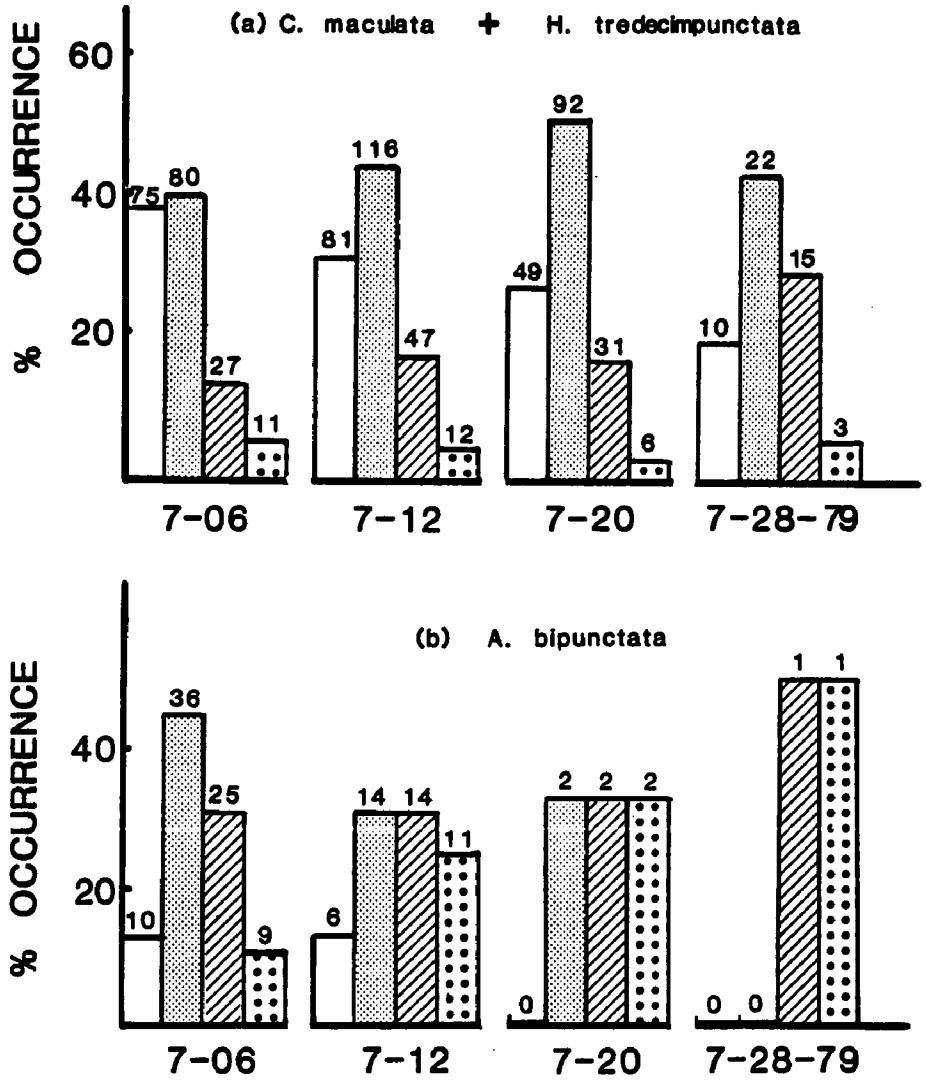


Figure 28

Vertical distribution of coccinellids on stickyboard traps, in onions through the season, at the M.S.U. Muck Farm, 1979 (a) Coleomegilla maculata plus Hippodamia tredecimpunctata, (b) Adalia bipunctata.

heights (one-way analysis of variance) considering the four sample dates as replicates, showed there was a significant difference ($F = 34.09$, $p = .01$) in the vertical distribution of C. maculata and H. tredecimpunctata but not for A. bipunctata. C. maculata and H. tredecimpunctata together show a strong preference for a flight altitude of 0.3 - 0.6 m and 0 - 0.3 m in that order and little preference for altitudes above 0.9 m (Table 15).

Muck Farm, 1980: This study was repeated in 1980 at the Muck Farm in a field of sorghum and at Eaton Rapids in fields of winter wheat and spring oat. Records were taken for the same three species as the year before. At the Muck Farm, 15 traps were used and trapping was done for a five week period, July 1 to August 7. In general, the numbers of C. maculata were higher at the beginning of the assessment period and declined thereafter (Appendix Table 4). An analysis of variance of the vertical distribution of C. maculata when the five sampling dates are considered as replicates (i.e., assuming no drastic changes in plant height), yielded no significant difference in the preference to the height segments (Table 16). However, a closer look at the data, showed that a high proportion of adults, 63%, preferred the lower 0 - 0.3 m height early in the season and very few occurred at the higher levels (0.9 - 1.2 m) (Appendix Table 4). This trend was followed through the next three weeks although there was a gradual shift in proportion towards the middle levels (0.3 - 0.9 m). By the final week of July and the

Table 15. Summary of vertical distribution of coccinellids caught on stickyboard traps located in onions at the Muck Farm, Laingsburg, 1979.

Height (m)	Mixed Pop. of CM & HT		AB	
	Mean %	f-test	Mean %	f-test
0 - .3	29.75a	34.09**	6.50	3.419 n.s.
.3 - .6	45.50b		27.25	
.6 - .9	19.75c		36.25	
.9 - 1.2	5.00d		29.75	

**f-test significant at p = 0.01.

Means followed by the same letter are not significantly different on Student-Newman-Keuls multiple range test, p = 0.05.

Table 16. Summary of vertical distribution of coccinellids on 15 stickyboard traps located in spring sorghum at the Muck Farm, Laingsburg, 1980.

Height (m)	Coleomegilla maculata		Hippodamia tredecempunctata		Adalia bipunctata	
	Mean %	F-test	Mean %	F-test	Mean %	F-test
0 - .3	35.40a	1.49 n.s.	4.60a	11.831**	12.00a	5.629**
.3 - .6	29.20a		52.40c		9.60a	
.6 - .9	20.20a		27.20b		53.20b	
.9 - 1.2	15.00a		15.80ab		21.20a	

*F-test significant at p = 0.05.

**F-test significant at p = 0.01.

Means followed by the same letter are not significantly different on Student-Newman-Keuls multiple range test, p = .05.

Figure 29. Vertical distribution of coccinellids on stickyboard traps, in sorghum through the season, at the M.S.U. Muck Farm, 1980 (a) Coleomegilla maculata, (b) Hippodamia tredecimpunctata, (c) Adalia bipunctata.

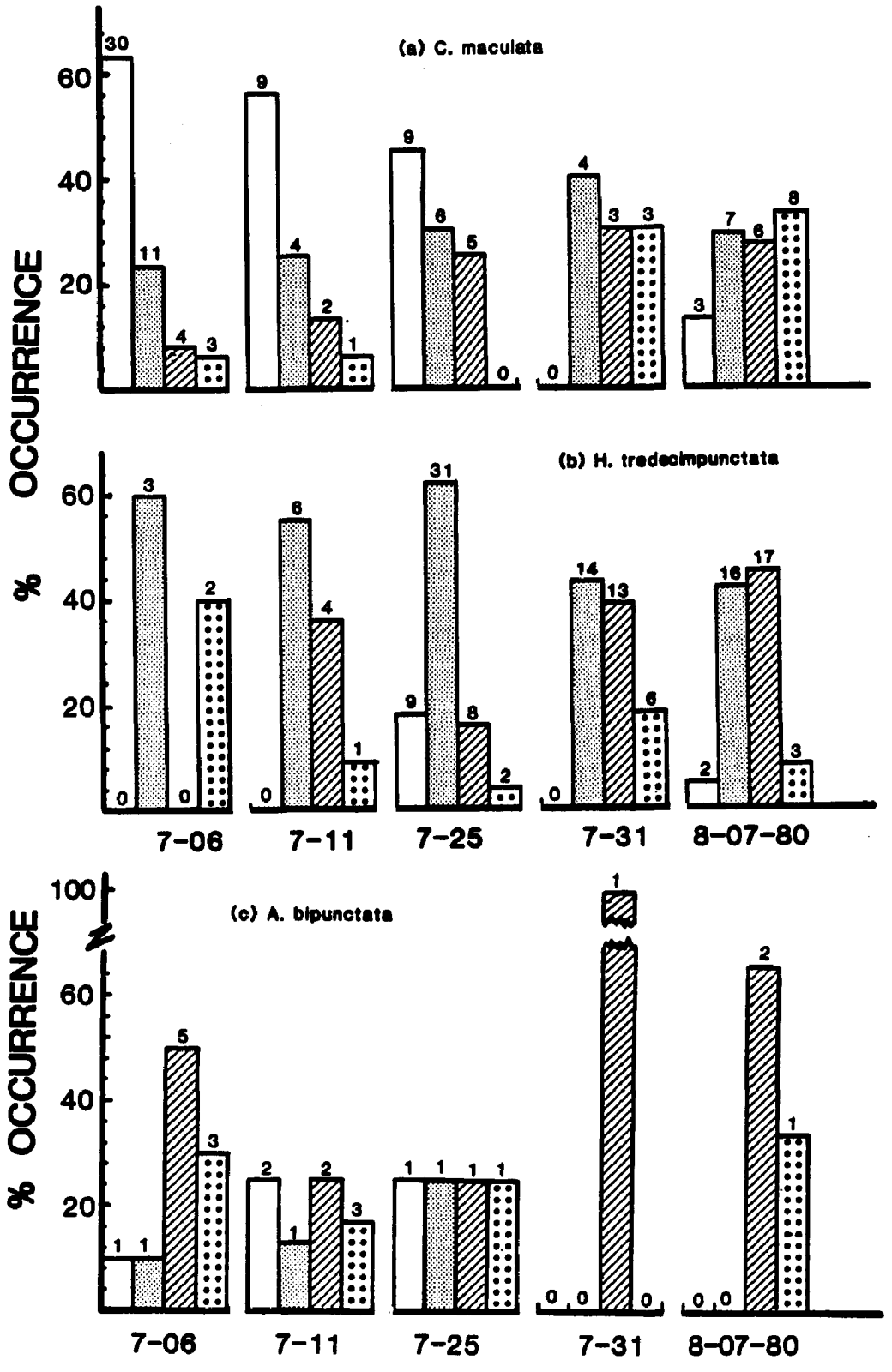

(a) C. maculata
% OCCURRENCE
60
40
20
30
11
4
3
9
4
2
1
9
6
5
0
0
4
3
3
3
7
6
8
(b) H. tredecimpunctata
% OCCURRENCE
60
40
20
3
0
0
2
6
4
1
0
31
9
8
2
14
13
6
0
16
17
2
3
7-06
7-11
7-25
7-31
8-07-80
(c) A. bipunctata
% OCCURRENCE
100
60
40
20
1
1
5
3
2
1
2
3
1
1
1
1
1
0
0
0
2
0
0
1
7-06
7-11
7-25
7-31
8-07-80

Figure 29.

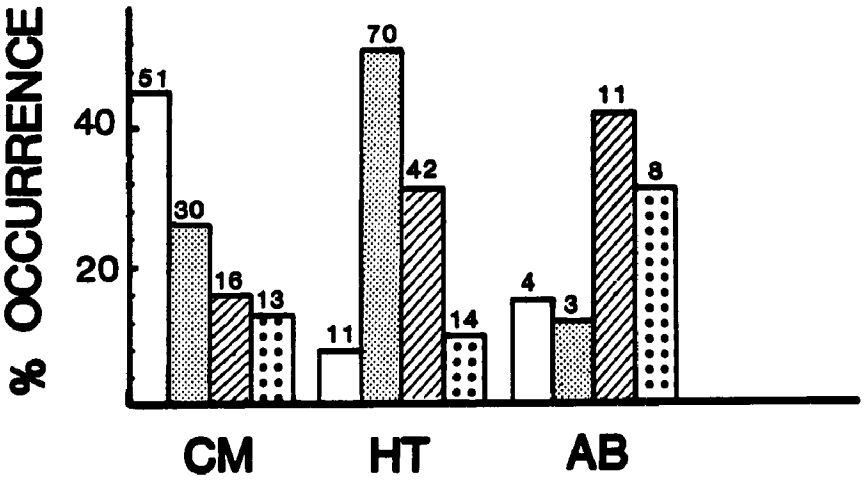


Figure 30. Vertical distribution of coccinellids on stickyboard traps, in sorghum, at the M.S.U. Muck Farm, 1980 (all trapping dates together).

first week of August, the weight of the distribution was heavy at the middle and upper levels and very weak at the lowest level (Fig. 29). It appears then that the assumption about the data being of the "same population" over the 5 week period which allowed these dates to be treated as replicates was not valid. A separate ANOVA for the first 3 weeks showed there was a strong preference for the lowest levels (0 - 0.3 m), ($F = 30.83$, $p = 0.01$), compared to the other height segments (Table 17). However, for the last 2 sampling dates, C. maculata avoided the lower levels and preferred the upper levels ($F = 7.92$, $p = 0.01$) (Table 17). This shows that there was a change in flight height as the season progressed, attributable to the increase in height of the sorghum plants. The sorghum was planted in late June and, by the fourth week of July, was about 0.6 - 0.8 m tall. Adult C. maculata were thus flying just above the plants and altering their elevations as the plants grew taller. Over the five weeks period, larger numbers of C. maculata occurred at 0 - 0.3 m (Fig. 30).

Compared to C. maculata, fewer adults of H. tredecimpunctata were trapped at the beginning of the sampling period but the number increased towards the end (Fig. 29). This confirms the observation in 1979 that the numbers of H. tredecimpunctata increased and they became the predominant coccinellid species towards the end of the growing season. Over the 5 weeks sampling period, the proportion of H. tredecimpunctata occurring at the middle level was significantly higher ($F = 11.83$, $P = .01$)

Table 17. Vertical distribution of C. maculata in sorghum during the periods 7-06-80 to 7-25-80 and 7-31-80 to 8-07-80 at the Muck Farm.

Height (m)	7-06-80 to 7-25-80 Mean %	F-test	7-25-80 to 8-07-80 Mean %	F-test
0 - .3	54.67a	30.83**	6.50a	7.92**
.3 - .6	26.00b		34.50b	
.6 - .9	15.33b		27.50b	
.9 - 1.2	4.00b		32.50b	

**Significant at p = 0.01.

Means followed by the same letter are not significantly different on Student-Newman-Keuls multiple range test, p = 0.01.

Figure 31. Vertical distribution of coccinellids on stickyboard traps, in winter wheat (July 2 through July 23, 1980) at Eaton Rapids (a) C. maculata, (b) H. tredecimpunctata, (c) A. bipunctata.

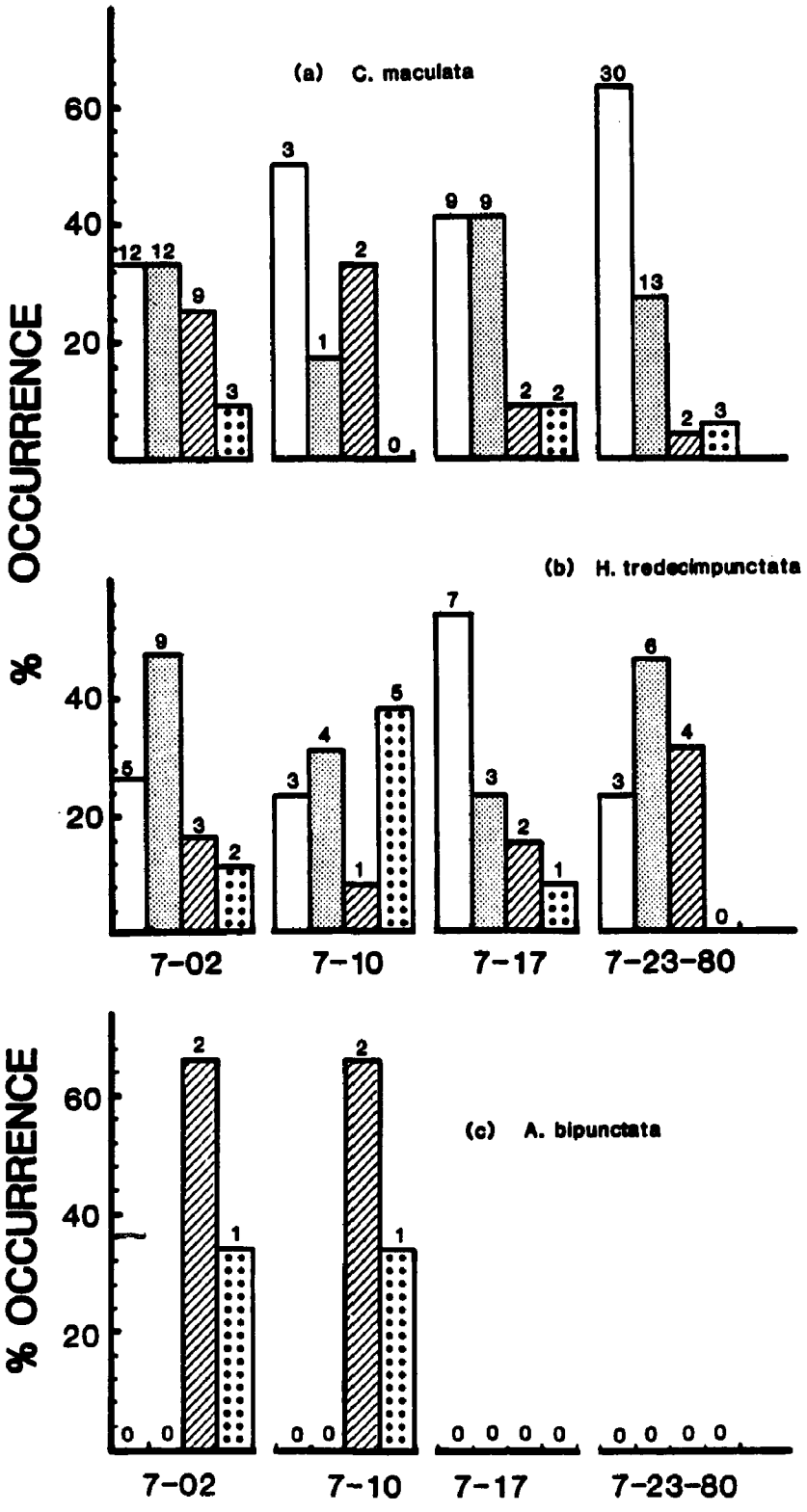

(a) C. maculata
% OCCURRENCE
60
40
20
12 12 9 3
3 1 2 0
9 9 2 2
30 13 2 3
(b) H. tredecimpunctata
% OCCURRENCE
40
20
5 9 3 2
3 4 1 5
7 3 2 1
3 6 4 0
7-02
7-10
7-17
7-23-80
(c) A. bipunctata
% OCCURRENCE
60
40
20
0 0 2 1
0 0 2 1
0 0 0 0
0 0 0 0
7-02
7-10
7-17
7-23-80

Figure 31.

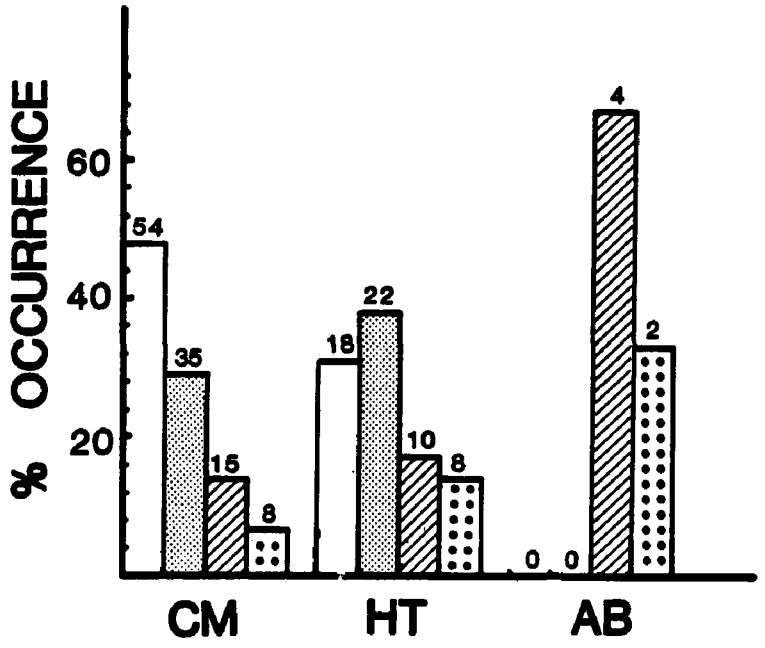


Figure 32. Vertical distribution of coccinellids on stickyboard traps, in winter wheat, at Eaton Rapids, 1980 (all trapping dates together).

than the lowest and highest levels (Appendix Table 4 and Table 16). The preferred flight height for H. tredecimpunctata then was 0.3 - 0.6 m (Fig. 30) and did not alter much during the five weeks observation period even though the sorghum plants increased in height to 0.6 - 0.8 m.

Adalia bipunctata occurred in very low numbers compared to the previous year and, even though they seemed to prefer flying at 0.6 - 0.9 m, the generally low numbers makes this a questionnable conclusion (Appendix Table 4, Figs. 29 and 30).

Eaton Rapids, 1980 -- Winter Wheat: Adults of both C. maculata and H. tredecimpunctata occurred in fairly good numbers during the period of trapping, July 2, 1980 to July 23, 1980, with C. maculata being almost twice as abundant as H. tredecimpunctata and again A. bipunctata being rare (Figures 31 and 32) (Appendix Table 5). Analysis of variance of the vertical distribution showed C. maculata strongly preferred the lowest level, 0 - 0.3 m, but H. tredecimpunctata and A. bipunctata did not show any preference (Table 18). However, the raw data seems to indicate H. tredecimpunctata preferred the lower two levels whereas the six A. bipunctata trapped preferred the upper level. C. maculata in winter wheat did not show the change in flight height that was observed at the Muck Farm in sorghum. This difference might be explained as follows -- the winter wheat was present in the field before the overwintered adult coccinellids migrated into the field and thus served as the host plant

Table 18. Summary of vertical distribution of coccinellids caught on 10 stickyboard traps located in winter wheat at Eaton Rapids, 1980.

Height (m)	Coleomegilla maculata		Hippoclamia tredecempunctata		Adalia bipunctata	
	Mean %	F-test	Mean %	F-test	Mean %	F-test
0 - .3	46.75	10.302**	31.50a	2.571 n.s.	0a	2.186 n.s.
.3 - .6	29.50b		36.75a		0a	
.6 - .9	17.75ab		17.70a		33.00a	
.9 - 1.2	6.00a		14.25a		17.00a	

**F-test significant at p = 0.01.

Means followed by the same letter are not significantly different on Student-Newman-Keuls multiple range test, p = 0.05.

Table 19. Summary of vertical distribution of coccinellids caught on 11 stickyboard traps located in or adjacent to spring oat at Eaton Rapids, 1980.

Height (m)	Coleomegilla maculata		Hippodamia tredecempunctata		Adalia bipunctata	
	Mean %	F-test	Mean %	F-test	Mean %	F-test
0 - .3	26.50ab	5.010*	23.50ab	4.027*	2.25a	6.159*
.3 - .6	44.75b		42.25b		11.75ab	
.6 - .9	21.00ab		29.00ab		30.50ab	
.9 - 1.2	7.75a		5.25a		55.50b	

*F-test significant at p = .05.

Mean followed by the same letter are not significantly different on Student-Newman-Keuls multiple range test, p = 0.05.

Figure 33. Vertical distribution of coccinellids on stickyboard traps, in spring oat (July 2 through July 23, 1980) at Eaton Rapids, (a) C. maculata, (b) H. tredecimpunctata, (c) A. bipunctata.

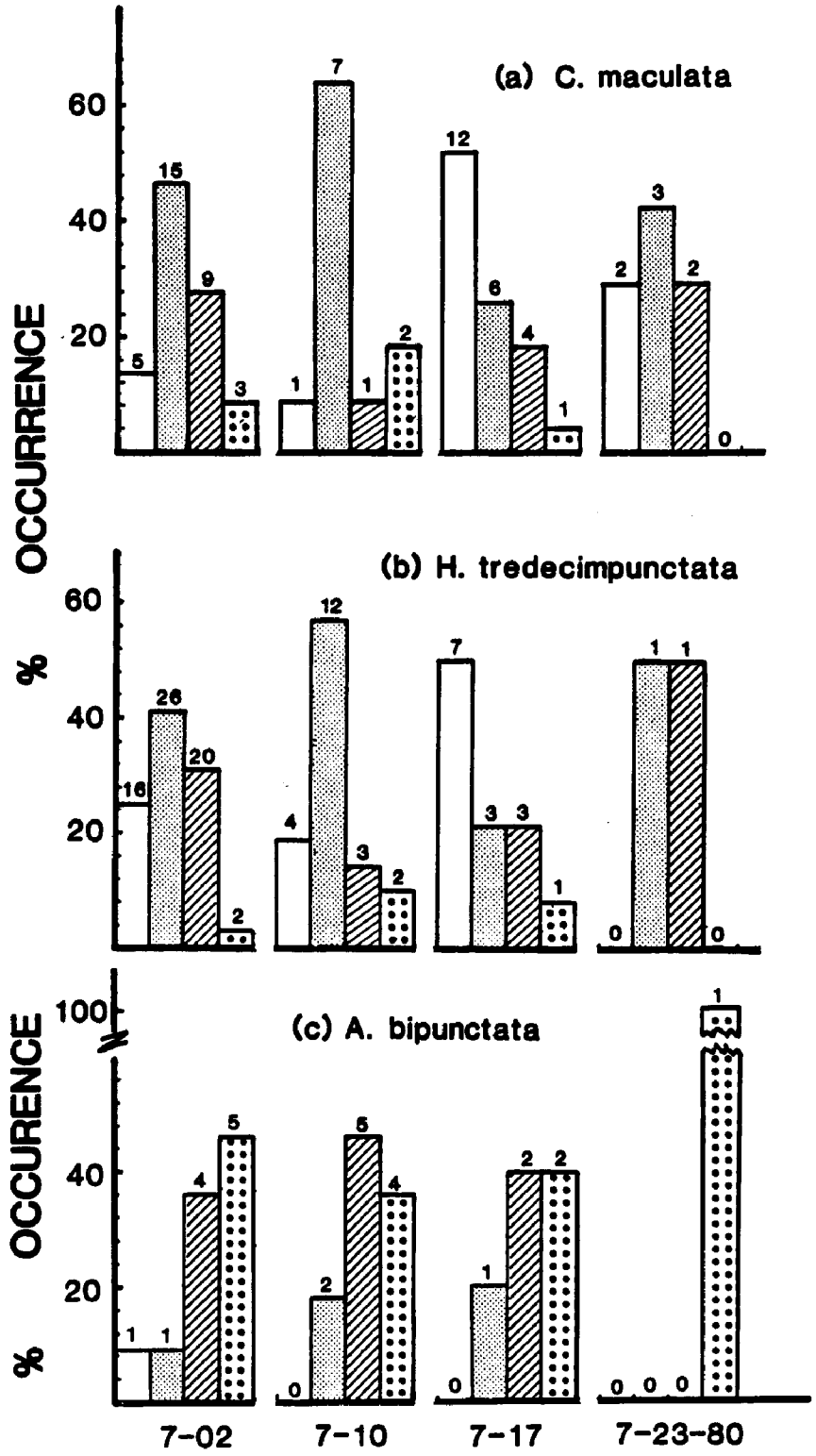

(a) C. maculata
(b) H. tredecimpunctata
(c) A. bipunctata
% OCCURRENCE
% OCCURENCE
7-02
7-10
7-17
7-23-80

Figure 33.

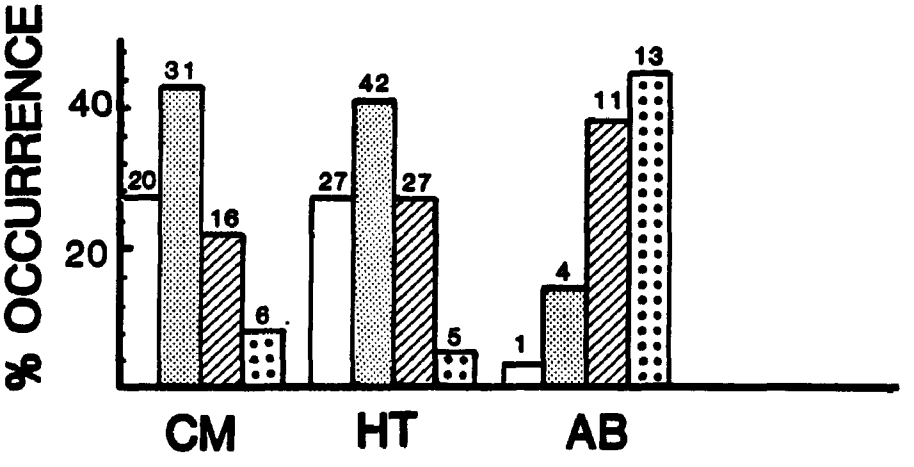


Figure 34. Vertical distribution of coccinellids on stickyboard traps, in spring oat, at Eaton Rapids, 1980 (all trapping dates together).

on which the various arthropod prey and later the coccinellids became established. By the time the trapping was started the wheat was already about 0.4 - 0.5 m tall and did not increase in height much for the rest of the season. It harboured a rather resident population that did not migrate much but stayed within the height (0 - 0.6 m) of the plants. Most adult coccinellids counted during quadrant sampling (see section 4.5.3.2) were actually found on the soil or near the bases of the wheat plants.

Eaton Rapids, 1980 -- Spring Oat: More H. tredecimpunctata were trapped in the spring oat than any other coccinellid species (Table 19 and Appendix Table 6). C. maculata and H. tredecimpunctata preferred the lower three levels (0 - 0.9 m) with the highest proportion occurring at 0.3 - 0.6 m ($p = 0.05$). A. bipunctata on the other hand preferred the highest level 0.9 m and above. These results are shown in Figures 33 and 34.

In general, the flight heights of the adult coccinellids were altered as the height of the surrounding vegetation increased. C. maculata preferred the flight height of up to 0.3 m when the surrounding plants were shorter than this height, while H. tredecimpunctata preferred the flight level of 0.3 - 0.6 m above the ground. The low numbers of A. bipunctata did not permit any firm conclusions to be reached on the flight height of this species.

4.5.3 Population Dynamics of Coccinellids

4.5.3.1 Population Index Using Behavioral Traps, 1979

The three trapping methods used to determine the species of coccinellids that occurred in the study areas, Sec. 4.5.1,

also served as a means of studying the population dynamics through the season. Since the trapping durations and number of traps were not the same for the three methods, the catch was converted into catch X trap $^{-1}$ X day $^{-1}$ which gives a common basis for comparing the methods without implying equivalency of the trapping ability of the traps. Because the numbers thus obtained were very low, they were converted to catch X 100 traps $^{-1}$ X day $^{-1}$. The sticky board traps caught the highest numbers of adult coccinellids and appears to be the most efficient of the three methods used. Care however must be used in interpreting the results of trap catches as the ability to trap the adults is dependent on environmental factors such as temperature and rainfall (affecting activity and the chances of moving into the trap vicinity) and by the behavior of the adults of the different species. The pitfall and flight interception traps are passive and are more likely to indicate adult activity. The bright yellow stickboard traps on the other hand can actively attract adults and hence interspecific and intra-specific (e.g., age and sex) differences in responding to the yellow color become important.

The dynamics of the adult populations of all the species of coccinellids as indicated by the three trapping methods at Eaton Rapids, 1979, are shown in Figure 35 (Appendix Tables 7, 8 and 9) for stickyboard, flight interception, and pitfall traps, respectively. The stickyboard trap method showed a distinct major peak in the numbers in the

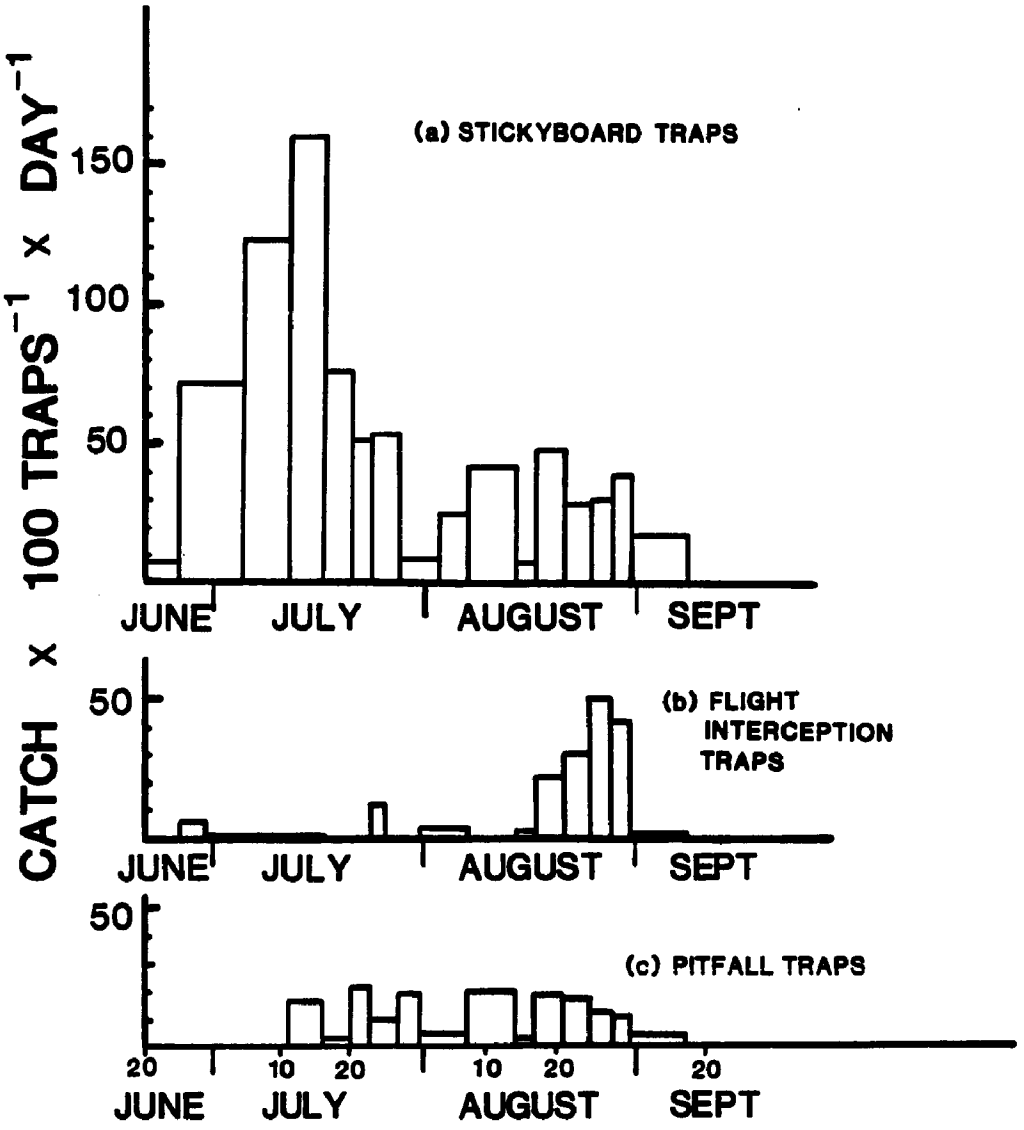


Figure 35. Population trend of coccinellids at Eaton Rapids as indexed by different trapping methods, 1979 (a) stickyboard trap, (b) flight interception trap, (c) pitfall trap.

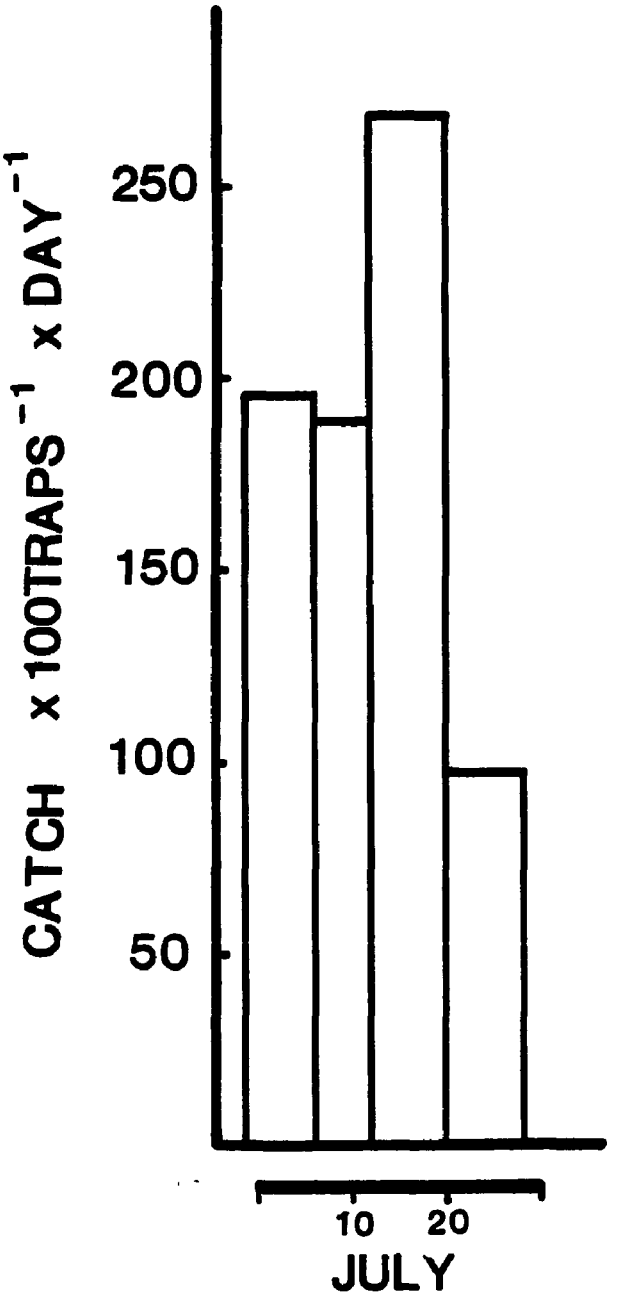


Figure 36. Population trend of coccinellids at the M.S.U. Muck Farm using stickyboard traps, July, 1979.

middle of July and a possible minor peak in August. The flight interception traps recorded extremely low numbers until August, when a weak peak in numbers seemed to occur (Fig. 35b). This weak peak may be confirming the existence of a second population peak as was observed with the sticky-board traps. It is not clear why the flight interception traps recorded such low numbers at the beginning of the season when many more adult coccinellids were observed in the field at this time. The pitfall traps appeared to catch about the same low numbers through the season (Fig. 35c). At the Muck Farm, only stickyboard traps were used and for only the month of July (Appendix Table 10 and Fig. 36). This trapping period was too short to indicate any trend in the population dynamics.

Since the adult coccinellids are not ground-dwellers, although they have been observed to walk across the ground to get to adjacent plants when they fall, very few of them occurred on the ground at one time between the onion plants, explaining the low and constant numbers caught in the pit-fall traps. The virtual absence of adults in the flight interception traps in warmer periods of the season might be due to the fact that the adults were active enough at that time to fly out again after landing at the open ends of these traps. As the temperature dropped in August, the adults were less active and did not fly away that readily but walked up the nylon mesh of the traps and were caught at the corners. A high activity in the early part of the

season placed the adults in the vicinity of the stickyboard traps and increased the likelihood of landing on the boards. Since the surfaces were coated with Tanglefoot ^{R}, the adults got trapped and could not get away.

4.5.3.2 Population Densities of Coccinellids at Eaton Rapids

Early Season: The coccinellids overwinter as adults and they are present in the fields in the early spring, long before the onion crop is even planted. During the early part of the 1980 season, in mid-May, adult coccinellids were present in the onion fields and surrounding oat and wheat fields at a time when the onions were only 2-3 weeks old, and about 5-8 cm tall. The coccinellids did not occur on the onion plants but rather on giant ragweed, Ambrosia trifida, that grew particularly in the inter-row spaces. In the spring oat adjacent to the onions, the coccinellids again occurred on the ragweed. The giant ragweed was up to 60 cm tall by May 24, 1980. A visual count made on all ragweed occurring in the first nine rows of onions and adjacent spring oat (Table 20) showed C. maculata was again the predominant species. H. tredecimpunctata occurred in moderate numbers but few C. transversogotata were found. Coccinella novemnotata Herbst, recorded for the first time during this study, occurred in low numbers. The ragweed evidently came from a permanent boarder on the west-side of the field that was almost entirely made up of ragweed. The density of this weed in the field was highest in the spring

Table 20. Occurrence of adult coccinellids on giant ragweed, Ambrosia trifida, growing among onions and in an adjacent oat plot. Eaton Rapids, May 24, 1980.

Source	No. of Ragweeds	Coccinellid Species					No. Coccinellids per Ragweed	Coccinellid Density (#/m^2)
		CM	HT	CT	CN	TOTAL		
In Oats	235	27	10	0	0	37	0.16	0.026
Rows 1-3 of Onions	170	88	15	7	3	113	0.66	0.116
Rows 4-9 of Onions	125	56	23	11	9	99	0.79	0.051
TOTAL AREA	530	171	48	18	12	249	0.47	0.11

oat that was next to the weed border and decreased away from the source. A total of 235 ragweed was counted in the oat and enough onion rows (or rather inter-row spaces) were surveyed to provide a similar number of ragweed for comparison. The first 9 row-area of onions provided 295 ragweed and this occupied an area of about 3000 m^2 compared to 1440 m^2 of oat. Thus the density of ragweed in the spring oat was twice that in the first nine row-area of onions. The density of ragweed decreased sharply for distances further away from the ragweed border. The number of coccinellids per ragweed increased from the spring oat into the field (Figure 37a). This was contrary to what was expected. Since the adults overwintered outside the oat and onion fields, because this area was completely bare over the winter, it would have been expected that the numbers of coccinellids would have been higher near the border - the possible route of immigrating into the field. The adults probably did not come from the ragweed bordering the field. The density of coccinellids was highest for the first 3 row-area of onions adjacent to the oat, twice the density for the next 6 row area of onions and about 5 times the density in the oat (Figure 37b). Very few coccinellids occurred in remaining onion area. It is not clear why the coccinellids occurred in this distribution pattern but it is understandable that they occurred on the giant ragweed at this time since these plants provided them with shelter and a host of arthropod prey. The early season occurrence of the coccinellids in the oat and onion fields cannot be

Figure 37. Occurrence of coccinellids on ragweed in spring oat and onion fields (a) number per ragweed, (b) density (number per unit ground area).

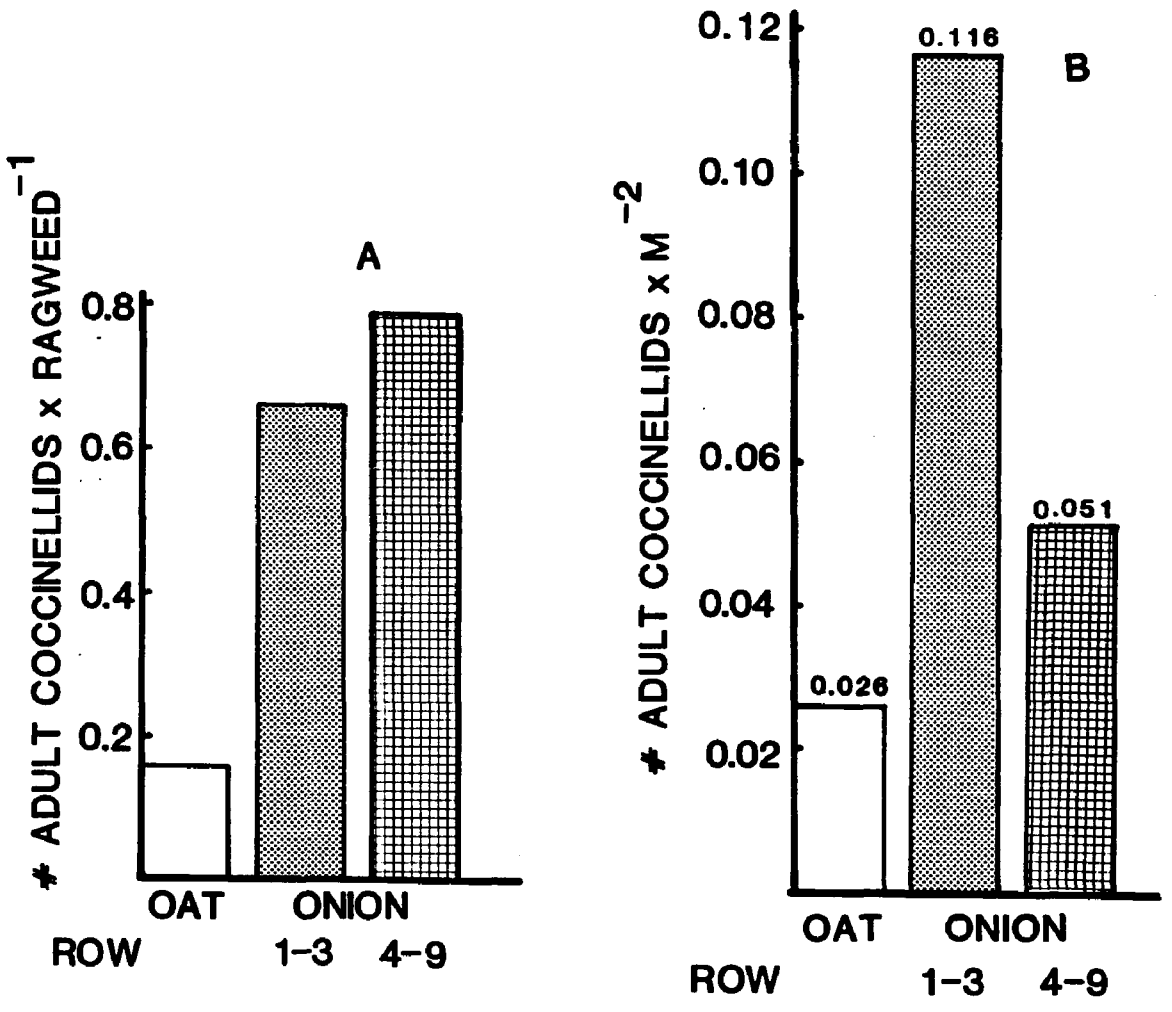

A
ADULT COCCINELLIDS x RAGWEED^{-1}
0.8
0.6
0.4
0.2
OAT
ONION
ROW
1-3
4-9
B
ADULT COCCINELLIDS x M^{-2}
0.12
0.10
0.08
0.06
0.04
0.02
0.116
0.051
0.026
OAT
ONION
ROW
1-3
4-9

Figure 37

attributed to either of these crops since they were too small at this time to harbor any prey for the coccinellids. Further, when the ragweed were removed from the onion field, the coccinellids virtually disappeared from this area but continued to remain in the oat since the ragweed here were not removed.

Within season densities: As stated above, the early season population of coccinellids was present early in the spring oat because there were ragweed present that provided food and shelter. As the oat grew, they became the food host of herbivorous arthropods upon which the coccinellids fed. The density of coccinellids within this area thus increased as shown by quadrat sampling that was started on June 6, 1980 (Appendix Table 11). The density in spring oat peaked in mid-July at 2.4 coccinellids/m^2 (Figure 38). The densities of coccinellids in winter wheat were much higher than in spring oat and probably peaked (4 coccinellids/m^2) in the former in the middle of June (Figure 38). High numbers of coccinellids were observed in the winter wheat at the beginning of the season when only few occurred in the spring oats. It appears that the coccinellids became established in the winter wheat early in the season when these plants provided food and shelter but as they matured and dried up towards mid-July they harboured fewer prey and hence fewer coccinellids. The density on onions, based on numbers visually counted per 9 x 150 m row of onions, was extremely low until early August when it started rising. More data is

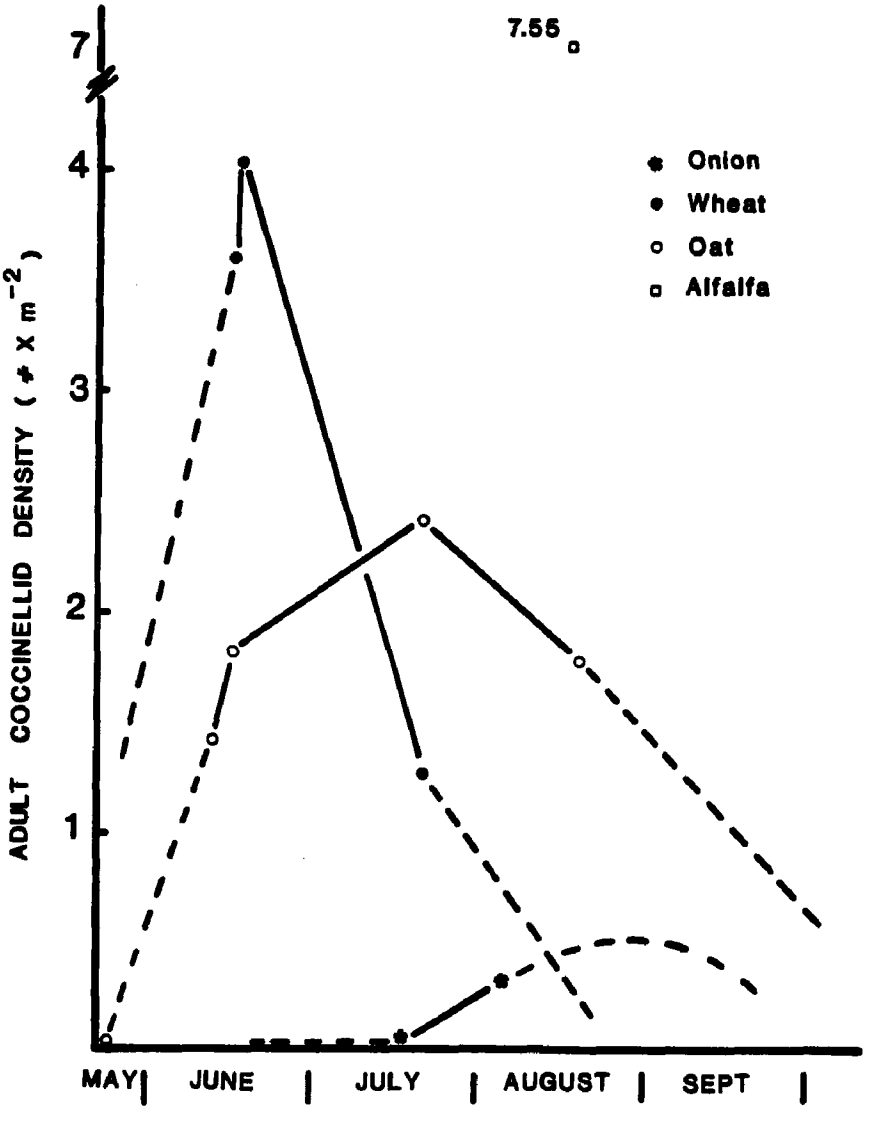


Figure 38. Density of coccinellids in onions, spring oat, winter wheat and alfalfa.

needed through the end of the season, although it is doubtful whether the visual assessment would have indicated much larger densities. It must be noted here that whereas the coccinellids appear to reside among the cereal crops throughout the day, very few were encountered on the onions early in the morning, in the heat of the day and late evening. There appeared to be a diel movement into and out of the onion field. Towards the end of the season, the density of coccinellids was highest in a plot of alfalfa that had been cut twice during the season but formed a good ground cover at this time and also harboured mirids, aphids and many other arthropods.

The coccinellid population thus appeared to be moving from one plant habitat to another within the field area, most probably moving to the plants that provided the best source of prey and shelter away from the weather. Onion, with all the inter-row bare spacing and the narrow leaves provided virtually no shelter and hence does not maintain a resident population.

4.5.4 Arthropod Complex Associated With Coccinellids

As stated earlier, the overwintered adult coccinellids become active in the fields in early spring, even before the onions are planted. At this time, the coccinellids are found in winter cereals and graminaceous plants bordering the fields, and on weeds in and around the fields. Inspection of these plants showed they harboured a variety of arthropods some of which served as prey for the coccinellids. Seventy

percent ethyl alcohol extractions were made of winter wheat and giant ragweed and later spring oat when these became important sources of coccinellids. These plants had the highest numbers of adult coccinellids.

The most important arthropods occurring on the giant ragweeds that could serve as prey for the coccinellids were thrips, accounting for 53.7% of all arthropods collected, followed by mirids and mites. On the winter wheat and spring oat, thrips were again the most abundant prey followed by aphids, the other arthropods occurring in low numbers (Appendix Table 12). About 10% of the thrips collected from the cereals were onion thrips.

Although no observations were made in the field to determine what prey the adult coccinellids fed on, the numbers of thrips available on the plants with which the coccinellids associated suggests thrips to be the most important food source during the spring and early summer.

4.5.5 Diel Activity Pattern of Coccinellids

Cursory observations, while conducting other studies at Eaton Rapids during the 1980 season, showed that the numbers of coccinellids within the onion field changed with the time of day and that the adult coccinellids were not permanently resident in the onions but seemed to fly into the onions in the morning and out towards the evening. Further, much lower numbers seemed to be present on the onions during the heat of the day but the numbers on onions were fairly constant on cloudy days. It was thus hypothesized

that the adult coccinellids took refuge outside the onion fields to escape the excess heat or cold. They move into the onions when the morning warms up but escape to their shelter again when the onion fields become too warm. They return when the place cools down and move out again at sundown to escape the cold nights in the rather exposed onion fields. If this hypothesis is correct, the following could also be observed in the field:

I. Few or no adult coccinellids will be seen in the onions in the early morning. The preferred shelter should provide hiding places away from the elements.

II. Few or no adult coccinellids will be seen on the exposed parts of these preferred shelter places (which was thought to be the cereals, alfalfa or the grasses) on cold mornings. Most or all of them should be concealed is such shelter areas probably down between the bases of the plants.

III. Adult coccinellids may be seen on the sunny sides of plants as the place begins to warm up.

IV. Diel movement into and out of the onion field could be observed and probably diel vertical movement as well within the places of shelter.

The principal shelter area by the middle of June 1980 near the onions being studied was the spring oat (Figure 3). The alfalfa plot next to the onions did not seem to be an important shelter area earlier in the season because these plants were small at this time and did not form a continuous ground cover as did the spring oat. The alfalfa plot became

an important shelter area towards the end of the season. The importance of the spring oat plot by mid June is evidenced by a density of 1.80 coccinellids/m^2 (Appendix Table 11). Visual counts of coccinellids (see sections 3.5.4.1) conducted every two hours did not show any clear patterns that the movement of the coccinellids originated from the oat (Table 21). It was expected that this visual count would show higher numbers of coccinellids on the onions near the oat plot (the source) and decrease for samples away from this end. The skewed distribution should be pronounced at the beginning of the day and become more or less uniform as the day progresses. That this phenomenon was not observed, might be due to the fact that the width of the onion field was narrow (28 m), compared to the flight range of the coccinellids. Adult coccinellids were observed to take off to altitudes of more than 5 m and fly across the onion field towards the oat in the evening.

Visual count of coccinellids that occurred on the exposed surfaces of oat plants showed very low numbers early in the morning (6:30 a.m.) when temperatures were low (10.5°C) but as temperatures increased, more coccinellids were seen on the leaf surfaces, particularly on the sunny surfaces (Table 22). Most of the coccinellids had also moved to the top of the plants where they could obtain more sunshine. A search between the oat early in the morning confirmed the presence of the coccinellids among the lodged stems near the soil surface. This data indicates that the coccinellids, both

Table 21. Visual count of coccinellids occurring on 150 m length rows of onions at different parts of the field.

Date	Time	Location	Number of Coccinellids recorded CM	HT
6-28-80	8:00	Oat edge	5	0
		Middle	4	0
		Alfalfa edge	3	0
	10:00	Oat edge	3	1
		Middle	4	0
		Alfalfa edge	2	0
	12:00	Oat edge	3	0
		Middle	2	1
		Alfalfa edge	2	0
7-18-80	8:00	Oat edge	7	0
		Middle	6	1
		Alfalfa edge	6	0
	10:00	Oat edge	2	1
		Middle	3	0
		Alfalfa edge	3	0
	12:00	Oat edge	3	0
		Middle	2	0
		Alfalfa edge	3	0

Table 22. Occurrence of coccinellids on exposed parts of Oat plants in early morning (6:30 a.m., 13.5°C) and mid-morning (10:00 a.m., 18°C), July 24, 1980. Eaton Rapids.

Sections of oat plant		Number of Coccinellids recorded			
		CM	HT	CT	All Larvae
Early Morning	Top	0	0	0	0
	Middle	2	0	0	0
	Base	1	0	0	0
Mid-Morning	TOP				
	Sunny	16	1	0	7
	Shade	0	0	0	0
	MIDDLE				
	Sunny	6	4	1	7
	Shade	1	1	0	3
	BASE				
	Sunny	1	0	0	0
	Shade	2	0	0	1

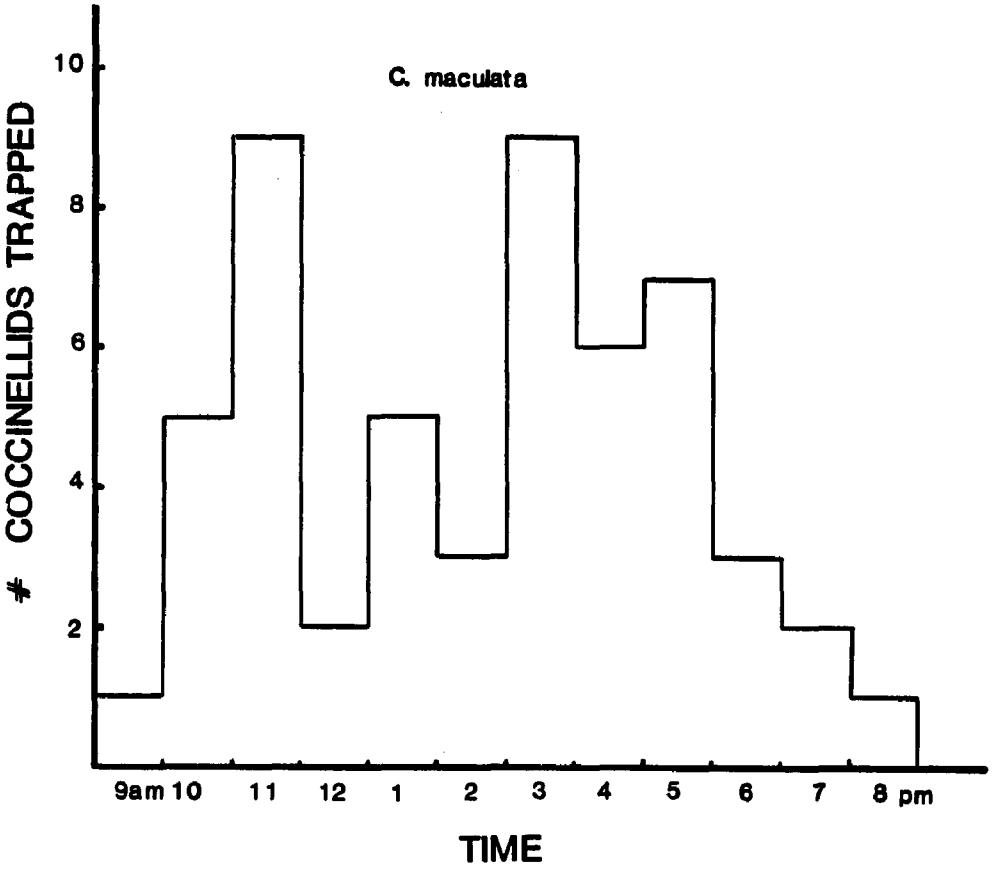


Figure 39. Diel activity pattern of Coleomegilla maculata.

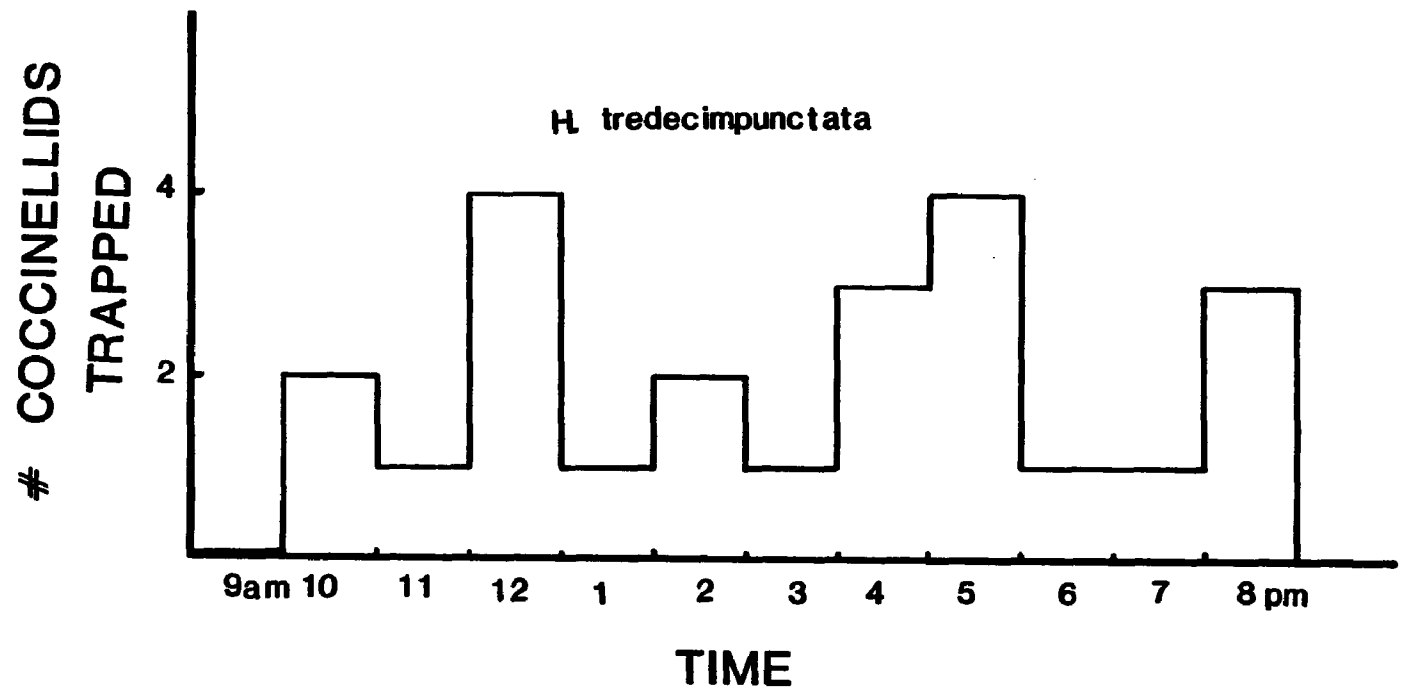


Figure 40. Diel activity pattern of H. tredecimpunctata.

adults and larvae, protect themselves away from the cold of the night by hiding near the bases of the oat plants.

The flight interception method (see section 3.5.4.2) of studying the diel activity showed the activity of C. maculata to be clearly bimodal (Appendix Table 13, Figure 39). The peak activity occurred between 10:00 a.m. to 1:00 p.m. and 3:00 - 5:00 p.m. H. tredecimpunctata occurred in very low numbers and did not show any patterns of activity (Figure 40). Mack and Smilowitz (1979) using stickyboard traps in potato fields showed that peak activity of C. maculata, Hippodamia convergens and C. transversoguttata occurred between 10:30 a.m. - 1:00 p.m. and 2:15 - 4:00 p.m.

Data from the flight interception traps were used to assess directional movement of coccinellids through the day (Appendix Table 13). Since two of the traps faced the oat plot and the other two the alfalfa plot, by separating the data into numbers caught inside as against those caught outside the traps, it was possible to obtain some indications of the flight direction. Coccinellids caught inside the traps facing the oat and those caught on the outside of those traps facing the alfalfa (together classified as "moving towards onions" from oat), were compared with adults caught inside the traps facing the alfalfa and those caught on the outside of the traps facing the oat (classified as "moving from the onions" towards oat). The assumption here was that the coccinellids flew predominantly from the oat into the onion field and back, and that there were no more flights once inside the onion field.

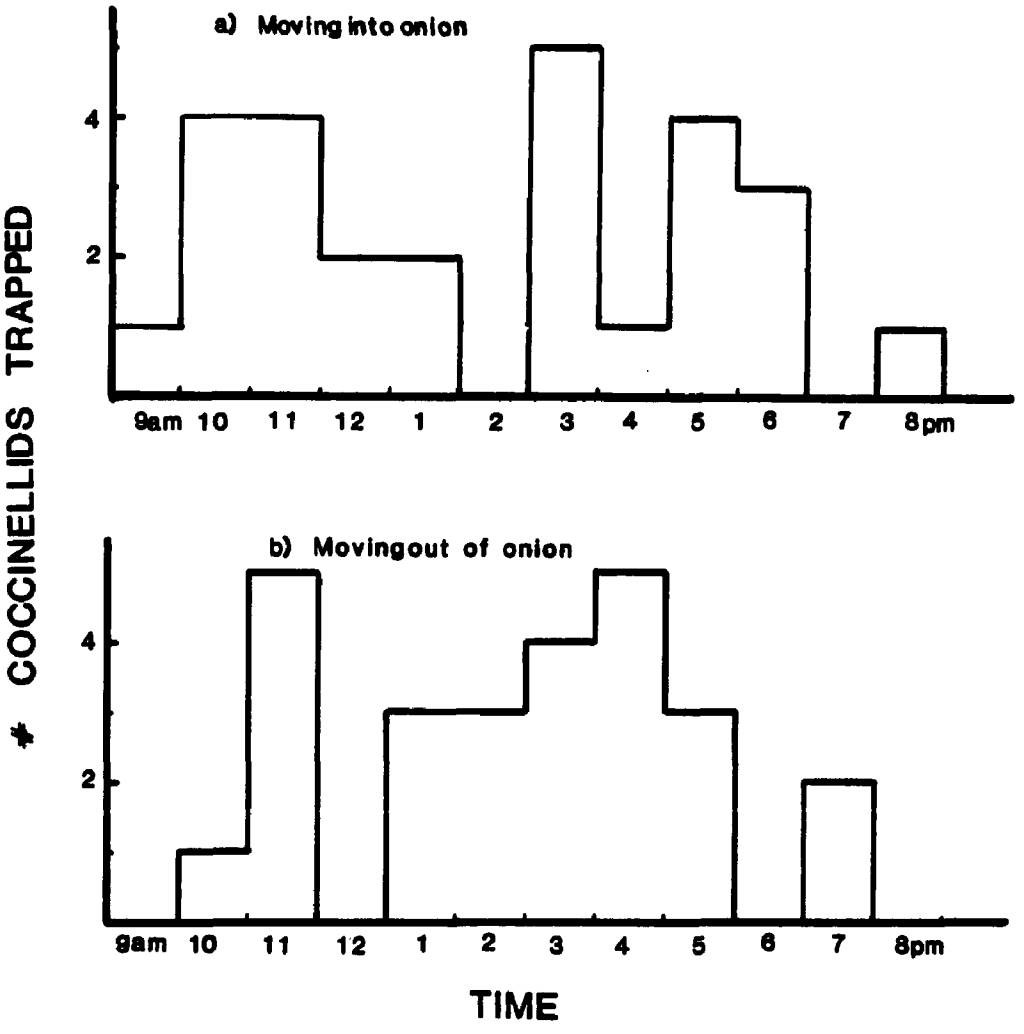


Figure 41. Diel flight pattern of C. maculata, (a) flight into onion field, (b) flight out of onion field.

Adult C. maculata showed a bimodal flight pattern from the oat into the onion field with peaks at 10:00 to 11:00 a.m. and at 3:00 p.m. (Figure 41a). Their outward bound flight from the onions would also be expected to be bimodal but out of phase with the in-bound pattern. This bimodal pattern was not observed but the numbers flying out of the onions was high in the middle of the day when few adults were flying into the onions (Figure 41b). H. tredecimpunctata, which occurred in very low numbers in the traps, showed only a slight indication of flying more into the onions at 12:00 noon and 5:00 p.m.. No obvious pattern in their flight out of the onion field was detected.

The existence of a diel activity pattern of adult coccinellids in the onions and the fact that there is movement into and out of the onion field depending on the time of day, means any estimates of density in the onions will be affected by the time of day this determination is done.

4.6 Predation by Coleomegilla maculata

Coccinellid predators are polyphagous and feed on a wide range of hosts including aphids and other homoptera (Psylloidea, Aleurodidae and Cicadoidea), mites, small nematocerous Diptera, Thysanoptera and young instars of Lepidoptera, and Coleoptera (Hodek, 196€). They have also been reported to be important controlling factors of pest in some crops e.g. C. maculata and Cycloneda sanguinea L. both preying on various Lepidoptera in corn and cotton (Szumkowaski, 1955), Coccinella undecimpunctata L. preying

on Prodenia litura F. on cotton (Bishara, 1934; Kamal, 1951) and Coccinella septempunctata L. preying on Thysanoptera spp. (Nefedov, 1961).

Predatory coccinellids have also been reported to be phytophagous especially on nectar and pollen (Hagan, 1962) and on green leaves (Brassler, 1930). Hodek (1966) however, cautions that this feeding on plant material may sometimes be apparent phytophagy because the coccinellids may actually be feeding on minute insect prey like the larvae of Thysanoptera that are not obvious to the observer. In some cases, Hodek explains, phytophagy is only a form of drinking water.

Throughout the 1978 and 1979 field seasons, although adults and larvae of coccinellids were present on onion plants in the field, very few of these predators were observed feeding on the thrips. Most times the adult coccinellids were found just sitting on the plants and apparently doing nothing. If even these coccinellids did prey on the thrips in the field, it is possible that this could have escaped observation as noted by Hodek (1966) since the larvae of thrips particularly the first instars are so tiny. Predation experiments were thus initiated in the laboratory using C. maculata since this was the most abundant coccinellid in the field, to establish whether this coccinellid was a predator of the onion thrips and if so, how important it was.

a. Laboratory experiments: Preliminary experiments in which different stages of thrips were offered to each coccinellid stage showed that all stages of the coccinellid

did feed on larvae and adult thrips except that the first instar C. maculata fed on few adult thrips, probably because they were not very successful at catching these thrips. After 24 hours starving of the different stages of the predator and offering each of them 10 prey (2nd instar onion thrips), the first instar larvae of the coccinellids took an average of 2.8 (±0.24 S.D) minutes to eat each of the prey, the second instars took 1.2 ± 0.19 minutes, the third instars 0.4 ± 0.10 minutes, the fourth instars 0.4 ± 0.07 minutes, and the adults spent 0.25 ± 0.03 minutes in eating each prey.

The number of onion thrips consumed per 24 hour period varies with the stage of predator (Table 23) and as will be seen later, also varies with the condition of the predator. The 4th instar of C. maculata is the most voracious and consumes an average of 277.4 (±161.2 S.D.) 2nd instar onion thrips per day. This stage feeds at about the same rate as the adult C. maculata (254.3 ± 68.2) but about 10 fold what is consumed by the first larva. When the predation rates of the various stages are compared to that of the adult, we obtain the "Predation equivalence" or how many of each stage equals one adult. This factor can be used in estimating the possible amount of predation that can occur in terms of adult predation when given the numbers of the various stages. This equivalence is based only on the consumption rate on 2nd instar onion thrips larvae (selection was based on size as before). The equivalence will also vary for predation on adult onion thrips since as noted above 1st instar

Table 23. Rate of consumption (#/day) of 2nd instar onion thrips by different stages of C. maculata.

Stage of C. maculata	Average Number of 2nd instar Thrips tabaci consumed per day ± S.D	(n)	Predation equivalence compared to Adult
1st instar	27.1 ± 8.5	(30)	0.11 x Adult
2nd instar	97.0 ± 27.1	(25)	0.38 x Adult
3rd instar	145.1 ± 55.7	(25)	0.57 x Adult
4th instar	277.4 ± 161.2	(25)	1.09 x Adult
Adult	254.3 ± 68.2	(20)	1 x Adult

C. maculata larvae do not seem very successful at catching the adult.

A similar equivalence however should be expected for predation on 1st instar onion thrips since the amount of biomass provided by a 1st instar larvae should be directly proportional (but not equal) to that provided by the 2nd instar onion thrips. We shall then be assuming that the amount of energy and time spent searching for and consuming prey is negligible, which we know is not true as demonstrated by Holling (1959). A mixed population of different stages of prey and also predators occurs in the field at any one time and hence the equivalence stated above, based only on certain stages, is a simplification of the real world situation, but can serve as a basis for understanding the predation process.

Having established that C. maculata is a potential predator of the onion thrips, it was next necessary to determine if a diet of only larval onion thrips could support the development of freshly emerged C. maculata larvae to the adult stage and if so, how many thrips will be required for such development. Using a similar setup as for the predation, freshly hatched C. maculata 1st instar larvae were supplied with second instar onion thrips larvae (again selection was based on size), and continued to be fed until they pupated, while recording the age of the predator and the amount of thrips consumed. By this continuous recording, the cummulative age (in hours) and the number of onion thrips

larvae consumed were established (Appendix Tables 14, 15 and 16). Because of the tediousness of placing living thrips individually in the plasticine cells, only 3 individuals were followed through to pupation. Measurements with seven other C. maculata larvae were discontinued because in one case the larva died due probably to mishandling and for the other six, there were periods when the predator finished eating all the prey provided before the next inspection of the cells, so that it was difficult to determine how long they took to consume what had been provided. Where this happened more than twice the observation was deleted because one could not say with certainty the predator exhibited its full potential in an "ideal situation of unlimited food supply" - the food was not unlimited in supply. The three first instar predator larvae consumed about the same amount of prey (91-101) by the time they molted into the second instar, but this number varied from 1785 to 2119 thrips larvae by the time they pupated (Figure 42). Considering the 4 instars as separate predators, straight line graphs then can be fitted to each section with very good correlation coefficients (Table 24). However, if the three predators are considered as replications, the correlation coefficient is still strong for the first instar but becomes weaker for the older instars (Table 25).

Even though straight lines have been fitted to the above data, each predator instar does not feed at a constant rate during each stadium but rather slows down towards the end as it prepares to molt. This difference in the feeding rate,

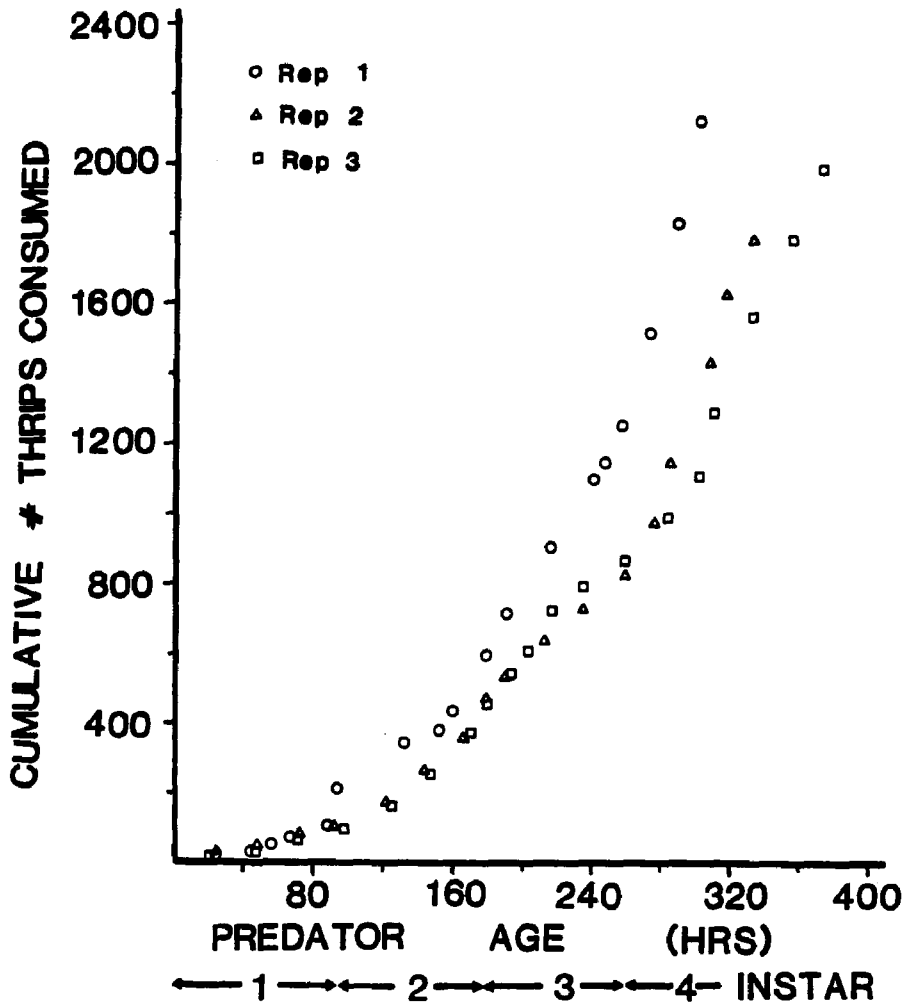


Figure 42. Rate of consumption of second instar Thrips tabaci larvae by Coleomegilla maculata larvae.

Table 24. Linear regression data for age of predator (hours) versus number of prey consumed.

Replication	Instar	Y-Intercept	Slope	r
1	1	-17.97	1.33	.99
	2	-263.23	4.37	.98
	3	-862.16	8.22	1.00
	4	-3350.42	18.08	.99
2	1	-3.90	1.07	.99
	2	-363.23	4.33	1.00
	3	-296.55	4.35	1.00
	4	-3029.79	14.59	1.00
3	1	-15.15	1.14	.99
	2	-394.51	4.47	1.00
	3	-484.62	5.35	.99
	4	-2257.65	11.42	1.00

Table 25. Linear regression of age (hours) of C. maculata versus number of thrips consumed for three C. maculata larvae together.

Instar	Y - Intercept	Slope	r
1	-11.64	1.17	.98
2	-206.48	3.88	.80
3	-363.67	5.00	.78
4	-528.43	6.62	.62

depending on the state of the predator, could account for the large standard deviations in the rate of prey consumtion (Table 23). Also, the rate of prey consumption, a slope of approximately 1, 4, 5 and 7 for instars 1 through 4 respectively (Table 25), is expected to be higher than what pertains in the field as an unlimited supply of prey was provided and, searching time for example, was eliminated in the closed experimental cells. Thus in the study of the developmental biology of the C. maculata in laboratory (see section 4.4), the larvae took a longer time to reach pupation.

b. Field predations experiments: After setting up the cages over the onions and cereal (see section 3.5.5.2), all coccinellids and other predators were removed from the caged plants. An attempt was made to record the number of onion thrips on all the onion plants inside the cages to provide information on the population index at the onset of the experiment. Of the total of 18 rows of onions (3 treatments, with 3 replications, each with 2 onion rows), only 8 rows were assessed. The number of thrips per 10 plants varied from 88.48 to 279.77 at this time (Appendix Table 17). Coccinellid predators occurred only on the cereals (wheat or oat) adjacent to the onions but not on the onion plants themselves. This is confirmed by the data from the three control plots. - Treatment 7, 8 and 9 (Appendix Table 17). Although the mean number of thrips per plants was least for onions adjacent to the wheat (winter cereal) and highest for the control plots (Appendix Table 18), no statistical

differences could be established (Table 26). This experiment could be improved by releasing the predators in the cages earlier in the season, increasing the number of replications, following the numbers on each of the marked plants weekly, and improving the cage, i.e. making them coccinellid-proof. During this experiment, it was noticed that the control plots at sometimes contained larvae of coccinellids. These larvae might have entered the cages as first instars by crawling through the cage netting. This movement across the netting was also observed in the other cages. Thus fewer coccinellids were recovered in some cases, particularly the wheat plots. In one of the oat plots, the number of coccinellids increased from 15 to 20.

No differences were observed in the mean weight per bulb from the three treatments (Table 26). This was expected since the thrips infestation rate was not significantly different in the three treatments and also the infestation was generally low. A high infestation of thrips, particularly when the plants are small, will be expected to decrease to photosynthetic area and hence the amount biomass that can be stored in the form of bulb tissue (see section 5.0)

4.7 Onion Thrips - Onion Plant Interaction

The results of the feeding rate of the onion thrips on onion leaf segments showed that the second instar larvae and the adults feed at about the same rate, averaging 4.51 sq. mm and 4.92 sq. mm per thrips per day respectively (Table 27 and Appendix Table 19a and b). Even though the thrips were enclosed on very small sections of the leaves, no overcrowding

Table 26. Mean thrips count at end of season and mean bulb weight of onions grown adjacent to different cereals (n = 10 plants).

Treatment	Mean # Thrips/plant (Treatment mean)[1]	Mean weight/bulb[1] (gm)
Cage 1: Winter wheat	11.2	55.1a
Cage 2: Winter wheat	8.4	54.7a
Cage 3: Winter wheat	5.3	48.5a
	(8.3a)	
Cage 4: Spring Oat	2.2	43.5a
Cage 5: Spring Oat	5.1	36.9a
Cage 6: Spring Oat	24.0	40.2a
	(10.4a)	
Cage 7: Control	14.3	56.0a
Cage 8: Control	42.0	45.4a
Cage 9: Control	13.4	44.6a
	(23.2a)	

[1]Means followed by the same letter are not significantly different (Student-Newman-Keuls Multiple range test, P>0.05).

Table 27. Feeding rate of Thrips tabaci on onion leaf segments.

Thrips Stage	Mean Area Fed x Thrips^{-1} x day^{-1}
2nd instars	4.51 (S.E. = 0.39)
Adults	4.92 (S.E. = 0.36)

effects were observed. Thus, providing a larger leaf area per thrips did not consistently alter the feeding rate.

In the next experiment, known numbers of adult thrips were enclosed on whole onion plants. The preliminary experiments, using young plants of about 20-30 days old (2-3 leaf-stage), twenty thrips completely destroyed and killed the plants in 4-6 days, showing the potential damage that can be caused by the thrips. In the actual experiment, using older plants whose senile leaves had been trimmed away, the feeding rate of 4.92 sq. mm x thrips $^{-1}$ x day $^{-1}$ was used to estimate the expected number of days a given number of adults will take to consume a known proportion (e.g. 25 or 50%) of the leaf area provided. By stopping the determination when this proportion of leaf area had been damaged, the experiments would have spanned a shorter period. However, it was not possible to tell with any degree of certainty when 25% or 50% of the leaf area had been damaged owing to the fact that fresh lesion were difficult to observe. The experiments were thus continued to 100% leaf area destruction. In the leaf segment experiments, observing the feeding lesions was not a problem because the leaf segments provided were inspected under binocular microscope and fresh lesions were easily spotted as "watery" green patches. The results of this experiment showed that the adult thrips took significantly longer ($\bar{x}$ = 40% longer) to feed on the leaf area provided compared to what was predicted (Table 28). The reason for the disparity can be due to the following:

Table 28. Feeding duration of adult Thrips tabaci for destroying plant surface area.

# of Leaves	Total leaf area (sq.mm)	# of adult thrips	Days to destroy leaf area Exp.[1]	Obs.	$X^2 = \frac{(O-E)^2}{E}$
3	1947.42	81	5	8	1.8
4	2110.64	40	11	9	.36
3	1635.10	64	5	9	3.2
2	603.19	46[2]	3	5	1.3
3	3389.78	78	9	9	0
3	1291.19	116	2	9	24.5
					$\Sigma X^2 = 31.2$

[1]Expected values, to the nearest day, estimated from adult feeding rate studies.

[2]About 50 adults died at the start of the experiment.

1. Using the surface area measured at the beginning of the experiment, to calculate the expected time for destroying the total surface area, assumes that the plant does not grow or increase in surface area over the period of determination. This assumption is more acceptable if the experiment is done over 1 or 2 days but is certainly wrong for the durations of these experiments since in 5 days or more the plants would have increased in surface area. In fact, new leaves were observed in some plants apart from increase in length of the initial leaves. It was not possible to measure the surface area at the end of the experiment because most leaves had withered by then. The increase in surface area means the thrips will take a longer period than expected.
2. It was assumed that no thrips deaths occurred after the beginning of the experiment. All thrips that survived the anaesthesia and handling at the onset were presumed to survive the whole period. It was not possible to cross-check the number alive and feeding daily without creating channels for escape since the only method would have required removing the plastic covers and counting the thrips. Also, the thrips were collected from the general thrips culture and hence of different ages and thus some of those used might have died naturally before the termination of the experiments.

The design of the whole onion plant experiment could be improved by first estimating the longevity of freshly emerged adults and running the experiments for periods when

most of them will still be alive. This will also reduce the variability of rates of feeding of adults of different ages.

As stated above, overcrowding of thrips in the leaf segment experiment did not affect the rate of feeding and no overcrowding occurred at all in the whole plant experiments since large leaf surface areas were available. In the field, onion thrips were usually observed to cluster together between closely touching leaf surfaces particularly the bases of the leaves. The result of such clustering is that larger feeding lesions occur at such sites although feeding lesions can be found all over the general surface of the plant. The cryptic and gregarious nature of the thrips make them prefer plants whose morphology provide them (thrips) with narrow and concealed spaces into which they can hide. This condition is satisfied by onion plants or varieties whose leaf bases are in close contact making a deep "V" rather than a wide "V"; whose newest leaves develop while the two preceeding ones have not yet separated; whose entire leaf surface are not smooth and uniform but develop small troughs along the inner surfaces and finally, those with long flabby leaves that bend over sharply and lie on each other. It is suggested that such plants provide suitable hiding places for thrips where their numbers may increase leading to severe plant damage. These morphological and growth characteristics could be useful for developing thrips-resistant onion varieties.

5. GENERAL DISCUSSION

Damage done by the onion thrips is primarily through rasping on the leaf surface and sucking up the contents of the plant tissue. This feeding causes the plant to lose moisture, nutrients and chlorophyll. The loss of chlorophyll reduces the plant's photosynthetic potential but is not obvious until later when the lesions dry up and appear as white blotches. Information on the rate of feeding on onion leaf tissue (or reduction in photosynthetic potential), forms the basis for assessing the physical damage that can be caused by the thrips and establishing the economic threshold.

The economic threshold concept is very important in pest management and is critical for making decision on resource allocation and utilization for the purpose of controlling the pest. Economic threshold has been defined variously by different authors. Stern et al (1959) defined it as the "pest density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level". From microeconomic theory, the maximum profit of using an input, e.g. an insecticide, is obtained when "all things being equal", the marginal revenue of using that input equals the marginal cost of that input (Ferguson, 1969). The marginal revenue (MR) and marginal cost (MC) are the incremental changes in the total revenue (TR) and the total cost (TC) respectively. That is,

$$MR = \frac{\Delta TR}{\Delta Q}$$

$$MR = \frac{\Delta TC}{\Delta Q}$$

where Q is the output or total yield. Profit is defined as TR - TC. Since profit is maximized at the point where MR = MC, the pest density associated with this point of equality, defines the economic threshold. Higher pest density will decrease the total revenue and hence decrease the profit. Similarly, a high total cost through too many pesticide applications will also decrease the profit margin. The control agent (pesticide input) should only be used when the marginal revenue it produces is equal to or greater than the marginal cost of using that input.

Rabb (1972) suggested a method of developing the economic threshold, of which the first important ingredient was studied in his project. The Rabb method involves collecting the following data:

1. Amount of physical damage related to various pest densities.
2. Crop yield and monetary value (TR) and production cost (TC) including cost of control at various levels of physical damage.
3. Amount of physical damage that can be prevented by the control measure.
4. Monetary value of the portion of the crop that can be saved by the control measure.
5. Monetary cost of the control measure.

Since thrips damage is done to the leaves and not the onion bulb directly, the damage (or feeding rate) needs to be tied in with knowledge of onion leaf surface area development

through the season. The leaf area development, in turn, needs to be related to onion bulb formation through the season, in order to obtain the amount of physical damage caused. Data on the production of leaf tissue (Figure 43 and Appendix Table 20) has been compiled by another project that was to develop an onion plant model (Bolgiano, 1980). The plant model project has accumulated data on leaf tissue production through the season over several years but has not as yet established the all important link with bulb formation. Typically, the graph for leaf area production over the growing season, has a sigmoid shape. It is hypothesized here that, in the early phase of the growth of the plant, virtually all energy excess of metabolism is channeled into the production of above ground leaf tissue. After a period, above ground leaf production slows down and the plant starts storing the excess energy in the form of below ground leaf tissue i.e. the bulb. It is further hypothesized that the point at which the above ground leaf production stops increasing at an increasing rate, is the critical point at which bulb formation begins or very soon thereafter. The yield or weight of the bulb will, among other things, depend on the total leaf area that the plant is able to produce throughout its life (since this area is proportional to the total photosynthetic potential); the time it takes to reach this maximum potential; the slope at the critical point and the time it takes to attain this slope. Integrating the area under the leaf area/time curve (Figure 43), gives a measure of how much leaf area is produced and maintained

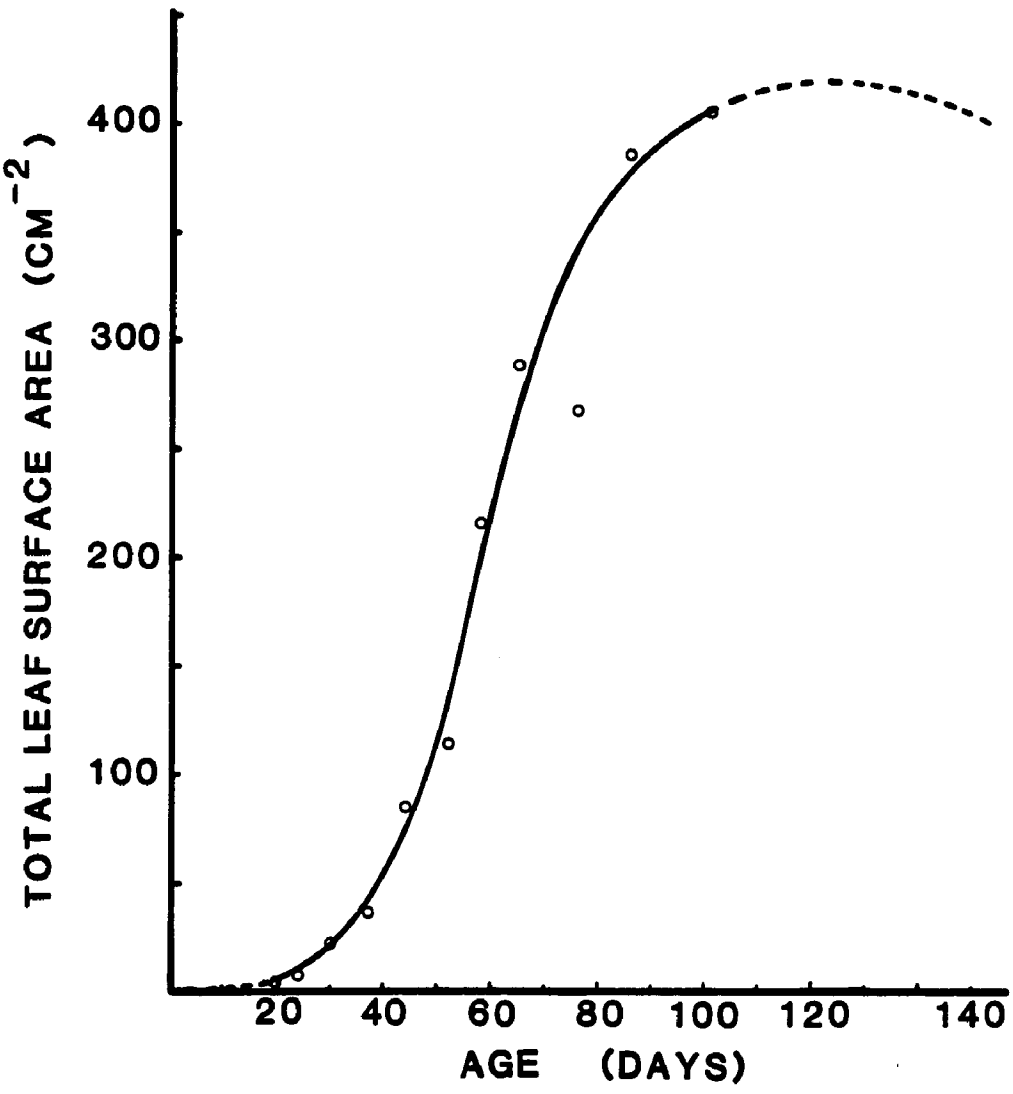


Figure 43. Onion leaf production through the season.

through the season, and thus the potential photosynthate that the plant can produce. The area under this curve from the "critical point" will be directly proportional to the size of onion bulb produced.

Thrips build-up is essentially exponential in form (baring any sudden drop due to environmental conditions like heavy rainfall) up to a few weeks before harvest. Knowing the amount of leaf area that can be destroyed per thrips per day, the size of the thrips population at any time can be converted to leaf area that can be destroyed per day. To develop the economic threshold, the precise effect of a given number of thrips at the various stages of the plant's growth needs to be estimated. This information is not available at this time but can be obtained from experiments in which onion plants at various stages of growth are subjected to different thrips-days of feeding. For each set of experiment, half the plants are harvested after a known period to determine the mean area damaged, while the remaining plants are relieved of the thrips pressure and allowed to grow to maturity and the weight of bulbs measured. The first half of each experiment needs to be ran for a fairly short period, e.g. two days, during which time it can be assumed the plant never changed in surface area.

Even though the precise relationship between the numbers of thrips and reduction in bulb weight is not known, it is quite unlikely that there is only one damage threshold level

for thrips throughout the season. Judging from the sigmoid pattern of leaf surface area development, it is likely that the early phase, when leaf area is small and increase is slow, will be more sensitive to loss in photosynthetic area. Thus a lower percentage loss of photosynthetic area will be desirable. For example, if a 5% leaf area loss is acceptable in the middle of the season, the acceptable level of loss at the beginning of the season may be lower. Using hypothetical levels of damage and the estimated rate of feeding of larval thrips (since this is the predominant stage through the season), and allowing the feeding pressure to last for 7 days a "scenerio" of expected damage and the corresponding density of thrips can be developed. A hypothetical thrips density function of 0.79 thrips/plant at 20 days old, 3.17 thrips at 30 days, 34.9 thrips at 60 days and 60.3 thrips at 90 days old was estimated based on a 5% acceptable photosynthetic area loss (Table 29). A 7-day turn-around time was used because this is a convenient frequency at which fields can be visited although more frequent visits can be made particularly at the more sensitive periods in the plant's development and also under conditions when thrips numbers are building up very fast. The latter occurs under prolonged dry and warm periods. The formula used for developing the above thrips density function is:

$$\text{Thrips Density} = \frac{A \times D}{0.045 \times T}$$

where A = total onion leaf surface area (cm^2)

Table 29. Hypothetical Thrips densities through the season that will cause certain percentage onion leaf area loss.

Age of Onions (wks)	Approx. # of Leaves	Hypothetical Thrips Densities (# Thrips/plant) (Percent Acceptable Leaf Area Loss) 1%	5%	10%	15%	20%
3	2	.14	.70	1.40	2.10	2.79
4	4	.63	3.17	6.35	9.52	12.70
5	5	1.11	5.56	11.11	16.67	22.22
6	6	1.78	8.89	17.78	26.67	35.56
7	7	3.33	16.67	33.33	50.00	66.67
8	8	5.08	25.40	50.79	76.19	101.59
9	9	7.78	38.89	77.78	116.67	155.56
10	12	9.37	46.83	93.65	140.48	187.30
11	11	10.95	54.76	109.52	164.29	219.50
12	11	11.75	58.73	117.46	176.19	234.92
13	11	12.22	61.11	122.22	183.33	244.44
14	9	12.70	63.49	126.98	190.48	253.97
15	9	13.17	65.87	131.75	197.62	263.49

D = acceptable damage as a fraction of total surface area

T = turnaround time or duration of thrips feeding pressure in days.

The amount of feeding per larval thrips per day is 0.045 cm^2. If the area used in this calculation process is the initial area, the plant would have increased in surface area by the end of the time period, T. This calculation can be improved by developing a logistic equation (similar to that developed for thrips temperature-velocity curve) and using this equation to predict the surface area by the end of period T, and thus the surface area at the "mid-point" of period T, i.e. one-half of that surface area is used for estimating the thrips density or action threshold.

The "scenerio" for a constant 5%, 10% and 15% leaf area loss (LAL) through the season, provided corresponding thrips density, functions (Figure 44). Since the onion leaf area development through the season had a sigmoid shape, the hypothetical constant LAL (of 5, 10 or 15%) yielded sigmoid functions. Field data from Eaton Rapids (1980) and the Muck Farm (1980) were then included for comparison. Both locations ran at 2 - 3% LAL up to day 50, after which the thrips density at Eaton Rapids started to rise faster. Thus by day 70, the Muck Farm plants were about 3% LAL level and those at Eaton Rapids were at 4.5% LAL level. At around days 80-82, the Muck Farm plants were losing about 5% of their leaf area to thrips and those at Eaton Rapids were losing over 10%. No loss in bulb weight was observed at the Muck Farm

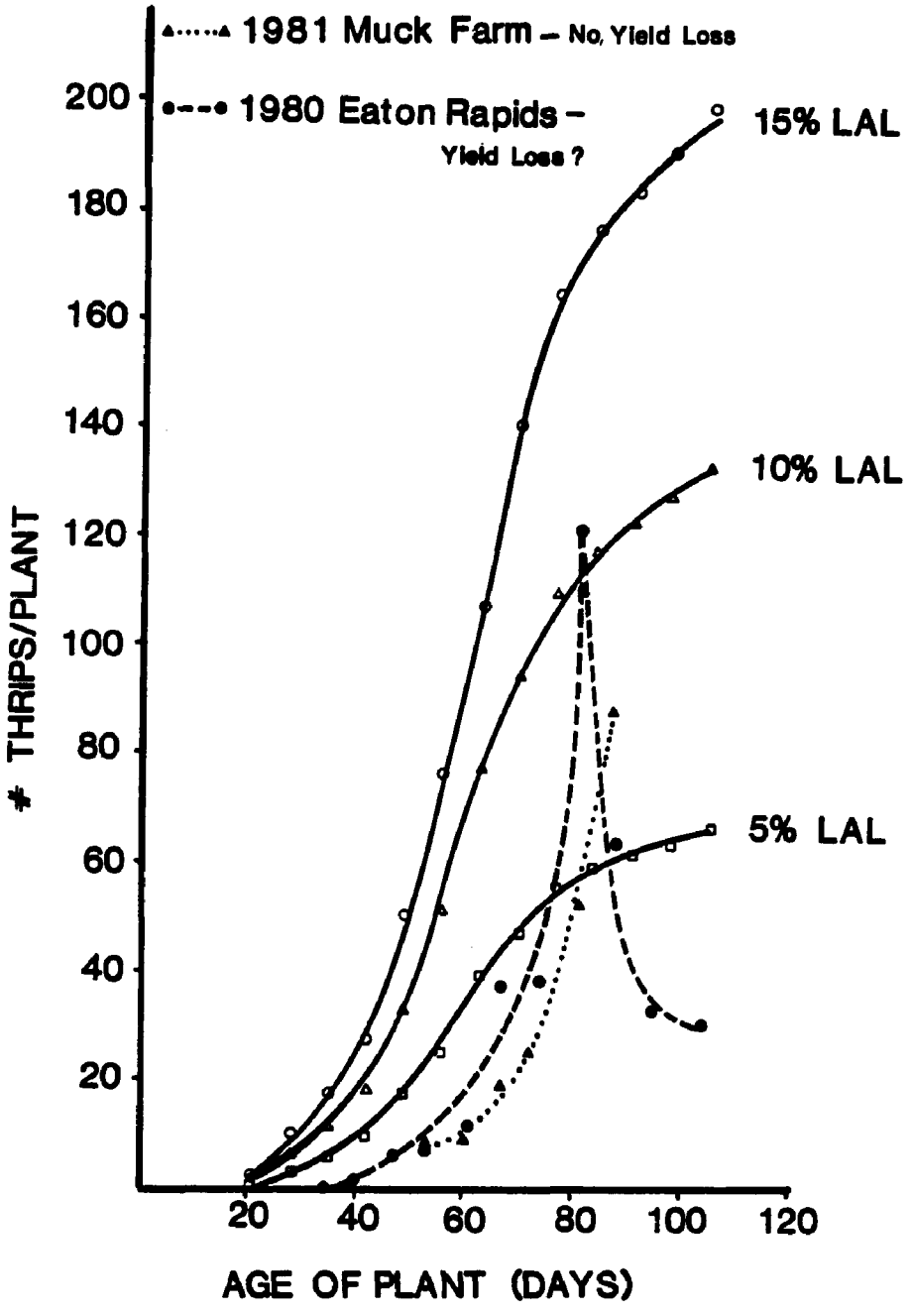


Figure 44. Comparison of field recorded thrips density levels (broken lines) with hypothetical thrips densities that assume constant 5%, 10%, and 15% leaf area loss (LAL) through the season.

(Table 6) although the mean number of thrips from the untreated plots (data used here) were at times significantly different from chemically treated plots. No accurate yield data was available from Eaton Rapids, although some loss was suspected due to high thrips infestation. The thrips density at Eaton Rapids may thus be around the damage threshold. The grower at Eaton Rapids reported that his yearly yield was always lower than the State of Michigan average but this may be due to a combination of many factors.

Using the data from Eaton Rapids (1980), as a density function that will cause unacceptable damage or at least close to the damage threshold, a sliding hypothetical action threshold can be developed that will fall below this function but above the Muck Farm (1980) function (except for the end of the season when the latter function appeared high). A suggested hypothetical action threshold will be as follows:

0.05 Thrips/plant (or 0.005 LAL) at 5 weeks;

5.00 Thrips/plant (or 0.01 LAL) at 8 weeks;

29.00 Thrips/plant (or 0.03 LAL) at 10 weeks, and,

59.00 Thrips/plant (or 0.05 LAL) at 12 weeks.

The potential controlling effects of the predator, C. maculata, could be tied in if information on how many thrips each predator consumes per unit time under field conditions is known. This field predation is not known now but the laboratory predation experiments provided the maximum predation rate. The rates reported here are expected to be much higher than what will occur in the field, since the laboratory

experiments provided the predators with an unlimited supply of prey and eliminated searching time and the cryptic nature of the thrips. However, using these high predation rates, and knowing the density of onion plants and hence the maximum allowable number of thrips in an area, the minimum number of predators that will be needed to keep the thrips population below a required level can be estimated.

The ability of the onion thrips to use grasses, cereals and a host of other plants as food sources, coupled with their rapid development in warm weather, make them common in all onion fields. Yet the use of chemicals on a regular basis for controlling them may not be justified as found by Shirck and Douglas (1956). Such control may be warranted when the thrips occur as unusually high infestation particularly if this happens early in the season when the plants are younger. Chemical control methods should be used judiciously since Richardson and Wene (1966) reported thrips resistance to dieldrin and other chlorinated hydrocarbons.

Heavy rainfall is a major mortality factor, causing over 70% mortality, both in this study and another by Harris et al (1936). Rainfall is more destructive to the larval population which is the predominant stage in the field through the season except for the first few weeks. Thus, even in periods of high thrips infestation, it may be necessary to recheck the fields following a heavy rain before instituting other control measures. A good pest management program should include the use of resistant cultivars. Sleesman (1934,1943),

Lall and Verma (1959), and Verma (1966) all found the white cultivars to be resistant to the onion thrips. Pawar et al (1975) also reported that cultivars with glossy foliage are resistant to thrips. The onion plant morphology (wrinkled surfaces) and the configuration of the leaves (when touching tightly at the bases) appear to enhance the development of the population by making them inaccessible to predators and rain action. These factors could be bred-out of desired cultivars.

6. SUMMARY

The onion thrips, Thrips tabaci is a major pest on onions that are grown in organic fashion, i.e. where no insecticides are used. Adult thrips migrated into the onion field when the onion plants were only a few weeks old and were dispersed nearly randomly through the field at the time. As the season progressed and the adults reproduced, the predominant stage present on the onions were larvae and the distribution became more contagious. The numbers of thrips per plant rose sharply and in exponential fashion to a peak by the end of the season. Thrips may exceed 100 per plant by the time of harvest. Sudden heavy rainfall was a high mortality factor and caused the population of thrips to crash.

The theoretical lower temperature developmental threshold was estimated as 7.4°C for the larval and pupal stages together. Under laboratory conditions at 29°C, the development of the two larval and pupal stages took under 8 days.

The rate of feeding on onion leaf tissue was similar for both adults and second instar thrips larvae, being 4.93 and 4.51 $mm^2 \times thrips^{-1} \times day^{-1}$ respectively. Inspite of differences in thrips infestation rate between chemically treated and untreated plots, no yield difference was established but preliminary investigation in the greenhouse showed that large numbers of thrips could kill the onion plant.

The main predators of the onion thrips in the field were coccinellids, the most important being Coleomegilla maculata. The coccinellid predators overwintered as adults and were present in the field very early in the season on cereals and

grasses at a time when the onions had not even been planted. At this time they fed on a host of small arthropods, the predominant prey being various thysanoptera.

Coleomegilla maculata appeared to have a preferred flight height of 0 - 0.6 m above the ground for short range flight between plants although it flew high above the plants, particularly over longer distances. It had a bimodal diel activity pattern with peaks in the late morning and late afternoon and a lull in the heat of the day.

C. maculata adults fed on about 250 second instar thrips per day. The first, second, third and fourth instar larvae fed at the rate of 0.11, 0.38, 0.57 and 1.09 compared to the adult. When fed only on onion thrips, C. maculata was able to complete its development and lay fertile eggs, indicating that onion thrips are suitable prey. The developmental rate when fed on onion thrips, is comparable to rates obtained by other authors using aphids as a food source.

A sliding hypothetical action threshold was developed for various ages of the onion plant based on the feeding rate of the thrips and leaf area production through the season.

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Appendix Table 1a. Summary of onion thrips recorded on onions, Eaton Rapids, 1978.

Date	Total # plants	Total # Thrips			# Thrips/plant		
		A	L	Σ	A	L	Σ
6-30-79	516	101	116	217	.20	.22	.42
7-12-79	322	341	110	451	1.06	.34	1.40
7-15-79	303	317	558	875	1.05	1.84	2.89
7-19-79	311	184	1216	1400	.59	3.91	4.50
7-24-79	213	143	1122	1265	.67	5.27	5.94
7-26-79	220	258	1253	1511	1.17	5.70	6.87
8-2-79	109	145	865	983	1.33	7.94	9.27
8-10-79	112	5674	2315	7989	50.66	20.67	71.33

A = Adult

L = Larvae

Σ = Total

Appendix Table 1b. Summary of onion thrips recorded on onions, Eaton Rapids, 1979.

Date	Total # plants	Total # Thrips			# Thrips/plant		
		A	L	Σ	A	L	Σ
6-28-79	120	15	1	16	.12	.01	.13
7-5-79	140	33	8	41	.24	.06	.30
7-13-79	120	70	52	122	.58	.43	1.58
7-21-79	120	64	77	140	.53	.64	1.17
7-26-79	160	267	150	417	1.67	.94	2.61
8-3-79	160	302	339	641	1.89	2.12	4.01
8-17-79	120	265	799	1064	2.21	6.66	8.87
8-24-79	120	216	1358	1574	1.80	11.32	13.12
8-28-79	120	98	2641	2739	.82	22.01	22.83
8-31-79	120	151	4130	4281	1.26	34.42	35.68
9-7-79	80	932	2527	3460	11.66	31.59	43.25
9-9-79	60	794	1977	2771	13.23	32.95	46.18
9-10-79	60	970	2479	3449	16.17	41.31	57.48

A = Adult

L = Larvae

Σ = Total

Appendix Table 1c. Summary of onion thrips recorded on onions, Eaton Rapids, 1980.

Date	Total # plants	Total # Thrips			# Thrips/plant		
		A	L	Σ	A	L	Σ
6-13-80	360	139	38	177	.39	.11	.71
6-19-80	300	162	163	325	.54	.54	1.08
6-26-80	300	420	1300	1720	1.40	4.33	5.73
7-2-80	300	633	1570	2203	2.11	5.23	7.34
7-10-80	300	794	2584	3378	2.65	8.61	11.26
7-16-80	300	4255	7324	11579	14.18	24.41	38.59
7-23-80*	150	1098	4525	5623	7.32	30.17	37.49
7-30-80	150	2345	16646	18991	15.63	110.97	126.61
8-6-80	150	1515	8001	9516	10.10	53.34	63.44
8-13-80	150	675	4166	4841	4.50	27.77	32.27
8-22-80	60	417	1384	1801	6.95	23.07	30.02

*Cultivation done early that morning. No thrips occurred on the upper parts of the leaves.

A = Adult

L = Larvae

Σ = Total

Appendix Table 1d. Summary of onion thrips recorded on onions at the Muck Farm, 1980.

Date	Total # plants	Total # Thrips			# Thrips/plant		
		A	L	Σ	A	L	Σ
7-25-80	60	57	96	153	.95	1.60	2.55
7-31-80	60	80	100	180	1.33	1.67	3.00
8-7-80	60	99	294	393	1.65	4.90	6.55
8-14-80	60	45	706	751	.75	11.77	12.52
8-28-80	60	90	667	757	1.50	11.12	12.62

A = Adult

L = Larvae

Σ = Total

Appendix Table 2. Sample means (#/plant) and variances for various onion thrips sampling dates transformed to log/log scale, for determining if onion thrips field distribution is normal, (sample size = 10 plants).

Date	$\bar{x}$	log $\bar{x}$	s^2	log s^2	$s^2/\bar{x}$
6-13-80	0.9	-0.05	1.88	0.27	2.09
	0.7	-0.15	0.71	-0.15	1.01
	0.7	-0.15	0.46	-0.34	0.66
	1.1	0.04	1.43	0.16	1.30
	1.4	0.15	0.60	-0.22	0.43
	1.0	0.00	1.11	0.50	1.11
	0.5	-0.30	0.50	-0.30	1.10
	0.9	-0.50	0.99	-0.004	1.10
6-19-80	0.8	-0.10	1.51	0.81	1.89
	1.1	0.40	1.21	0.08	1.10
	1.3	0.11	1.21	0.08	0.93
6-26-80	2.8	0.45	14.18	1.15	5.06
	1.6	0.20	1.82	0.26	1.16
	1.8	0.26	3.73	0.58	2.07
	8.1	0.91	34.35	1.54	4.24
	8.8	0.94	51.73	1.71	5.88
	8.9	0.95	12.32	1.09	1.38
7-10-80	22.1	1.34	599.43	2.78	27.12
	21.3	1.33	247.34	2.44	11.61
	26.0	1.41	587.33	2.77	22.59
7-30-80	132.8	2.12	6554.18	3.82	49.35
	61.9	1.79	1206.16	3.08	19.49

Appendix Table 3. Vertical distribution of coccinellids caught on Stickyboard traps located in onions at the Muck Farm, Laingsburg, 1979. (A total of 23 traps were used until 7-12-79 and only 9 traps thereafter).

Collection Date	Height (m)	CM & HT		CM & HT	
		Total #	Percent	Total #	Percent
7-06-79	0 - .3	75	39	10	13
	.3 - .6	80	41	36	45
	.6 - .9	27	14	25	31
	.9 - 1.2	11	6	9	11
TOTAL		193	100	80	100
7-12-79	0 - .3	81	32	6	13
	.3 - .6	116	45	14	31
	.6 - .9	47	18	14	31
	.9 - 1.2	12	5	11	25
TOTAL		256	100	45	100
7-20-79	0 - .3	49	28	0	0
	.3 - .6	92	52	2	33
	.6 - .9	31	17	2	33
	.9 - 1.2	6	3	2	33
TOTAL		178	100	6	99
7-28-79	0 - .3	10	20	0	0
	.3 - .6	22	44	0	0
	.6 - .9	15	30	1	50
	.9 - 1.2	3	6	1	50
TOTAL		50	100	2	100
ΣΣ		677		133	

Appendix Table 4. Vertical distribution of coccinellids caught on 15 stickyboard traps located in spring sorghum at the Muck Farm, Laingsburg, 1980.

Collection date	Height (m)	CM		HT		AB	
		Total #	Percent	Total #	Percent	Total #	Percent
7-06-80	0 - .3	30	63	0	0	1	10
	.3 - .6	11	23	3	60	1	10
	.6 - .9	4	8	0	0	5	50
	.9 - 1.2	3	6	2	40	3	30
TOTAL		48	100	5	100	10	100
7-11-80	0 - .3	9	56	0	0	2	25
	.3 - .6	4	25	6	55	1	13
	.6 - .9	2	13	4	36	2	25
	.9 - 1.2	1	6	1	9	3	17
TOTAL		16	100	11	100	8	100
7-25-80	0 - .3	9	45	9	18	1	25
	.3 - .6	6	30	31	62	1	25
	.6 - .9	5	25	8	16	1	25
	.9 - 1.2	0	0	2	4	1	25
TOTAL		20	100	50	100	4	100
7-31-80	0 - .3	0	0	0	0	0	0
	.3 - .6	4	40	14	43	0	0
	.6 - .9	3	30	13	39	1	100
	.9 - 1.2	3	30	6	18	0	0
TOTAL		10	100	33	100	1	100
8-07-80	0 - .3	3	13	2	5	0	0
	.3 - .6	7	29	16	42	0	0
	.6 - .9	6	25	17	45	2	66
	.9 - 1.2	8	33	3	8	1	34
TOTAL		24	100	38	100	3	100
ΣΣ		118		137		26	

Appendix Table 5. Vertical distribution of coccinellids caught on 10 sticky-board traps located in winter wheat at Eaton Rapids, 1980.

Collection date	Height (m)	CM		HT		AB	
		Total #	Percent	Total #	Percent	Total #	Percent
7-02-80	0 - .3	12	33	5	26	0	0
	.3 - .6	12	33	9	47	0	0
	.6 - .9	9	25	3	16	2	66
	.9 - 1.2	3	9	2	11	1	34
TOTAL		36	100	19	100	3	100
7-10-80	0 - .3	3	50	3	23	0	0
	.3 - .6	1	17	4	31	0	0
	.6 - .9	2	33	1	8	2	66
	.9 - 1.2	0	0	5	38	1	34
TOTAL		6	100	13	100	3	100
7-17-80	0 - .3	9	41	7	54	0	0
	.3 - .6	9	41	3	23	0	0
	.6 - .9	2	9	2	15	0	0
	19 - 1.2	2	9	1	8	0	0
TOTAL		22	100	13	100	0	0
7-23-80	0 - .3	30	63	3	23	0	0
	.3 - .6	13	27	6	46	0	0
	.6 - .9	2	4	4	31	0	0
	.9 - 1.2	3	6	0	0	0	0
TOTAL		48	100	13	100	0	0
ΣΣ		112		58		6	

Appendix Table 6. Vertical distribution of coccinellids caught on 11 sticky-board traps located in or adjacent to spring oat at Eaton Rapids, 1980.

Collection date	Height (m)	CM		HT		AB	
		Total #	Percent	Total #	Percent	Total #	Percent
7-02-80	0 - .3	5	16	16	25	1	9
	.3 - .6	15	47	26	41	1	9
	.6 - .9	9	28	20	31	4	36
	.9 - 1.2	3	9	2	3	5	46
TOTAL		32	100	64	100	11	100
7-10-80	0 - .3	1	9	4	19	0	0
	.3 - .6	7	64	12	57	2	18
	.6 - .9	1	9	3	14	5	46
	.9 - 1.2	2	18	2	10	4	36
TOTAL		11	100	21	100	11	100
7-17-80	0 - .3	12	52	7	50	0	0
	.3 - .6	6	26	3	21	1	20
	.6 - .9	4	18	3	21	2	40
	.9 - 1.2	1	4	1	8	2	40
TOTAL		23	100	14	100	5	100
7-23-80	0 - .3	2	29	0	0	0	0
	.3 - .6	3	42	1	50	0	0
	.6 - .9	2	29	1	50	0	0
	.9 - 1.2	0	0	0	0	2	100
TOTAL		7	100	2	100	2	100
ΣΣ		73		101		29	

Appendix Table 7. Coccinellids caught on 16 stickyboard traps at Eaton Rapids, 1979, transformed to catch x 100 traps^{-1} x day^{-1}.

Date	Trapping Days	No. of Traps	Total Coccinellids	Catch x traps^{-1} x Day^{-1}	Catch x 100 trap^{-1} x day^{-1}
6-20-79	START				
6-25-79	5	16	6	.075	8
7-04-79	9	16	104	.722	72
7-11-79	7	16	140	1.250	125
7-16-79	5	16	128	1.600	160
7-20-79	4	16	48	.750	75
7-23-79	3	16	56	.500	50
7-27-79	4	16	34	.530	53
8-02-79	6	16	8	.083	8
8-06-79	4	16	16	.250	25
8-13-79	7	16	47	.420	42
8-16-79	3	16	4	.083	8
8-20-79	4	16	31	.484	48
8-24-79	4	16	18	.281	28
8-27-79	3	16	14	.292	29
8-30-79	3	16	18	.375	38
9-07-79	8	12	16	.167	17
TOTAL	79	252	688		

Appendix Table 8. Coccinellids caught in 8 flight interception traps at Eaton Rapids, 1979, transformed to catch x 100 traps^{-1} x day^{-1}.

Date	Trapping Days	No. of Traps	Total Coccinellids	Catch x traps^{-1} x day^{-1}	Catch x 100 trap^{-1} x day^{-1}
6-25-79	START				
6-29-79	4	8	2	.06	6
7-16-79	17	8	1	.007	0.7
7-20-79	4	8	0	0	0
7-23-79	3	8	0	0	0
7-25-79	2	8	2	.125	13
7-27-79	2	8	0	0	0
7-30-79	3	8	0	0	0
8-06-79	7	8	2	.036	4
8-13-79	7	8	0	0	0
8-16-79	3	8	1	.042	4
8-20-79	4	8	7	.219	22
8-24-79	4	8	10	.313	31
8-27-79	3	8	12	.500	50
8-30-79	3	8	10	.417	42
9-07-79	8	8	1	.016	2
TOTAL	74	120	48		

Appendix Table 9. Coccinellids caught in 15 pitfall traps at Eaton Rapids, 1979, transformed to catch x 100 traps^{-1} x day^{-1}.

Date	Trapping Days	No. of Traps	Total Coccinellids	Catch x traps^{-1} x day^{-1}	Catch x 100 traps^{-1} x day^{-1}
7-11-79	START				
7-16-79	5	15	13	.173	17
7-20-79	4	15	2	.033	3
7-23-79	3	15	10	.222	22
7-27-79	4	15	6	.100	10
7-30-79	3	15	8	.178	18
8-06-79	7	15	5	.048	5
8-13-79	7	15	21	.200	20
8-16-79	3	15	2	.044	4
8-20-79	4	15	11	.183	18
8-24-79	4	15	10	.167	17
8-27-79	3	15	6	.133	13
8-30-79	3	15	5	.111	11
9-07-79	8	15	6	.050	5
TOTAL	58	180	105		

Appendix Table 10. Coccinellids caught on stickyboard traps at the Muck Farm, Laingsburg, 1979, transformed to catch x 100 traps^{-1} x day^{-1}.

Date	Trapping Days	No. of Traps	Total Coccinellids	Catch x trap^{-1} x day^{-1}	Catch x 100 trap^{-1} x day^{-1}
6-30-79	START				
7-06-79	7	29	398	1.96	196
7-12-79	6	29	324	1.86	189
7-20-79	8	9	194	2.69	269
7-28-79	8	9	70	.97	97
ΣΣ	29	76	986		

Appendix Table 11. Population density of coccinellids in various crops at Eaton Rapids, 1980.

Density includes larval, pupal and adult stages as indicated.

Crop	Date	Sampling Method	Sample Size	Density (#/m^2)	Remarks
Spring Oat	5-24-80	Visual count on Ragweed	235 Ragweed	0.026	Adults only
Onions	5-24-80	Visual count on Ragweed	170 Ragweed	0.116	Adults only
Onions	5-24-80	Visual count on Ragweed	125 Ragweed	0.051	Adults only
Spring Oat	6-12-80	$1m^2$ Quadrat	20	1.40	Adults only
	6-16-80	$1m^2$ Quadrat	50	1.80	Adults only
	7-21-80	$1m^2$ Quadrat	20	2.40	Larvae, pupae, Adults
	8-19-80	$1m^2$ Quadrat	12	1.75	Larvae, pupae, Adults
Winter wheat	6-16-80	$1m^2$ Quadrat	10	3.75	Adults only
	6-17-80	$1m^2$ Quadrat	20	4.05	Adults only
	7-21-80	$1m^2$ Quadrat	20	1.25	Larvae, pupae, Adults
Alfalfa	8-18-80	$1m^2$ Quadrat	20	7.55	Larvae, pupae, Adults
Onions	7-18-80	Visual count on Onions	9x150m row of onions	0.02	Larvae & Adults
	8-4-80	Visual count on Onions	9x150m row of onions	0.26	Larvae & Adults

Appendix Table 12. Arthropods extracted from giant ragweed, *Ambrosia trifids*, winter wheat and spring oat, at Eaton Rapids, 1980.

Source	Date Extracted	Arthropod	Number Collected
Giant Ragweed	6-02-80	ARACHNIDA	
		Araneida	2
		INSECTA	
		Collembola	13
		Thysanoptera	51
		Hemiptera (Miridae)	20
		Homoptera (Aphidae)	3
		Diptera	6
Winter Wheat	6-05-80	ARACHNIDA	
		Acarina	2
		INSECTA	
		Collenbola	3
		Thysanoptera	1151
		Homoptera (Aphidae)	37
		Diptera	2
Spring Oat	6-20-80	ARACHNIDA	
		Acarina	2
		INSECTA	
		Collenbola	1
		Thysanoptera	280
		Homoptera (Aphidae)	56
		Coleoptera	4
		Diptera	6

Appendix Table 13. Diel activity of adult coccinellids in onions as indexed by four flight interception traps at Eaton Rapids, August 4, 1980.

Time	Temp.°C	Number Caught Moving towards onions		away from onions		Total	
		CM	HT	CM	HT	CM	HT
800	13.5	start					
900	16.0	2	0	0	0	2	0
1000	21.3	4	2	1	0	5	2
1100	23.0	4	0	5	1	9	1
1200	25.0	2	3	0	1	2	4
1300	26.3	2	1	3	0	5	1
1400	26.8	1	1	3	1	4	2
1500	27.0	5	1	4	0	9	1
1600	25.8	1	0	5	3	6	3
1700	25.4	4	3	3	1	7	4
1800	24.8	3	1	0	0	3	1
1900	23.5	0	1	2	0	2	1
2000	23.0	1	2	0	1	1	3

Appendix Table 14. Number of Thrips tabaci larvae (second instar) required for development of C. maculata from hatching to pupation. (Replication 1).

Age of C. maculata		Cummulative number of Thrips tabaci larvae consumed
Hours	Instar	
23	1	17
43	1	35
56	1	52
67	1	74
88	1	101
111	2	211
131	2	333
153	2	387
159	2	439
179	3	591
189	3	712
214	3	902
239	3	1097
245	4	1145
256	4	1245
273	4	1515
288	4	1832
299	4	2119

Appendix Table 15. Number of Thrips tabaci larvae (second instar) required for development of C. maculata from hatching to pupation. (Replication 2).

Age of C. maculata		Cummulative number of Thrips tabaci larvae consumed
Hours	Instar	
24	1	22
48	1	44
72	1	79
92	1	91
122	2	170
145	2	255
165	2	357
178	3	471
190	3	530
211	3	635
234	3	720
258	3	822
276	4	960
283	4	1144
307	4	1432
317	4	1622
331	4	1785

Appendix Table 16. Number of Thrips tabaci larvae (second instar) required for development of C. maculata from hatching to pupation. (Replication 3).

Age of C. maculata		Cummulative number of Thrips tabaci larvae consumed
Hours	Instar	
22	1	14
46	1	29
71	1	71
96	1	94
123	2	158
146	2	253
170	2	368
180	3	448
192	3	531
202	3	606
216	3	719
234	3	789
258	3	857
280	4	973
301	4	1113
308	4	1281
330	4	1521
354	4	1781
371	4	1986

Appendix Table 17. Numbers of onion thrips and coccinellid predators on onions and cereals within caged plots at the time of installing cages.

Date	Cage # (treatment)[1]		# of plants sampled	Thrips tabaci				Coccinellids				
				Adults	Larvae	Total	#/10 plants	CM	HT	Larvae	Pupae	Eggs
7-23-80	5(=oat)	Row 1	35	73	313	386	130.55	3	0	6	0	18
		Row 2	20	134	198	332						
7-24-80	6(=oat)	Row 2	24	70	302	372	155	3	0	1	0	0
7-28-80	7(=control)	Row 1	17	156	405	561	180	0	0	0	0	0
		Row 2	27	84	201	285						
7-24-80	8(=control)	Row 2	33	24	268	292	88.48	0	0	0	0	0
7-28-80	9(=control)	Row 1	26	248	432	680	279.77	0	0	0	0	0
		Row 2	17	205	318	523						

[1]Cages 1-3 (wheat) and cage 4 (oat) were not checked at this time because of insufficient time.

Appendix Table 18. Numbers of onion thrips and coccinellid predators on onions and cereals within caged plots at the end of the season.

Date	Treatment	# of plants Sampled	Thrips tabaci				Coccinellids				
			Adults	Larvae	Total	#10/plants	CM	HT	Larvae	Pupae	Eggs
8-5-80	1(=wheat)	10	39	286	325	325	1	0	1	0	0
8-11-80	4(=oat)	10	12	112	124	124	3	1	4	2	0
8-19-80	1(=wheat)	10	6	106	112	112	2	0	1	0	14
8-19-80	2(=wheat)	10	3	81	84	84	7	1	0	0	0
8-19-80	3(=wheat)	10	0	53	53	53	1	0	0	1	0
8-19-80	4(=oat)	10	3	19	22	22	9	0	0	4	13
8-19-80	5(=oat)	10	5	46	51	51	16	0	1	3	0
8-19-80	6(=oat)	10	10	230	240	240	9	0	2	1	0
8-19-80	7(=control)	10	2	141	143	143	0	0	0	0	0
8-19-80	8(=control)	10	13	407	420	420	0	0	0	0	0
8-19-80	9(=control)	10	3	131	134	134	0	0	1	0	0

Appendix Table 19a. Feeding rate of second instar Thrips tabaci on onion leaf segments.

# of Thrips	Time (Hrs.)	Area Provided (mm^2)	Area Provide x $Thrip^{-1}$	Area Consumed (mm^2)	Area Fed x $Thrips^{-1}$ x day^{-1}
11	22	141	12.82	61	4.07
24	22	165	6.88	108	4.91
40	22	195	4.88	174	4.75
30	20	215	7.17	160	6.40
20	20	135	6.75	81	4.86
20	20	170	8.50	65	3.90
20	20	131	6.50	63	3.78
20	20	152	7.60	102	6.12
20	20	206	10.30	35	2.10
20	20	210	10.50	71	4.26

Mean = 4.51 (S.E. = 0.39)

Appendix Table 19b. Feeding rate of adult Thrips tabaci on onion leaf segments.

# of Thrips	Time (Hrs)	Area Provided	Area Provided x Thrips^{-1}	Area Fed	Area Fed x Thrips^{-1} x day^{-1}
14	14	207	14.79	51	6.24
12	21	226	18.83	25	2.38
15	21	170	11.33	58	4.42
15	21	160	10.67	31	2.36
12	21	160	13.33	62	5.90
10	22	170	17.00	61	6.65
10	20	201	20.10	48	5.76
10	20	180	18.00	42	5.04
10	20	135	13.50	33	3.96
10	20	146	14.60	41	4.92
10	20	215	21.50	39	4.68
10	20	190	19.00	51	6.12
10	20	175	17.50	32	3.84
10	20	181	18.10	45	5.40
10	20	150	15.00	52	6.24

Mean = 4.92 (S.E. = 0.36)

Appendix Table 20. Summary of 1979 Onion leaf parameters, M.S.U. Muck Farm.

Date	Age Days	N	Mean # Leaves (S.E.)	Total surface area in cm^2 (S.E.)	Total Leaf Length in mm (S.E.)
6-08-79	21	20	2.45 (.14)	4.44 (.29)	280.10 (11.86)
6-12-79	24	20	2.95 (.09)	6.92 (.46)	377.30 (13.28)
6-18-79	30	20	4.40 (.15)	22.32 (2.33)	712.65 (46.50)
6-25-79	37	9	5.22 (.15)	36.10 (4.62)	888.22 (64.58)
7-02-79	44	10	6.20 (.29)	85.19 (11.18)	1520.00 (106.54)
7-10-79	52	10	6.80 (.33)	114.35 (19.90)	1950.10 (209.21)
7-16-79	58	10	8.00 (.33)	215.22 (27.66)	2973.00 (205.34)
7-23-79	65	10	9.20 (.36)	288.12 (31.75)	3275.80 (260.91)
8-03-79	76	5	11.80 (1.07)	267.25 (53.86)	2786.60 (488.05)
8-13-79	86	10	10.90 (.59)	384.74 (32.52)	4682.80 (364.33)
8-28-79	101	10	8.90 (.60)	404.74 (68.06)	4290.70 (441.25)