SEASONAL ABUNDANCE OF APHIDOPHAGOUS PREDATORS ON WATERMELON AND POTENTIAL OF COCCINELLIDS FOR MELON APHID CONTROL

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Bachelor of Science

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1982

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in Partial Fulfillment of
the Requirements for
the Degree of
MASTER OF SCIENCE
July 1994

OKLAHOMA STATE UNIVERSITY

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PREFACE

This thesis is comprised of four parts. Chapter I is a review on melon aphid and two important aphidophagous coccinellids, *Hippodamia convergens* Guerin-Meneville, and *Coleomegilla maculata* (DeGeer). Chapter II is concerned with the surveys of aphidophagous predators and sampling techniques for estimating the population densities of coccinellids. Chapter III, entitled "Predation of melon aphid by a spotted lady beetle and the convergent lady beetle", was a further study of the two predominant predators of melon aphid. The feeding abilities of these coccinellids were assessed under the laboratory and field conditions. The last part of the thesis, Chapter IV, reports the research which was designed to experimentally evaluate the influence of coccinellid predators on the population densities of melon aphid in the watermelon fields. The general objective of this thesis was to provide some information on the seasonal occurrence of aphidophagous predators and the potential of coccinellids as a biological control agent in watermelon fields in Oklahoma.

This project would not have been completed without guidance and help from many people. First, I wish to express my sincere thanks to my major advisor, Dr. Bob Cartwright, for his teaching and guidance, his encouragement and patience, during my master's program. To Dr. Jonathan V.

Edelson, Dr. Geriit W. Cuperous, Dr. Raymond D. Eikenbary, and Dr. Brian A. Khan, I would like to extend my warmest thanks for serving on my advisory committee. Their advice during my experiments and the critical review of my thesis were invaluable.

I wish to express my gratitude to Sandy Caldwell, for her help in the data processing and thesis preparation. Her assistance made me tide over many crises.

I would like to thank Tim Ebert, for his time spent assisting me, for those interesting talks when we are stationed at the WWAREC. Thanks are extended to Dr. Veazie Perkins of the South Central Agricultural Research Laboratory, USDA, for the slide shooting service. To Dr. Julia Whitworth of the Horticulture Department, Oklahoma State University, I extend my appreciation for her generous help with slide making and instruction on computer work.

My deepest love and gratitude are extended to my family, particularly, my wife, Hongying. Their support and encouragement were the ultimate energy source for all the work I did.

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CHAPTER I

LITERATURE REVIEW

Watermelon production is a progressive industry in Oklahoma in terms of growth in acreage and crop values. In 1988, 9000 acres of watermelon were reported statewide with a economic value of $ 3,600,000 (Motes 1988).

Insect damage is one of the key factors hindering the improvement of crop yield and quality. According to Cuperus' survey (1991), the melon aphid, *Aphis gossypii* (Glover), along with the squash bug, *Anasa tristis* DeGeer, are the most injurious species of insect pests in watermelon fields. The prevalent means of controlling melon aphid is pesticide spraying. Aphids have tremendous potential increase rate through parthenogenesis, and growers are often forced to make repetitive pesticide applications to manage them. Nevertheless, pesticide control may be confounded by the development of pesticide-resistance in aphids. *A. gossypii* associated with many crop has acquired resistance to a wide spectrum of insecticides (O'Brien & Graves 1990, Kerns and Gaylor 1992, Furk et al. 1980, Bingzhong et al. 1987). Insecticide resistance in melon aphid on watermelon has not been confirmed, but lack of control with pesticide application is often encountered. To extricate aphid control from the exclusive reliance on pesticide application, an alternative strategy which makes maximum use of natural enemies in combination with selective use of insecticides becomes imperative.

A number of predaceous and parasitic arthropods which feed on _A_. *gossypii* occur under natural conditions. The convergent lady beetle, *Hippodamia convergens* Guerin-Meneville, and a spotted lady beetle, *Coleomegilla maculata* (DeGeer) are two indigenous species of aphidophagous coccinellids. They have been regarded as important biocontrol agents of aphids because of their numeric abundance and prominent effect on aphid population suppression in various crop systems (Bieberdorf 1956, Hagen 1962, Elliott & Kieckheffer 1990). Integrating the use of coccinellid predators into the watermelon pest management system may reduce the intensity of insecticide application and alleviate selective pressure of insecticides on melon aphid so that a more stable and economical control of melon aphid can be achieved.

A Review *of Aphis gossypii* (Glover)

A. gossypii is a cosmopolitan pest and is regarded as one of the most destructive aphids in the United States. It attacks a wide spectrum of plants which cover at least 64 species from 23 families. Cotton, citrus, cucurbits and other vegetable and ornamental plants are often subject to attack (Calilung 1969, Slosser et al. 1989).

There are two types of life cycle in A. *gossypii*, anholocycle and holocycle. The former refers to those aphids with permanent parthenogenetic ovoviviparous reproduction, and the latter refers to those aphids with a series of parthenogenetic generations and one annual cycle of sexual reproduction. All the offspring from parthenogenesis and those hatching from fertilized eggs of sexual reproduction are females. In the northern United States the aphids reproduce in the spring and summer parthenogenetically, and a generation of sexual forms appear in the fall. These forms mate and the females lay overwintering eggs which hatch the next spring. However, in the southern United States, the aphids are mainly anholocyclic and feed on plants year round (Metcalf et al. 1962).

There are no distinct broods of melon aphid. The length of the life cycle depends on environmental conditions. Maturity is reached in 4-10 days. The reproductive period is about 3 weeks, and the average length of life of an adult is approximately one month. A maximum of 51 generations can be completed in a year with each female producing about 85 young under greenhouse conditions (Little 1957).

Aphids feed on plants by sucking sap from the stem and foliage through stylets inserted into the phloem sieve tube.

Depending on stage of development, an aphid may ingest 10-133% of its own fresh body weight per hour (Kennedy & Stroyan 1959, Auclair 1963). Aphids may also vector virus diseases. Melon aphid has been reported to be capable of transmitting watermelon mosaic virus and cucumber mosaic virus (Coudriet 1962, Tripathy & Joshi 1985).

Aphids are very adaptive organisms. The development of pesticide resistance is a principal factor that can complicate the melon aphid control. Currently, melon aphid populations have been known to have become resistant to HCN, organophosphate and chlorinated hydrocarbon insecticides (Slosser et al. 1989). O'Brien & Graves (1990) reported that *A. gossypii* in cotton fields has shown substantial tolerance to bifenthrin, chlorpyrifos, oxydemeton-methy, dicrotophos phosphamidon, profenofos, and endosulfan even after 6-8 months in culture. A noticeable build-up of the melon aphid populations after three chemical applications in cotton fields has been observed (O'Brien & Graves 1990).

A Review of *Hippodamia convergens* Guerin-Meneville

H. convergens is a widely distributed North American coccinellid species. It has received much attention as an aphidophagous predator since the early 1900s and has proven to be the most common and abundant aphid attacker in a complex of crop systems (Hagen 1962).

H. convergens has three immature developmental stages. The eggs hatch in about 5 days in warm weather. The larvae complete their development in 2-4 weeks depending on conditions and the availability of food. The pupal stage lasts about 4-8 days, thus the entire life cycle from egg to adult takes about 4-6 weeks. The adults can live one year and one female adult may lay over 1,000 eggs (Smith and Hagen 1956). Obrycki and Tauber (1982) found the preimaginal development period of *H. convergens* was 230 degree-days above a threshold of 12^0C, and the optimal temperature for development was 29^0C. However, various geographic populations demonstrate significant differences in developmental rates as well as the duration of each life stage (Miller 1992).

Convergent lady beetle is usually univoltine with facultative imaginal dormancy. The unique feature of the biology of this lady beetle is migratory habit. According to Stewart's (1967) observation in Arkansas, it is most common during spring months. In June, the lady beetle populations in crops drop sharply and the beetles migrate to higher elevations for estivation from the first to the last week in June. The beetles at higher elevations have undeveloped ovaries and low oxygen-consumption rates. This estivation is viewed as facultative and is associated with low prey population. When aphids were abundant, as in early spring and fall, the beetles tend to be sexually active and show a

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Both adults and larvae of *H. convergens* feed on aphids. Intensive studies on their voracity have been done and the results varied with experimental conditions and the geographic origins. Goodarzy and Davis (1958) reported the average daily consumption of apterous spotted alfalfa aphids at 27°C and 43.3% RH was 26.0 and 32.9 for larva and adult, respectively. Total consumption averaged 468.2 over a 21-day period. Simpson and Burkhardt (1960) reported that male and female could eat an average of 2912 and 5665 spotted alfalfa aphids, respectively, in 48 days. They also noticed cold temperature influenced feeding and other activities of the lady beetle. The average aphid consumption was less than one per day at the temperature of 7°C. Nielson & Currie (1960) concluded that the daily consumption of aphids per larval instar was in direct arithmetic proportion and total consumption in direct geometric proportion to the larval instar. The adult males lived longest on a diet of 100 and females on 90 aphids per day when fed with the spotted alfalfa aphid.

Although *H. convergens* is a polyphagous predator, it exhibits a preference for aphids. Considering its high feeding capacity, coupled with its abundant occurrence in fields, *H. convergens* rank as the most effective predator of aphids (Goodarzy & Davis 1958, Simpson & Burkhardt 1960, Nielson and Henderson 1959). This species occurs on watermelon, cantaloupe, etc, and the populations of predator increased rapidly following the population growth of the watermelon aphids and prevented the aphids from reaching a damaging level (Michelbacher 1950).

The role of H. convergens in California's alfalfa aphid control has been thoroughly examined. The predators entered alfalfa fields in early spring and preyed heavily on the aphids. From January until March the beetles reduced aphid populations even though weather and plant growth conditions favored aphid population growth. The excellent performance of *H. convergens* resulted in the development of an integrated control system and the abandonment of pesticide sprays in springtime. Although there was period when the lady beetle did not remain in the field as a result of emigration to estival hibernal quarters, the whole predator complex in the field was able to keep the aphid populations below the economic threshold (Hagen & van den Bosch 1968, Neuenschwander et al. 1975).

Tamaki and Weeks (1973) investigated the impact of *H. convergens* on populations of *Myzus persicae* (Sulzer). They found the elytrum-removed lady beetles played an important part in reducing aphid populations on field-grown sugar beets. Periodic colonization of *H. convergens* through the collection of beetles from their overwintering aggregations and release into crop fields used to be a routine practice in aphid control in some areas, but the rapid dispersal of predators made this method unrewarding. Introduction and release did not achieve the result of supplementing local predator population (Hagen et al. 1976).

A Review of *Coleomegilla maculata* (DeGeer)

C. maculata is widely distributed east of the Rocky Mountains in North America (Richerson & Deloach 1973). It is abundant in various crop systems and has been considered an important predator of numerous insect pests (Putman 1964, Conrad 1959, Warren and Tadic 1967, Shade et al. 1970).

Like *H. convergens*, *C. maculata* passes through three immature developmental stages to complete the development from egg to adult. The length of the development period varies with the ambient temperature and type of food. Larvae usually have 4 instars, but under laboratory conditions some larvae have 5 instars. Under a temperature of 26.7^{0}C, the duration of development averaged 20.6 days when fed pork liver and 18.2 days when fed fall webworm *(Hyphantrian cunca* (Drury)) eggs (Warren & Tadic 1967). When fed green peach aphid, *M. persicae*, the average duration of development was

48 days under 16^0C, 25 days under 21^0C, and 22 days under 24^0C (Gurney & Hussey 1970). An accumulation of 236 degree days, above a threshold of 11.3^0C, is required to complete the from oviposition to the emergence of the adult (Obrycki & Tauber 1978). The optimum temperature range with shortest developmental duration and highest survival is $24\text{-}26.7^0$C (Obrycki & Tauber 1978). The fecundity is highest at 25^0C, and longevity for laboratory-reared adults is longest at 23^0C (Smith & Williams 1976).

C. maculata feeds on many aphid species, including green peach aphid, pea aphid, cabbage aphid, corn leaf aphid, cotton or melon aphid, etc. It also preys on spider mites, Lepidopteran eggs, coleoptera eggs and small larvae (Bartholomai 1954, Conrad 1959, Warren & Tadic 1967, Smith 1961, Putman 1957, Putman 1964, Shade et al. 1970, Whitcomb 1967, Whitman 1975). Either live or dried aphids will meet the nutritional requirement for the development and reproduction of this coccinellid (Atallah & Newswom 1966, Smith 1965a, 1965b).

This coccinellid can complete development on a diet of various pollens (Smith 1961). Groden et al. (1990) found that *C. maculata* adults did not preferentially feed on aphids, but consumed whatever prey they encountered. Despite the fact that *C. maculata* can feed on a wide spectrum of diets, the quality and quantity of food strongly influence its development. The development rate is slower when it feeds on spider mites, *Tetranychus telarius* (L.) than on aphids, *Rhapolosiphum rufomaculatum* (Putman 1957). Smith (1965b) reported that the development of this coccinellid was more rapid and survival of larvae was higher when it was reared on a mixture of corn leaf aphids and corn pollens than when the larvae received either food alone.

In another study, Hazzard & Ferro (1991) found that when Colorado potato beetle eggs and green peach aphids were available in equal numbers, female adults did not prefer either prey at low prey densities, but they preferred green peach aphids over Colorado potato beetle eggs at high densities. The attack rate against the Colorado potato beetle eggs was reduced by 36.7%, compared with those continuously feeding on this prey alone. The fecundity of the predator was also reduced when fed the beetle eggs. The average number of eggs laid per female adult per day was 3.89 on the aphid diet and 0.87 on beetle eggs. The proportion of reproductive female adults decreased when it fed on beetle eggs. Eighty percent of the female adults of *C. maculata* produced eggs when feeding on aphids, whereas only 25% of them produced eggs when feeding on beetle eggs.

During the larval stage, *C. maculata* can consume 272 *M. persicae* or 486 *A. gossypii*. In comparison, a seven-spotted lady beetle, *Coccinella septempunctata* (L.) consumes an average of 173 *M. persicae* during its larval stage (Gurney & Hussey 1970). Temperature has a profound effect on the feeding rate of the beetles. Mack & Smilowitz (1982) reported that the feeding rates of larvae and adults on green peach aphid increased linearly in the temperature range of 15-32.2^{0}C.

C. maculata is multivoltine with facultative diapause in adults. As in the case of the convergent lady beetle, food is considered as a principal cue in the regulation of diapause, although temperature is also involved (Hodek 1986). *C. maculata* adults hibernate in large aggregations in grass and leaf litter accumulated in protected places such as fence rows and at the bases of trees. These microhabitats provide insulation against drastic temperature fluctuations (Solbreck 1974). The beginning of diapause, and thus the number of generations in a year, depends greatly on the abundance of food. Smith (1965c) indicated that, as *C. maculata* can complete development and reproduce on different plant pollens as well as a wide spectrum of insects. The prevailing temperature conditions in eastern North America could allow this species to have 2-3 generations in a year. Solbreck (1974) observed that this coccinellid had 2 generations in Iowa.

C. maculata has been shown to be effective in suppressing aphid populations in a number of crop systems. It often occurs concurrently with other coccinellid species, and the coccinellid complex exercises substantial aphid control in the field. Obrycki & Tauber (1985) reported that the coccinellid complex made up over 70-95% of the predators in potato fields, of which *C. maculata* and *H. convergens* were the most numerous species. These coccinellids demonstrated good control of the green peach aphid populations in August, the late portion of the growing season. Rice & Wilde (1988) demonstrated that a complex of *C. maculata* and other coccinellids, was the predominant biological control agent of greenbug, and therefore, played an important role in controlling this pest in Kansas winter wheat and grain sorghum. The aphid population levels were significantly greater in plots where coccinellids were excluded than in those plots where coccinellids were partially excluded or not excluded. Kring et al. (1985) determined that the regulation of greenbug populations in the Texas High-Plains sorghum crop was the result of predation by a complex of indigenous coccinellids, of which *C. maculata* was a primary constituent.

Wright & Laing (1980) found that the coccinellid populations responded rapidly to corn leaf aphid populations through numerical responses once the aphids became exposed to predation when the plants tasselled. Coccinellids did not provide economical control at the critical time of tasselling because the aphids hid inside the whorl of leaves surrounding the tassel where coccinellid could not access them. However, the coccinellids could maintain the aphid populations at tolerable levels for the rest of the growing season.

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CHAPTER II

SURVEY OF MELON APHID PREDATORS AND A COMPARATIVE STUDY OF THREE METHODS FOR COCCINELLID SAMPLING

Introduction

The melon aphid, *Aphis gossypii* (Glover), is a serious pest in Oklahoma watermelon fields. Feeding and subsequent damage by melon aphid can cause reductions in yield and quality of the crop (Cartwright, 1992).

Under natural conditions, melon aphids can be attacked by a number of natural enemies. Coccinellid predators have been known to play a major role in repressing populations in various crop systems (Hodek 1973, Kring et al. 1985, Frazer et al. 1981). In Oklahoma, Bieberdorf (1956) reported that indigenous coccinellids, mainly *Hippodamia convergens,* reduced aphid populations on alfalfa. However, neither the occurrence of coccinellid and other aphidophagous predators on watermelon nor their potential for controlling melon aphid have been studied.

To examine the impact of natural enemies on the population dynamics of insect pests, accurate and precise estimates of both natural enemies and pest population densities are necessary. To be accurate denotes that the estimated means represent the true population means, and to be precise implies that the individual sample variances are close to their mean. For the estimation of melon aphid numbers, a leaf sampling technique is routinely used, and an economic threshold has been established in Oklahoma watermelon fields (Cartwright, unpublished data). For predator sampling, however, no techniques have been established, and an effective sampling method is needed.

As an essential step toward establishing an IPM program in watermelon systems, we initiated a field survey to examine the composition of aphidophagous predator populations and their seasonal abundance. Meanwhile, a series of experiments was conducted to compare the effectiveness of different methods for the sampling of predators. Since coccinellids are the most prominent aphidophagous predators on watermelon, our study focused on them. Information gained from this study will provide a understanding of the population regulation of melon aphid and will facilitate the development of practical sampling techniques for coccinellid predators.

Materials and Methods

Field Survey: Predaceous arthropods were surveyed in

1992 and 1993 growing seasons at three locations representing watermelon producing areas in southern Oklahoma. In 1992, two 4-ha commercial fields in Atoka, one 5-ha commercial field in Rush Springs, five 5-ha commercial fields in Terral, and a 0.4-ha experimental field at the Wes Watkins Agricultural Research Center (WWAREC) in Lane, were surveyed, respectively. In 1993, a survey was made at the WWAREC in a 0.4-ha experimental field with a blend of watermelon and cantaloupe.

Two types of approaches, visual search and sticky traps, were used to estimate the abundance of melon aphids and their predators. The former involved search and *in situ* counting of melon aphid on selected leaves and predators in certain areas of the plants; the latter consisted of examining the captures of melon aphid and their predators on sticky traps. In commercial fields, surveys were started between late May and early July and lasted until harvest. Samples were taken at 10 to 14-day intervals. A field was divided into 4 rectangular sections of approximately the same size. Twenty-five evenly spaced plants were selected along a diagonal line in each section so that a total of 100 plants were selected from a field. On each plant, a 930 cm^2 (30.5 x 30.5 cm) metal wire quadrat was placed randomly in a central and peripheral area respectively. Numbers of predators within each quadrat were recorded. In addition, two leaves, one from the inner and another from the outer portion of the plant, were selected randomly. Numbers of apterous and alate aphids on each selected leaf were recorded.

The scheme for predator sampling in the WWAREC experimental fields differed from that described above but melon aphid sampling followed the same leaf survey method. The fields were not divided into sections. In the 1992 survey, 60 plants were randomly selected from a 0.4-ha field on each survey date. On each selected plant, a 1-m^2 area was selected by randomly placing a lightweight metal frame on the canopy. This area was then searched and numbers of predators were recorded. In the 1993 survey, 100 plants were sampled from 20 plots on each sampling occasion. Two 930-cm^2 areas from each plant were searched for predators.

Sticky traps was established between late May and early July. Traps were made of an adhesive yellow card stapled to a 30 x 3 cm wooden stick. Both sides of the card were adhesive. The foot of the traps were stuck into the soil so that a distance of 25 cm between the lower edge of the card and the soil level was maintained. Trap numbers varied with locations, either 6 or 12 traps set up in each field. Where 12 traps were used, the field was divided into four sections and 3 traps were located in each section. The 3 traps were placed in a straight line spaced 20 m apart. The traps were oriented south to north, east to west, and horizontally, respectively. In the fields with 6 traps, the traps were uniformly distributed in the field without specific orientations. Traps were collected 1 or 2 weeks after being put in the fields and new traps were placed at the same point with the same orientation as the previous ones. Traps collected were individually put in plastic bags and transferred to the laboratory. Numbers of melon aphids and aphidophagous predators caught were then counted.

Cultural practices and pesticide applications in commercial grower's fields were not known. In the experimental fields at the WWAREC, no insecticides were used while fertilization, irrigation, and weed and disease control were performed following the Oklahoma State University Cooperative Extension Service recommendations.

Efficiencies of Different Methods for Coccinellid Sampling: This experiment was conducted at the WWAREC in the summer of 1993. Watermelons were direct seeded in plastic pots (80 cm in diameter and 50 cm in height) in the greenhouse. Potted plants were transferred into a cage built in the field when vines were ca. 1 m length. Pots were buried in the soil so that the tops of the pots were at the same level as the soil. The cage measured 3 x 3 x 1.5 m and was made of a wooden frame covered with nylon screen. Nine pots, 0.7 m apart, were put inside the cage. Plants were artificially infested with melon aphids. Two days inoculation, 250-300 adults of lady beetle, *Coleomegilla maculata,* were released into the cage. One hour later, when the predators were assumed to have been evenly distributed among plants, tests were then started.

This part of the study was conducted to compare three techniques for sampling coccinellids on watermelon. The first technique involved visual search and recording of the number of coccinellids in two 930-cm^2 quadrats from a watermelon plant. The second technique involved checking the number of coccinellids on a whole plant. The third technique was to estimate the number of coccinellids on a plant by counting the number obtained by sucking the plant with a suction machine. These three techniques are henceforth called "quadrat", "whole-plant", and "suction", respectively.

The whole-plant and suction methods estimated the number of the coccinellids per plant, while the quadrat method estimated the densities of coccinellid per unit area on a plant. Before the comparative study of different sampling techniques started, a preliminary test was performed to determine a standard suction duration in the suction method. Three durations, 5, 10, and 20 seconds, were selected for which the suction machine was used to capture *C. maculata* from a plant. The orifice of the suction machine was gently moved on top of a plant canopy according to the predetermined durations. A twenty-second sample was found to capture the greatest numbers of the predators, and therefore was used as a standard duration in suction methods.

A randomized complete block design was used. Eight plants were sampled in the cage. Quadrat, whole-plant, and suction methods were performed sequentially on each of the 8 selected plants. During the quadrat and whole-plant searches, extreme care was exercised to minimize the disturbance of plant so that the distribution of the predators would not change. This procedure was replicated 8 times during 24-27 September, 1993.

Data Analyses: In the 1992 growing season, incidence of melon aphid and predators was low in all the fields surveyed and on most of the sampling occasions. The survey was often interrupted by severe weather conditions as well. In most of the fields, the survey covered only a portion of the growing season. The survey in the 1993 growing season was relatively complete but the data were obtained only from one field. Such limitations as low numbers of individual species, great variance, and incomplete coverage of the season made it impossible to compare the abundance of predators between different fields and growing seasons. Therefore, data of visual search and sticky trap records from all sampling occasions in the two years were pooled to obtain general information on the species composition and relative abundance of aphidaphagous predators during the watermelon growing season. The mean numbers of coccinellid complex obtained from visual search in the 1993 growing season were used to demonstrate the seasonal abundance of aphidophagous predators.

Data from coccinellid sampling were subjected to different statistical procedures (SAS Institute 1988). In the process of selecting a standard duration of suction machine sampling, an analysis of variance (ANOVA) was conducted to compare the number of coccinellids obtained by suction under different duration regimes. Subsequently, the mean captures by suction, quadrat, and whole-plant method were compared using ANOVA with a mean separation determined by the Ryan-Einot-Gabriel-Welsch Multiple F Test (SAS Institute 1988).

Based on an assumption that whole-plant sampling best estimates the true population levels of the coccinellid, the accuracy of the suction method was evaluated by regressing the estimates of the numbers obtained by suction method against the whole-plant counts. Linear regression analyses were also performed to generate a calibration model for converting the mean numbers obtained from quadrat methods into estimated mean numbers of whole-plant sampling.

The precision of different sampling methods was evaluated by comparing their coefficients of variation (CV). CV values serve as an index of sample variability relative to the mean of the samples and were calculated by the formula, CV = 100 x (standard deviation)/mean. A comparison of CVs indicates which sampling method produced the most consistent estimates of the population levels. Because estimates of CVs do not followed a normal distribution (Caldwell, unpublished), a distribution-free nonparametric multiple comparison test, the Kruskal-Wallis Test, was performed.

Results and Discussion

Melon Aphid Infestation: Melon aphids infested watermelon plants, and their densities varied from field to field. During the 1992 growing season, melon aphid population densities were very low in all fields surveyed. In Rush Springs, the greatest aphid density was only 2.7 aphids/leaf, occurring on June 18. In Atoka, aphid densities were below 0.3/leaf. Colonies of melon aphid were detected in most of the fields surveyed early in the season, but populations remained localized and did not spread out as the season progressed. Melon aphids disappeared from most of the fields in the middle of the season and the survey was forced to terminate. In 1993, melon aphid populations occurred throughout the growing season. In the experimental field at the WWAREC, melon aphids were detected consistently but always at low population levels. The greatest density of melon aphids, occuring on July 15, was 2.0/930 cm^2 (Fig. 1).

Predator Composition: Watermelon fields harbored a variety of predators. Pooling the data of two years' survey, visual observations and sticky traps combined, the aphid predator complex comprised 12 species from 5 families (Table 1). No effort was made to identify species other than coccinellids. Although the species composition and relative abundance varied with area, field, and growing season, coccinellids occupied a dominant position in terms of magnitude of numbers and duration of existence in the field. Among a total of 2982 adults observed in 13 fields, 90% were coccinellids, 9% were predaceous bugs, and 1% were other predators. The majority of the predaceous bugs were big-eyed bug, *Geocoris spp.*. In some fields, flower bugs, *Orius spp.*, were common on some sampling occasions. In spots where large number of melon aphids were present, numerous chrysopids were occasionally observed.

The components of the aphidophagous predator complex captured by sticky traps were more diversified than that reflected by field visual observation. Most of the species were collected only from sticky traps. Despite this, *C. maculata* and *H. Convergens* were the most consistently present and abundant predators.

Seasonal Abundance of Coccinellids: A complex of coccinellids was observed in watermelon fields. Eight species of coccinellids were encountered during the course of our field surveys. *Hipppodemia convergens* and *Coleomegilla maculata* existed in appreciable numbers during June, July, and August and were the most abundant predators in all of the fields surveyed. *Scymnus spp.* were numerous in a few fields, but their occurrence did not seem connected to melon aphid infestation. *Coccinella septempunctata* inhabited some fields but never attained high population densities. Other coccinellids were only occasionally encountered.

Population densities of coccinellids varied greatly from year to year and from field to field, depending on the population levels of melon aphid. The seasonal fluctuation of the coccinellid complex reflected this correlation. In a field surveyed in Atoka, very few aphids were observed during the 1992 growing season. As a result, coccinellid populations failed to increase to high levels and the highest density was 0.2 adults per 930 cm^2 (Fig. 2). Conversely, in the experimental field at the WWAREC in the 1993 growing season, melon aphids existed in higher population densities, and so did the coccinellid predators. Before July, very few melon aphids were observed, so coccinellids were rarely detected. The number of coccinellids increased steadily with the population growth of melon aphid and reached a peaked of 0.4 adult/930 cm^2, on July 25, 10 days after the peak of melon aphid abundance. Coccinellids remained in the field until the end of the season (Fig. 1). In this field, numbers of coccinellid adults caught by sticky traps fluctuated following a similar trend as demonstrated in visual observation except that the peak date was August 5, about 10 days later than that of visual observation (Fig. 3). Coccinellids continued to be abundant until late August. From the results of our observations, abundance on sticky traps can be used as indexes of coccinellid abundance. The population trend reflected from visual search and trap records concurred except that the peak time shown in trap counting was 10 days later. Results of visual searches recorded the numbers of coccinellids at the moment when counting was occuring, whereas trap counts recorded the number of coccinellids accumulated during the 7 days when the traps were out in the field. To improve the accuracy and precision of population estimation, more traps should be placed in the field, and more even distribution and more frequent collection of the traps should be considered.

Although coccinellid adults were the most abundant predators in the fields, their larvae were seldom detected. This might be because most of the coccinellid adults were migatory rather than residential inhabitants of the fields. This aspect is discussed in the fourth chapter of this thesis.

Efficiencies of Different Methods for Coccinellid Sampling: A duration test demonstrated that sucking a watermelon plant with the suction machine for 5, 10, and 20 seconds showed significantly different captures of *C. maculata* ($p = 0.0001$, $F = 78.56$, $df = 2, 141$). Twenty-second suction captured the highest number of beetles. It was subsequently used as the standard duration for the sucking method in the comparative study of sampling methods.

Significant differences in the mean captures of *C. maculata* were observed among the three sampling techniques ($P = 0.001$, $F = 74.98$ df = 2, 182). A whole-plant visual search provided larger number of the coccinellid than did the suction machine. The mean number of coccinellids per plant obtained with the suction method was 5.5, as compared to 10.3 obtained by the whole-plant search. Thus, the suction method gave an underestimate of *C. maculata* by 47%. Despite this, comparison of CV values revealed the underestimate was relatively consistent. The mean CV of the suction method was not significantly different from that of the whole-plant search (Table 2). A calibration model was thus generated, through a linear regression to convert the suction estimate into whole-plant estimate ($P = 0.0001$, $R^2 = 0.77$) (Fig. 4). The mean CV of quadrat sampling was 67.8%, the highest of the three methods (Table 2), which suggests that this method is the least precise for sampling coccinellid adults. However, the mean CV for quadrat sampling was not significantly different from that for the suction method. Regression analysis produced a conversion equation which can be used to predict the intensity of coccinellid adults from the quadrat captures ($P = 0.0001$, $R^2 = 0.53$) (Fig. 5).

Different types of suction have been widely used for sampling arthropods on cotton (Smith et al. 1976, Gonzalez et al. 1977,) and other agroecosystems (Cartwright & Kok 1983, Zalom et al. 1993). In our study, the suction machine captured only 53% of the total numbers of *C. maculata* estimated in a whole-plant sample. Its consistency demonstrates that this method is useful in sampling predators on watermelon at the early stage of plant growth when the vines have not extensively spread out. However, as the season progresses, the canopies of the plants overlap and the boundary of a plant is hard to distinguish. The aperture of the suction machine is easily blocked by leaves, which make it impossible to capture insects without destroying the plant. Suction is also a relatively expensive method. With these limitations, vacumm suction is not a feasible method for sampling predators in watermelon fields. Whole-plant sampling is reliable, but is very time-consuming. It also requires overcoming the difficulty of plant overlap in the mid- and late season. Therefore, whole-plant surveys are not a preferable sampling method either. Quadrat sampling gives biased coccinellid population estimates, but it is roughly as precise as the suction method. It is easy to perform and less labor-intensive than the whole-plant and suction sampling. Therefore, we conclude that the quadrat estimate is the most practical method for predator sampling on watermelon.

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Table 1. Continued

Arilis sp.	0	0	0	0
Neuroptera				
Chrysopidae				
Chrysopa sp.	0	0	0	31 (9)
Total No. Predators	1073	153	462	353

[a] Figures in parentheses represent the relative abundance (percentage) of a specific group of predators in the predator complex.

Table 2. Mean captures of *C. maculata* adults and their mean CVs by three sampling methods.*

Sampling Method	Mean Capture **	Mean CV ***
Whole Plant	10.31 A	37.97 B
Suction	5.47 B	54.64 AB
Quadrat	-------	67.83 A

* Means are separated by REGWF multiple comparison procedure. Means for each column with the same letters are not significantly different at $\alpha = 0.05$ level.

** ANOVA indicates model is significant with a probability of a larger F value smaller than 0.0001.

*** Nonparametric Kruskal-Wallis Test indicates that model is significant with a probability of larger χ^2 value equal to 0.0182.

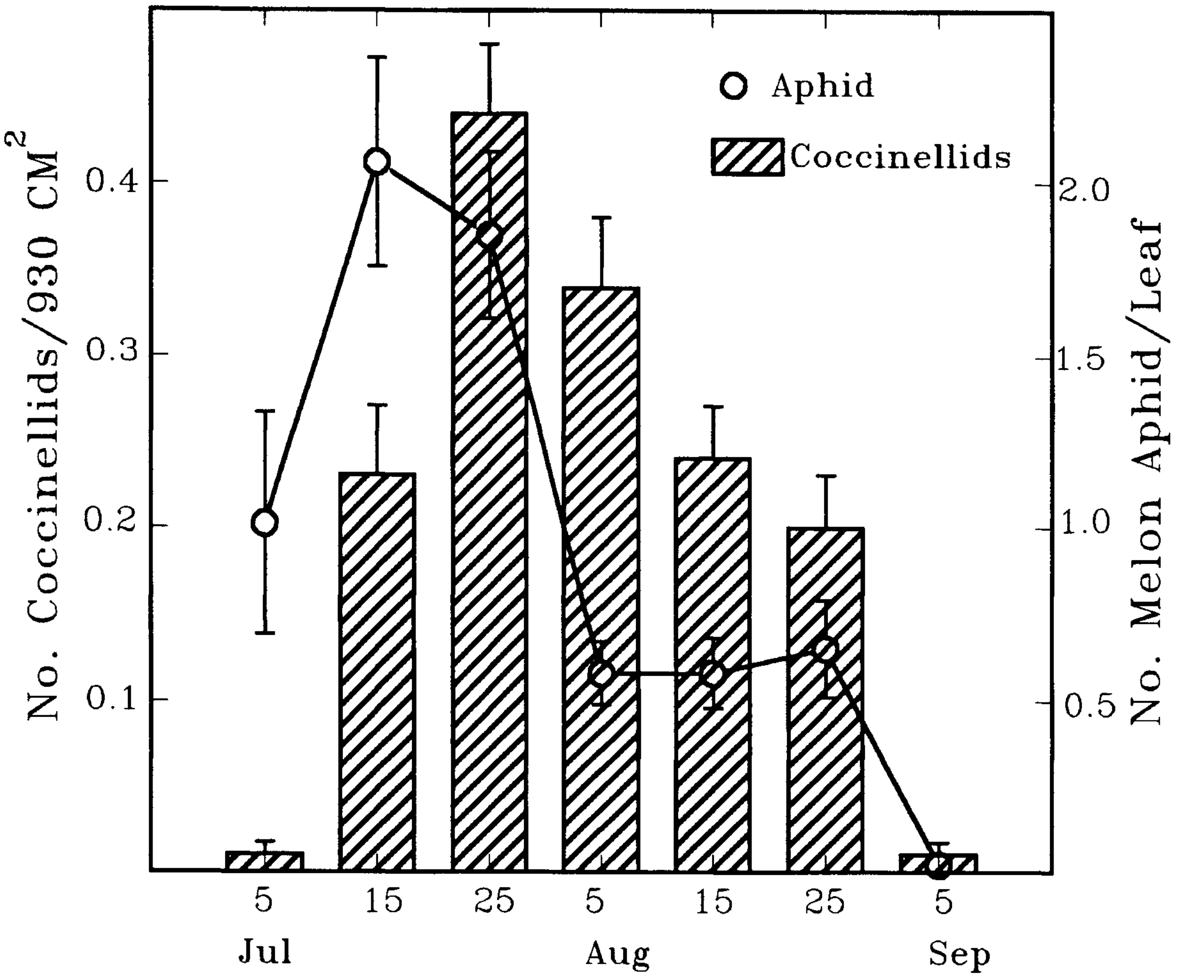

Fig. 1. Population fluctuation of coccinellids and melon aphid (Lane, 1993)

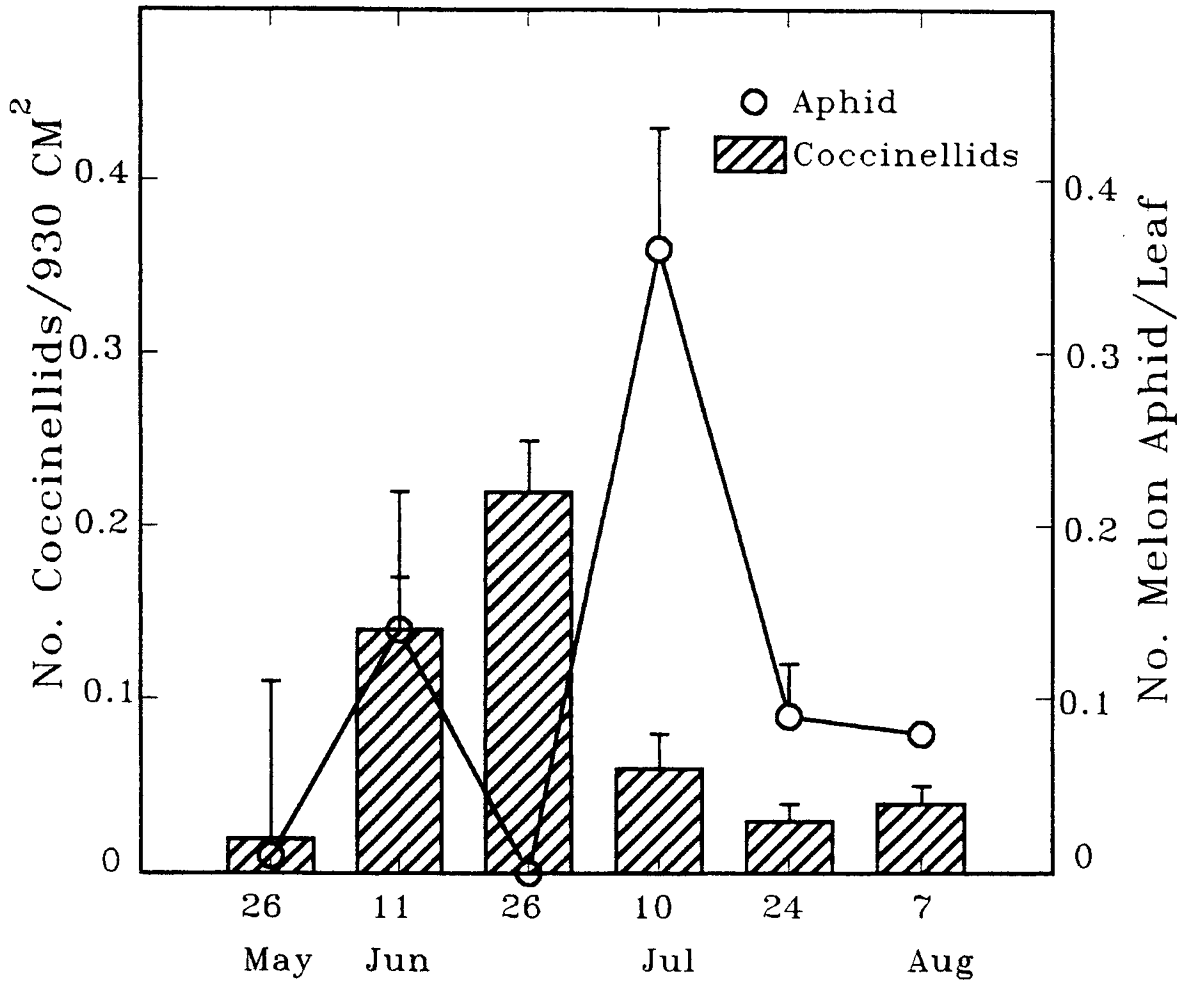

Fig. 2. Population trends of melon aphid and coccinellids (Atoka, 1992)

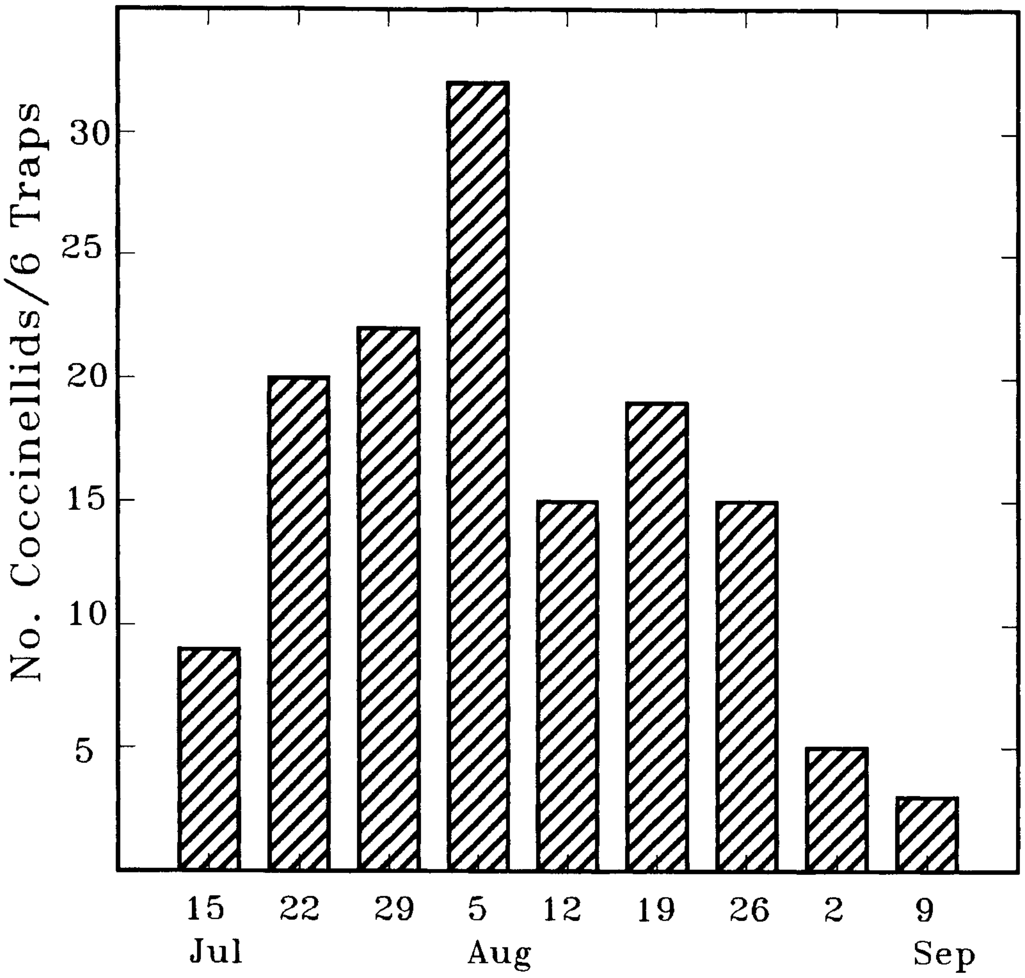

Fig. 3. Number of coccinellids caught on sticky traps (Lane, 1993)

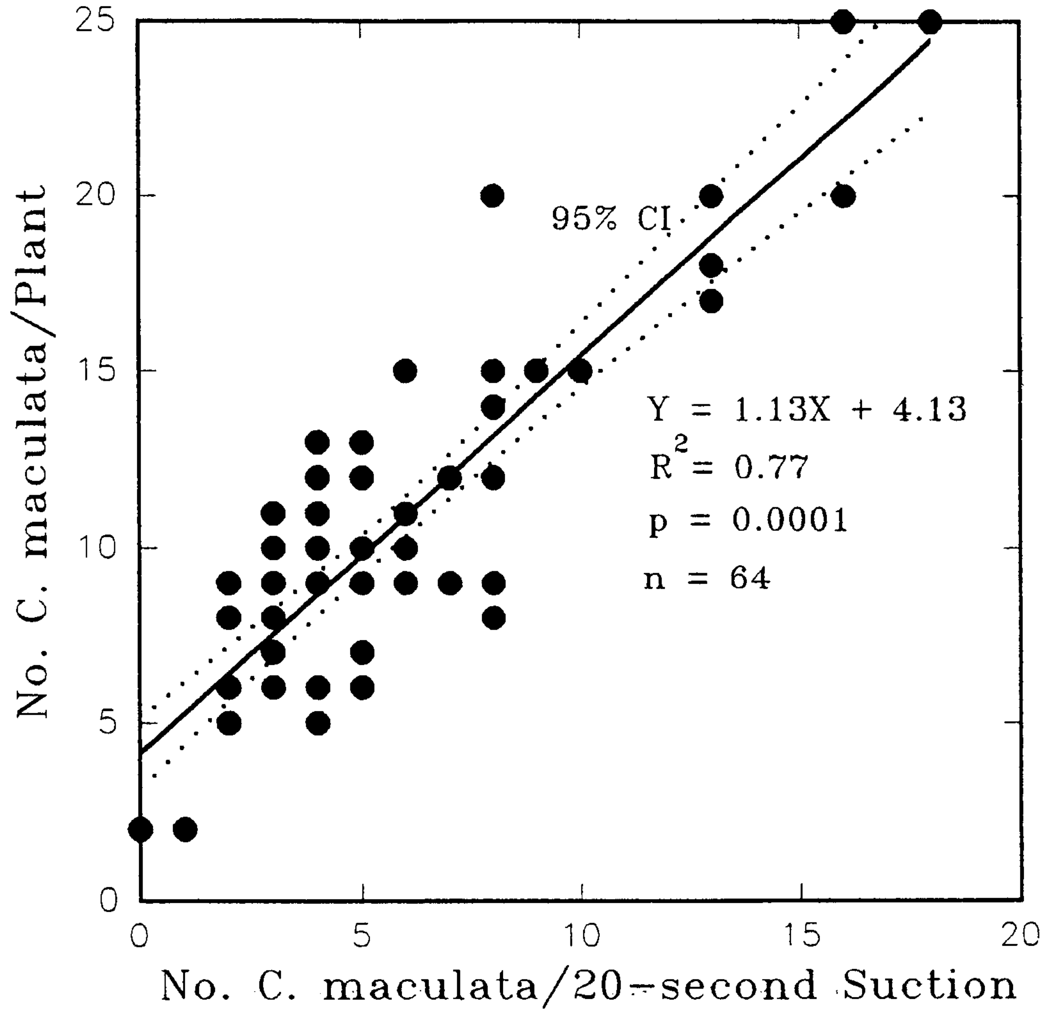

Fig. 4. Relationship between the numbers of coccinellids sampled by suction and whole-plant search

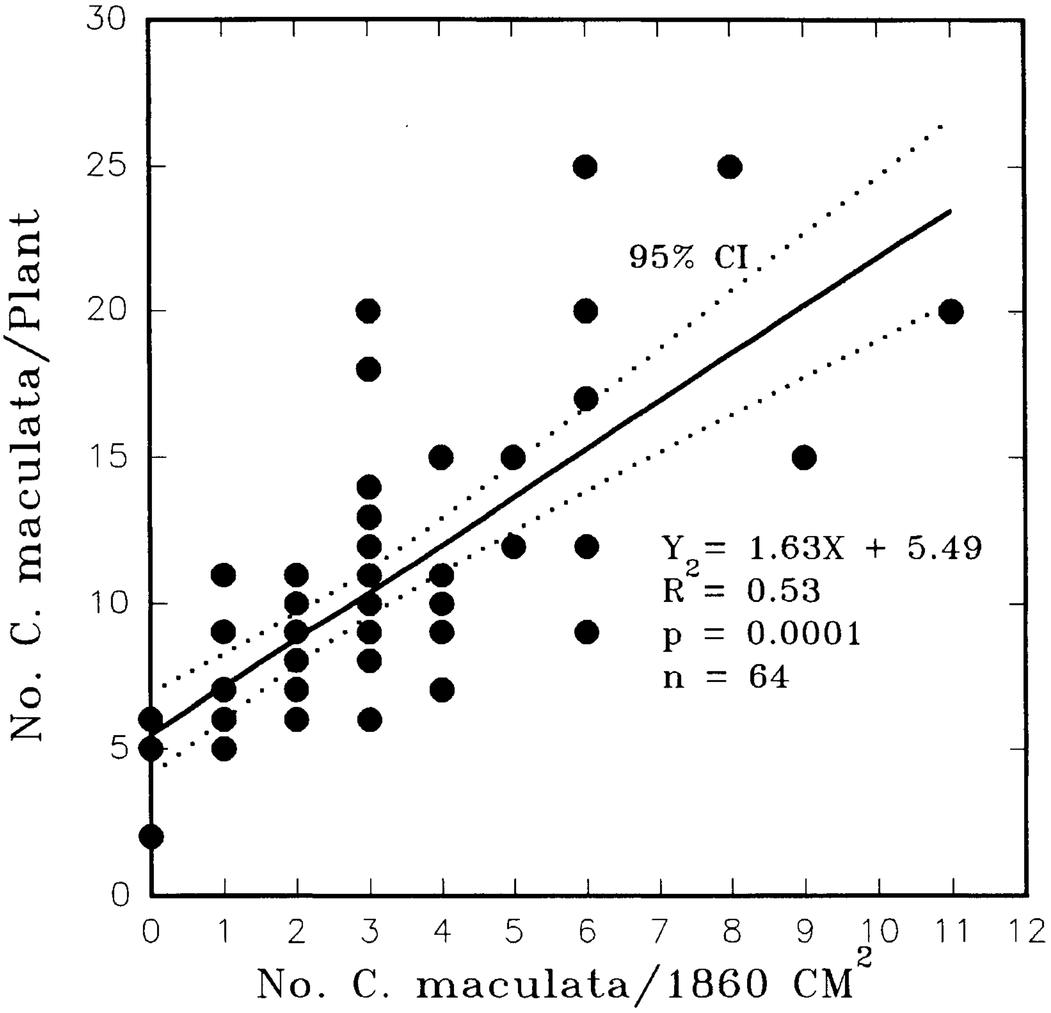

Fig. 5. Relationship between the numbers of coccinellids sampled by quadrat method and whole-plant search

CHAPTER III

PREDATION OF MELON APHID BY A SPOTTED LADY BEETLE AND THE CONVERGENT LADY BEETLE

Introduction

Coccinellids are common predators of aphids in various agroecosystems, but their roles as biological control agents have not been defined in many of these systems. The degree of success of using coccinellids in controlling aphid populations varies with regions, crops, and years (Frazer & Gilbert 1976, Foott 1973, Michelbacher 1950, Neuenschwander et al. 1975). Melon aphid, *Aphis gossypii* Glover, is a serious pest on watermelon in Oklahoma, and it requires regular use of insecticides to avert yield losses. A number of coccinellid species occur in watermelon fields, but their potential for regulating melon aphid populations has not been systematically studied. To fill this void, we initiated a series of field and laboratory experiments to evaluate the potential of using indigenous coccinellids to control melon aphid population development.

Materials and Methods

Melon Aphid: Melon aphids were obtained from stock cultures on watermelon plants at the Wes Watkins Agricultural Research and Extendion Center (WWAREC), Lane, OK. The colony originated from aphids collected in Atoka County, OK, on watermelon, and reared continuously on watermelon for ca. 3 years. Plants were maintained in a greenhouse with temperatures ranging from 20 to 30^0C and relative humidity from 50 to 75%.

Coccinellids: The founder adults of *H. convergens* and *C. maculata* were collected from watermelon, strawberry, and sweet corn fields on the experimental farm of WWAREC, and reared in an insectory. Coccinellids were paired and reared in plastic petri dishes 9 cm in diameter. Pieces of watermelon leaf with a surplus of melon aphid supply were provided as a source of food. Droplets of diluted honey and frozen sweet corn pollen were added on the leaves in the petri dishes as supplementary food. A small water-soaked cotton ball was placed in each petri dish to maintain moisture and act as a water source for the lady beetles. Once eggs were laid in a petri dish, the paired lady beetles were transferred to a new dish. Eggs were kept intact until larvae were hatched. Newly-hatched larvae were transferred individually to different petri dishes provided with an abundance of melon aphids to avoid cannibalism. Only female adults less than 20 days old were used in experiments.

Cages for Experiments: For the field experiments, each cage was made of a wood frame measuring 60 x 60 x 120 cm with mesh nylon organza mounted on top and four sides. Cages were sealed with glue and tape. A 144 cm^2 (12 x 12 cm) window was cut on one side of each cage for access but kept sealed with a Velcro® attachmemt. The four feet of the each cage were stuck ca. 30 cm into the soil with earth piled at the base of each cage to maintain a seal with the soil surface.

The basic structure of the cage for the laboratory experiments was similar to that used for field experiments except that the bottom of each cage consisted of plywood (1.27 cm thick) rather than being open so that a cage could be put on a table in the laboratory. Dimensions were 70 x 80 x 50 cm with a 70 x 80 cm opening on one side, sealed with Velcro®, to allow access.

Aphid Consumption Test in Field Cages: Experiments were conducted from 9 August through 10 September 1993. Watermelon was seeded in plastic pots (15 x 18 cm) in a greenhouse. Three plants were maintained in each pot. When plants grew to the stage of 3-4 completely expanded leaves, a known number of melon aphids were introduced onto the plants to achieve similar levels of infestation. Pots with aphid-infested plants were moved into cages already positioned in the field. After 24 hours, the number of aphids on the three plants in each pot was counted. Following counts, *C. maculata* adults were released through the window into the cages according to four predetermined predator to prey ratios, 1:20, 1:40, 1:80, and 1:160. A control without predator release was maintained for comparison. Five days after predator release, the number of melon aphids remaining on the caged plants were counted. The experiment was replicated through time (dates) and conducted as a randomized complete block design. Each of the four release ratios and the non-release control were replicated twice, and the whole set of treatment replicated five times over different dates from 9 August to 10 September; therefore each treatment was replicated a total of 10 times.

Aphid Consumption Test in Laboratory Cages: Laboratory experiments were carried out in July and August of 1993 in an insectary with temperature maintained at 25±2^{0}C and relative humidity of 60-70%. A 16:8 photoperiod was maintained with 2 40-watt fluorescent lights placed 15 cm above each cage. The experiment was arranged as a completely randomized design. The protocols of predator release and aphid counting were the same as in the field cage experiment described above.

For both field and laboratory experiments, aphid density reduction rates were used for comparison. They were subjected to analyses of variance (PROC ANOVA, SAS Institute 1988) with means separated by Ryan-Einot-Gabriel-Welsh multiple F test (SAS Institute 1988; P =0.05).

Functional Response: The experiment was conducted during the fall and winter of 1993. *C. maculata* and *H. convergens* were tested for their functional responses under different temperatures. Five densities of alate adult aphids, 5, 10, 15, 20, and 30/arena, were used for the functional response test. Each test was executed under five temperature regimes: 15, 20, 25, 30, and 33^{0}C. These temperatures were chosen to cover the temperature range which the coccinellids normally experience in the growing season of watermelon. All tests were performed in a growth chamber with programmed temperature control. Lady beetles and melon aphids were reared in the same way as described in aphid consumption tests. Only female adults of the predators were used in this part of the research. They were starved for 24 h before testing to achieve a similar level of hunger. A plastic petri dish (9 cm in diameter) was used as an arena for predator-prey interaction to take place. Alate adults of melon aphid were transferred from watermelon leaves into the arena with a small brush. One female lady beetle adult was introduced into each arena. Observations were made at one-hour intervals for 10 consecutive hours to check the number of melon aphids consumed by the predator. At each check, number of melon aphids consumed by the predator was recorded, and the predator was transferred to a new arena with the original density of aphids.

The experiment was arranged in a completely randomized design. An analysis of variance (ANOVA) was performed (SAS Institute 1988) to test for effects of temperature and aphid density on aphid consumption. Data were also subjected to regression analyses (SAS Institute, 1988) to generate regression models describing feeding rates of *C. maculata* and *H. convergens* as a function of temperature and aphid density.

Results

Aphid Consumption Tests: Predation by *C. maculata* caused significant reductions in melon aphid numbers in both laboratory and field cage tests at all predator-to-aphid ratios. In the laboratory test, the reduction rate of melon aphid numbers ranged from 89.43 to 99.58% (Table 1. F = 553.31, df = 4,36, P =0.0001). In the laboratory test, *C. maculata* released at the predator-to-prey ratios of 1:20 and 1:40 almost completely eliminated melon aphid populations by the termination of the 5-day observation. Release ratios of 1:80 and 1:160 provided slightly lower levels of predation than 1:20 and 1:40. Nevertheless, aphid reduction rates were not significantly different among the predator release rates. In cages where no predators were released, the number of melon aphids increased by 116.41% above initial aphid populations by the end of the 5-day observation.

selected. The functional response models from the multiple regression analyses for *H. convergens* and *C. maculata*, respectively, were:

$$E = 0.7728\ T + 0.3407\ D - 0.0036\ (T)\ (D) - 0.0138\ T^2 - 0.0058\ D^2 - 9.3923$$

$$(R^2 = 0.79,\ MSE = 0.2362)$$

$$E = 0.6125\ T + 0.2134\ D + 0.0024\ (T)\ (D) - 0.0118\ T^2 - 0.0062\ D^2 - 6.7703$$

$$(R^2 = 0.64,\ MSE = 0.3804)$$

Where E = number of aphid eaten by one predator per hour.
T = temperature.
D = density of melon aphid.

Discussion

The results from this study indicated that convergent lady beetle and spotted lady beetle consumed melon aphids. A noticeable feature of the functional responses of the two coccinellid species was that within the range of aphid densities tested, the number of aphids consumed approximated a linear response relative to the densities of aphid under each of the five temperature regimens. This is close to the simple linear, or type I response (Holling 1959), but not completly conform. A linear relationship were present only when the melon aphid densities were within the range from 5 to 20/arena. Atival and Sethi (1963) reported that *Coccinella septempunctata* L. showed a type I response in attacking cabbage aphid *Lipaphis erysini* (Kalt). Chant (1961) demonstrated that the predacious mite, *Typhlodromus occidentalis* Nesbitt, exhibited a type I response to various densities of *Tetranychus telarius* L. This type of response is only meaningful across the range of densities tested, and the consumption rate should level off at a point. In our experiments, the number of melon aphids consumed by a convergent or spotted lady beetle decreased when aphid densities reached 30 per arena.

In evaluation of feeding tests for spider species, Mansour and Heimbach (1993) found a type II functional response described the prey consumed, but a linear relationship existed between the prey density and prey killed. Flinn (1991) reported that a parasitoid, *Cephalonomia waterstoni* (Gahan) paralyzed more hosts than it could actually lay eggs on. Hodek (1973) indicated that starved coccinellids can initially completely devour the first few prey they attack, but the beetles exploit subsequent prey with a gradually decreasing efficiency. In our study, we also observed some of the aphids killed by coccinellids were only partially consumed.

The rate of successful search, time available for searching, time spent in handling prey, and the hunger level of the predator were major factors affecting the functional response of a predator (Holling 1966). The increase in the number of aphids killed with increased prey density can be explained by the fact that at lower densities, aphids are more dispersed and therefore, a predator takes more search time to encounter a prey. At high prey density, encounters with prey are more frequent. A predator remains in an area to feed until satiation.

Satiation of predators at high densities of melon aphids might have caused the reduction in predation of melon aphids by the coccinellids. Meanwhile, disturbance of predation during feeding by other prey can make a predator abandon its current prey to feed on a new prey. When aphid density exceeded 30/arena, the excessive disturbance of predation made the predator allocate more time to pursuing the aphids and the capture of aphids became more difficult.

The ability to adjust to variable resources is very important if predators are to have an effective impact on their prey (Hodek 1973). The decreasing efficiency in prey consumption at higher prey densities can be compensated through numerical response. We have observed that the numerical response of coccinellids the primary response of coccinellid to melon aphid population increase is demonstrated by an immigration of predators (unpublished data).

Mack and Smilowitz (1982) reported that the impact of *C. maculata* on green peach aphid is strongly temperature-dependent. Although the temperature range of 24-26 is optimal for *C. maculata* growth and development (Obrycki and Tauber 1978), the predation continued to increase with an increase in temperature, up to > 29^0C (Mack & Smilowitz 1982). Our experiments provided evidence of a similar occurrence in relation to melon aphid. At a given temperature, the predation rate of melon aphid by *C. maculata* increased within the range of 15-30^0C. When temperatures reached 33^0C, feeding rates decreased.

For *H. convergens*, the optimal temperature for growth and development is 29^0C (Obrycki and Tauber 1982), a similar pattern of increase in predation was exhibited with the temperature increase within the range of 15-30^0C. However, the predation decreased when temperature exceeded the optimal temperature.

Under field conditions, the efficiency of coccinellids as predators may be reduced due to weather, inter- and intraspecific competitions, etc, as compared to the experimental conditions. However, the results of our research indicated that coccinellids are important biological control agents for melon aphid. Further study is needed to test the feeding efficiency under field conditions in order to develop practical coccinellid-aphid interaction models which will be incorporated in an IPM system in the field.

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Table 1. Reduction in melon aphids on watermelon in the laboratory cages with different release rates of *Coleomegilla maculata*

Predator Release Ratio	Number of Replications	Mean No. Aphids/Plant at Predator Release	Mean No. Aphids/Plant 5 Days After Predator Release	Mean Percentage Reduction in Aphid (±SE)
1:20	10	694.0 A	2.8	99.58 ± 0.23 A
1:40	10	642.0 A	5.1	99.18 ± 0.34 A
1:80	10	599.9 A	37.4	94.21 ± 0.94 A
1:160	10	599.9 A	63.5	89.43 ± 0.61 A
No Coccinellids	10	583.7 A	1244.2	-116.41 ± 9.11 B

Means within each column followed by same letters are not significantly different at $\alpha = 0.05$ by REGWF multiple comparison procedure.

Table 2. Reduction in melon aphids on watermelon in the field cages with different release rates of *Coleomegilla maculata*.

Predator Release Ratio	Number of Replications	Mean No. Aphids/ Plant at Predator Release	Mean No. Aphids/Plant 5 Days After Predator Release	Mean Percentage Reduction in Aphid (±SE)
1:20	10	765.5 A	15.0	98.01 ± 1.36 A
1:40	10	739.6 A	34.8	94.71 ± 2.42 A
1:80	10	772.0 A	128.9	82.35 ± 2.51 A
1:160	10	711.8 A	329.8	53.40 ± 7.35 B
No Coccinellids	10	630.0 A	1183.5	-95.14 ± 11.13 C

Means within each column followed by same letters are not significantly different at ∝ = 0.05 by REGWF multiple comparison procedure.

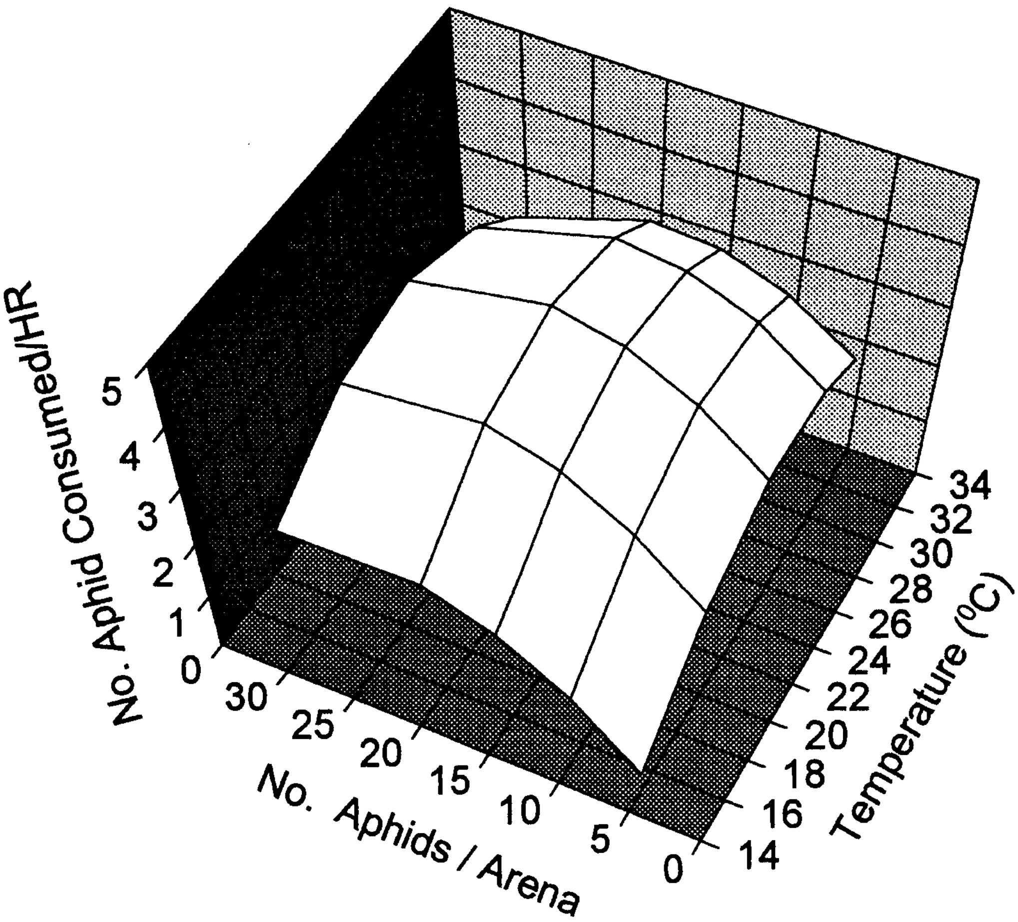

Fig. 1. Temperature-dependent functional responses of <u>H</u>. <u>convergens</u> adult to melon aphid.

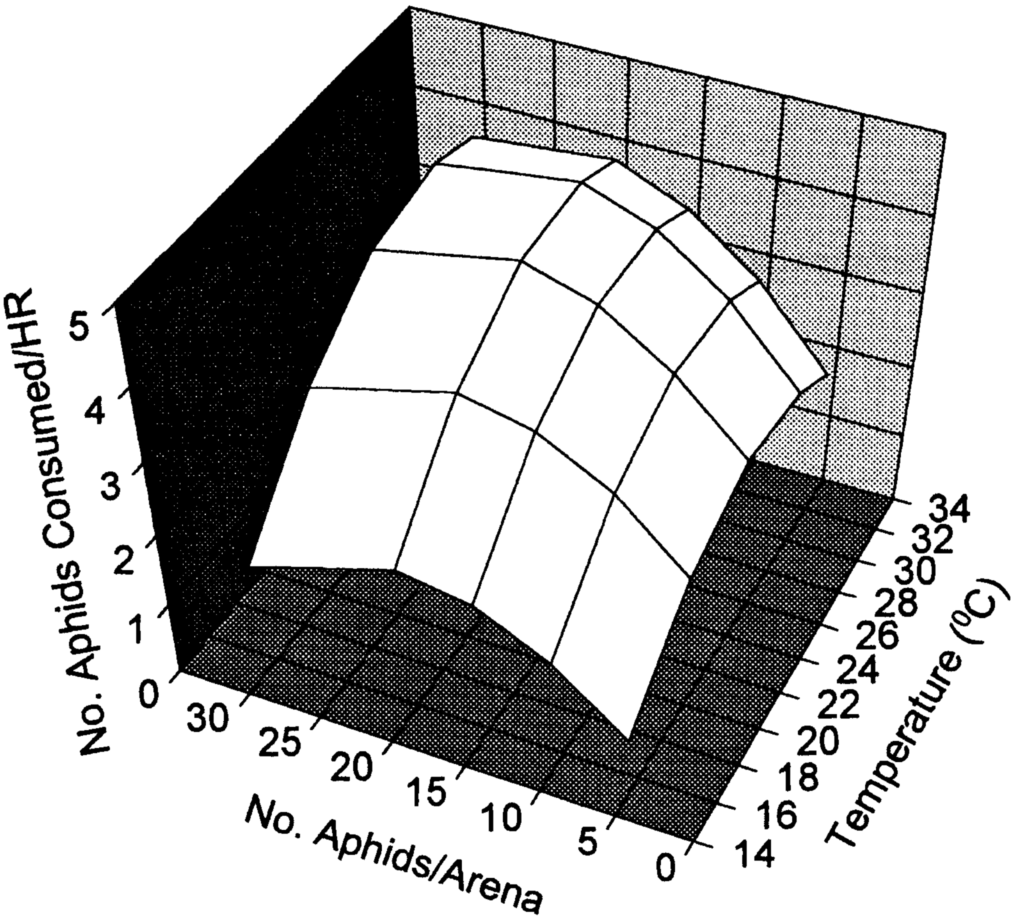

Fig. 2. Temperature-dependent functional responses of *C. maculata* adult to melon aphid.

CHAPTER IV

INFLUENCE OF COCCINELLIDS ON THE POPULATION DYNAMICS OF MELON APHID

Introduction

The melon aphid, *Aphis gossypii* Glover, is one of the most injurious pests of cotton and cucurbit crops. It also attacks citrus, many vegetable and ornamental crops and has been recorded from at least 64 plant species (Blackman & Eastop 1985, Cuperus 1991). Insecticides are the major tools to control this pest. On watermelons, pesticides are applied one to five times to prevent economic loss, depending on the degree of infestation.

Chemical control is frequently confounded by the development of insecticidal resistance. *A. gossypii* has shown resistance to a wide spectrum of insectides (O'Brien & Graves 1990, Kerns & Galor 1992, Furk et al. 1980, Bingzhong et al. 1987). To extricate aphid control from sole reliance on chemical application, an alternative approach which makes maximum use of natural enemies in conjuction with selective pesticide applications should be explored.

A number of predaceous arthropods prey on aphids, including melon aphid under natural conditions. Of these, coccinellids have received extensive attention because of their wide occurrence, relative abundance, and their potential in controlling aphid populations in an array of agroecosystems. Manipulation of native coccinellids, primarily *Hippodamia convergens* Guerin-Meneville, and *Coleomegilla maculata* DeGeer has achieved varible success. *C. maculata* is a euryphagous coccinellid, and can complete its development on corn pollen (Smith 1960, 1961), lepidopteran eggs (Warren & Tadic 1967), pea aphid and corn leaf aphids (Smith 1965a, b). It has been exploited to control spotted alfalfa aphid, *Therioaphis maculata* (Buckton) , green bug, *Schizaphis graminum* (Rondani), and corn leaf aphid, *Rhopalosiphum maidis* (Fitch). *H. convergens* is a polyphagous predator, but exhibits a preference for aphids. It has been reported as one of the most effective predators of aphids and has served a significant role in suppressing population of green peach aphid, *Myzus persicae* (Sulzer), spotted alfalfa aphid, and melon aphid (Goodarzy & Davis 1958, Simpson & Burkhardtet al. 1960, Nielson & Henderson 1959, Michelbacher 1950, Neuenschwander et al. 1975, Tamaki & Weeks 1973).

In spite of the extensive literature, available information on the aphid-coccinellid interaction, and the effectiveness of individual coccinellid species as predators of aphids is very varibale. There is a complex of coccinellid species occurring in Oklahoma watermelon and cantaloupe fields, but little is known about their importance and impact on the population dynamics of melon aphids. The objectives of this study were to view the coccinellid complex as a integral entity and establish the facts of coccinellid and aphid population dynamics in the field so as to improve our understanding of the role of coccinellids in regulating melon aphid populations.

Materials and Methods

An experiment was conducted during the 1993 growing season at the OSU Wes Watkins Agricultural Research and Extension Center, Lane, Oklahoma. Chemical exclusion was used to evaluate the impact of coccinellid predators on aphid populations. Begining 1 July, four types of chemical treatments were applied to field plots: 1) carbaryl spray (Sevin XLR Plus, Rhône Poulenc Ag Company) (0.56 kg ai/ha) at 5- or 10-day intervals to exclude natural enemies; 2) bifenthrin spray (Brigade 10 W, FMC Corp.) (0.04 kg ai/ha) at 5-day intervals to eliminate melon aphid and coccinellids; 3) bifenthrin spray (0.04 kg/ha) when melon aphid population reach the economic threshold of 15 aphids/leaf infestation (Cartwright, unpublished data). 4) no chemical application to allow the existence of natural enemies and melon aphid. Insectides were applied to the row with a hand-held CO_2 sprayer with two TX-18 nozzles calibrated to deliver 756 liters/ha.

In initiating this study, we assigned a treatment which would require insecticide application when the aphid population reached the economic threshold of 15 aphids per leaf (Cartwright, unpublished data). However, the aphid number never attained that level during the experiment, therefore treatment 3 was not utilized.

A split-block experimental design was used with the three chemical treatments arranged in main plots and two cucurbit crops (watermelon and cantaloupe) in subplots. The treatments were replicated five times. Watermelon ('Allsweet') was transplanted into beds on 22 June and cantaloupe ('Perlita') was direct seeded on 4 June in plots measuring 6.7 m by 1.4 m with 6 plants (0.6-m plant spacing) in a row in each plot. A 3.7- and 4.7-m buffer was kept between rows and between plots in a row, respectively. The Oklahoma State University Cooperative Extension Service recommendations were followed for fertilization and irrigation. Irrigation was applied as needed using a surface level trickle system. Benlate DF (Benomyl, Du Pont Company) (0.56 kg/ha) and Dithane DF (Mancozeb, Rohm and Haas Company) (3.36 kg/ha) were sprayed alternately at 1-week intervals from 7 July throug 18 August to control fungus diseases. Weeds were mechanically controlled.

From 1 July through 5 September, melon aphid and coccinellid abundance were estimated at 5-day intervals. Samples were taken between 9:00 and 15:00 hours. Five plants were surveyed in a plot. For aphid census, two leaves, one from the central and another from the outer area, were randomly taken from each plant. Numbers of apterous and alate aphids were recorded. A quadrat approach was used for surveying coccinellids. A 930-cm^2 steel wire frame (30.5 x 30.5 cm) was placed randomly in a central and peripheral area of each plant. Within each quadrat, the numbers of coccinellid adults and other predators were recorded. The weight of watermelon and cantaloupe fruits from plots receiving different treatments were measured so that a yield comparison could be made.

Insect and yield data were subjected to analysis of variance using SAS General Linear Models (GLM) with mean separation determined with Ryan-Einot-Gabriel-Welsch multiple F test (REGWF) at $\alpha=0.05$ level of probability (SAS Institute, 1988). Data from the non-chemical treatment (control) plots were further used for a regression analysis (SAS Institute, 1988) to examine the relationship between the densities of aphids and adult coccinellids. Data from watermelon and cantaloupe were analyzed separately to determine the possible difference in the aphid-coccinellid interactions. Three regression analyses were performed. First, densities of coccinellids were regressed on the densities of melon aphid on the same date. Next, densities of coccinellids were regressed on the densities of melon aphid five days previously. Finally, densities of coccinellids were regressed on the percentage infestation of plant leaves.

Results

During the 1993 growing season, *H. convergens* and *C. maculata* were the predominant coccinellid species on both watermelon and cantaloupe, composed of 92% of the total number of coccinellids observed during the experiment. Other predators occasionaly detected included *Coccinella septempunctata* L., *Geocoris spp.*, *Orius spp.*, *Scymnus spp.*, *Cycloneda spp.*, and *Chrysopa spp.*. These predators were detected during sampling or obtained from sticky traps established in the field.

Results from analysis of variation (ANOVA) indicated that the mean numbers of melon aphid and coccinellids were not significantly different among treatment plots until 20-25 days after the start of the treatments. After that, the mean numbers of melon aphid per leaf and coccinellids per square foot were consistently different among treatment plots. There were significant differences between the the numbers of melon aphid on watermelon and cantaloupe. However, no significant difference existed between the numbers of coccinellids on watermelon and those on cantaloupe on most of the dates (Table 1). As there were significant differences in the numbers of melon aphids on different crops, the data were reanalyzed separately to examine the relationship of coccinellid and aphid populations on watermelon and cantaloupe, respectively.

The seasonal abundance of melon aphid on watermelon and cantaloupe on the sampling dates are described in Figs. 1 & 2, and Tables 2 & 4. On both crops aphid numbers increased more rapidly in carbaryl-treated plots than in plots receiving no insecticide application. On watermelon, aphid density in the carbaryl-treated plots increased steadily and reached a peak on 5 August when the mean number of aphids per leaf was 37 times that of the control plots. Following a slight decline between 5 August and 15 August, melon aphids attained another peak on 30 August with a density of 32.6/leaf, 68 times the density in the control plots. After the second peak, melon aphid population drastically declined. The densities of melon aphids from the control plots were very low throughout the experiment and usually comparable to the densities from the bifenthrin-treated plots. On cantaloupe, aphid numbers in both chemical-treated and untreated plots were much lower than on watermelon, and no significant differences were present between the population densities of melon aphid in chemical-treated and control plots on most of the survey dates (Table

4).

Coccinellid adults was rare in carbaryl- and bifenthrin-treated plots on watermelon and cantaloupe alike. On most of the sampling dates no coccinellids were detected in chemical-treated plots. However, an appreciable number of coccinellids were present in control plots for most of the the growing season. Before mid-July,the numbers of coccinellids were low (0.01-0.03 adults/930 cm^2). Following the growth of melon aphid populations, coccinellid numbers increased steadily and remained relatively abundant and constant from mid-July until the end of August when melon aphids almost disappeared from watermelon and cantaloupe. The abundance of coccinellids on watermelon and cantaloupe usually was not significantly different (Tables 1, 3, & 5, Figs.3 & 4).

The results of regression analyses for the coccinellid-aphid relationship indicated that the coccinellid complex followed aphid population through an immediate response. The coefficients of determination (R^2) were greater for immediate responses than lag responses on both watermelon and cantaloupe (watermelon $R^2 = 0.47$ vs. 0.28; cantaloupe $R^2 = 0.36$ vs. 0.16), which suggests that the densities of coccinellids were more closely associated with the aphid densities at the time when sampling was taken than the densities 5 days before the sampling occurred. The results of regression of coccinellid adult densities on percentage infestaion of leaves indicated that numbers of coccinellids appeared to be closely related to the percentage infestaion of leaves by melon aphid. The coefficients of determination were greater for watermelon than for cantaloupe ($R^2 = 0.68$ vs. 0.48). The immediate numerical responses of the coccinellids are depicted in Figs. 5, 6, 7, & 8.

Despite the prominent difference in the abundance of coccinellids and melon aphid among plots receiving different treatments, yields per unit area of watermelon or cantaloupe were not significantly different (Table 6). Honeydew contamination by melon aphid was not serious in the experiment plots, therefore no further comparison was conducted.

Discussion

Previous studies have provided varible conclusions about the effectiveness of coccinellids as aphid control agents. Most field experiments demonstrated that coccinellids can play an active role in delaying or suppressing the growth of aphid populations for at least a portion of the growing periods of the crops in various agroecosystems (Neuenschwander et al. 1975, Michelbacher 1975, Wright & Laing 1980). Frazer (1987) gave a definition of "effective" as this: Effective means that the pattern of abundance in time or density of an aphid population would be different if the coccinellids were not present, with the difference being demonstrated by field experimentation or simulation modeling. According to this standard, our experiment provided evidence that the three coccinellid species can be effective predators of melon aphid. Melon aphids were always at lower population levels in insecticide-free plots than in plots receiving carbaryl applications. This difference should be first of all ascribed to the difference in predator activities, for the most distinctive consequence from the treatments was that coccinellids were present in insecticide-free plots but eliminated in the carbaryl- or bifenthrin-treated plots during the study.

In untreated plots, coccinellids held the melon aphid populations in check throughout the growing season by numerical response which is defined as "a change in predator density brought about by a change in prey abundance" (Grawley 1975). In our study, we found that coccinellids respond to aphid density in an immediate numerical response instead of a lag response. This is coincident with the conclusion of Wright and Laing (1980), who conducted a similar investigation in corn. Although a complex of predators occurred in the watermelon and cantaloupe field during the experiment, coccinellids were by far the most abundant predators. Other predators such as chrysopids, lygaeids and anthocorids were only occasionally observed. As coccinellids were present in the untreated plots consistently during most of the growing season, their predation must have played a dominant role in repressing the aphid population.

Carbaryl application itself might have been partially responsible for the rapid increase of melon aphid. The development of pesticide resistance in *Aphis gossypii* has become a principal factor confounding chemical control on cotton (Slosser et al. 1989, O'Brien & Graves 1990). Apparent resistance in this species has not been confirmed on watermelon, but the control difficulties in some cases implies that a certain degree of tolerance may exist (Cartwright, unpublished data).

Cantaloupe sustained a lower numbers of melon aphids than watermelon, but the numbers of coccinellids observed on cantaloupe were not significantly different from those on watermelon. Several factors might account for this. First, the true difference in the abundence of coccinellids on these two crops might have been obscured by sampling protocol we used. Coccinellids are very mobile predators and have a intrinsic tendency to leave a given plant substrate. Aphid densities have little influence on the duration of a coccinellid on a plant, for individual coccinellids are constantly moving onto and off the plants, and into and out of the field (Frazer & Raworth 1985, Frazer & Gilbert 1976). Based on the results of a comparative study on the responses of coccinellids to aphid densities at three hierarchical scales, Ives et al. (1993) concluded that the underlying responses of coccinellids to the densities of aphids should be viewed at a large scale. The response pattern of coccinellids to the variation in aphid densities on watermelon and cantaloupe might have been clearer if a larger-scale sampling scheme had been adopted. Second, the coccinellids observed on cantaloupe might be associated with some nutrients which the coccinellids needed and happened to encounter on cantaoupe plants. Coccinellids are "opportunists" in searching for food. They can not deliberately select plants with aphid colonies, nor do they have the ability to detect the existence of aphids at long distance (Hodek 1973). The primary coccinellid species occurring in the field, *C. maculata, H. convergens,* and *C. septempunctata,* are all polyphagous predators. They not only prey on aphids but also feed on other insects. Most coccinellids use plant pollens and nectar as sources of supplementary nutrition. *C. maculata* even has a preference for pollens (Andow & Risch 1985). The field used for our experiment was adjacent to plots of tomato, cabbage, sweet corn, bell pepper, strawberry, etc. Sweet corn pollen could have drifted and been deposited on cantaloupe. Some lepidopteran insects such as corn earworm, *Heliothis zea* (Boddie) and cabbage looper, *Plusia brassicae* L., might have invaded the experimental area to lay eggs on cantaloupe.

Cantaloupe pollens may also serve as a good food source for coccinellids. These possibilities should be be investigated in future studies.

When carrying out this experiment, we tried to record the occurrence of coccinellid predators of all stages but never observed any egg masses or larvae. We surmise that the length of retention of adult coccinellids might be too short for them to have enough time to lay eggs, or some special environments or conditions for oviposition were not met in our watermelon or cantaloupe plots.

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CHAPTER IV

INFLUENCE OF COCCINELLIDS ON THE POPULATION DYNAMICS OF MELON APHID

Introduction

The melon aphid, *Aphis gossypii* Glover, is one of the most injurious pests of cotton and cucurbit crops. It also attacks citrus, many vegetable and ornamental crops and has been recorded from at least 64 plant species (Blackman & Eastop 1985, Cuperus 1991). Insecticides are the major tools to control this pest. On watermelons, pesticides are applied one to five times to prevent economic loss, depending on the degree of infestation.

Chemical control is frequently confounded by the development of insecticidal resistance. *A. gossypii* has shown resistance to a wide spectrum of insectides (O'Brien & Graves 1990, Kerns & Galor 1992, Furk et al. 1980, Bingzhong et al. 1987). To extricate aphid control from sole reliance on chemical application, an alternative approach which makes maximum use of natural enemies in conjuction with selective pesticide applications should be explored.

A number of predaceous arthropods prey on aphids, including melon aphid under natural conditions. Of these, coccinellids have received extensive attention because of their wide occurrence, relative abundance, and their potential in controlling aphid populations in an array of agroecosystems. Manipulation of native coccinellids, primarily *Hippodamia convergens* Guerin-Meneville, and *Coleomegilla maculata* DeGeer has achieved varible success. *C. maculata* is a euryphagous coccinellid, and can complete its development on corn pollen (Smith 1960, 1961), lepidopteran eggs (Warren & Tadic 1967), pea aphid and corn leaf aphids (Smith 1965a, b). It has been exploited to control spotted alfalfa aphid, *Therioaphis maculata* (Buckton) , green bug, *Schizaphis graminum* (Rondani), and corn leaf aphid, *Rhopalosiphum maidis* (Fitch). *H. convergens* is a polyphagous predator, but exhibits a preference for aphids. It has been reported as one of the most effective predators of aphids and has served a significant role in suppressing population of green peach aphid, *Myzus persicae* (Sulzer), spotted alfalfa aphid, and melon aphid (Goodarzy & Davis 1958, Simpson & Burkhardtet al. 1960, Nielson & Henderson 1959, Michelbacher 1950, Neuenschwander et al. 1975, Tamaki & Weeks 1973).

In spite of the extensive literature, available information on the aphid-coccinellid interaction, and the effectiveness of individual coccinellid species as predators of aphids is very varibale. There is a complex of coccinellid species occurring in Oklahoma watermelon and cantaloupe fields, but little is known about their importance and impact on the population dynamics of melon aphids. The objectives of this study were to view the coccinellid complex as a integral entity and establish the facts of coccinellid and aphid population dynamics in the field so as to improve our understanding of the role of coccinellids in regulating melon aphid populations.

Materials and Methods

An experiment was conducted during the 1993 growing season at the OSU Wes Watkins Agricultural Research and Extension Center, Lane, Oklahoma. Chemical exclusion was used to evaluate the impact of coccinellid predators on aphid populations. Begining 1 July, four types of chemical treatments were applied to field plots: 1) carbaryl spray (Sevin XLR Plus, Rhône Poulenc Ag Company) (0.56 kg ai/ha) at 5- or 10-day intervals to exclude natural enemies; 2) bifenthrin spray (Brigade 10 W, FMC Corp.) (0.04 kg ai/ha) at 5-day intervals to eliminate melon aphid and coccinellids; 3) bifenthrin spray (0.04 kg/ha) when melon aphid population reach the economic threshold of 15 aphids/leaf infestation (Cartwright, unpublished data). 4) no chemical application to allow the existence of natural enemies and melon aphid. Insectides were applied to the row with a hand-held CO_2 sprayer with two TX-18 nozzles calibrated to deliver 756 liters/ha.

In initiating this study, we assigned a treatment which would require insecticide application when the aphid population reached the economic threshold of 15 aphids per leaf (Cartwright, unpublished data). However, the aphid number never attained that level during the experiment, therefore treatment 3 was not utilized.

A split-block experimental design was used with the three chemical treatments arranged in main plots and two cucurbit crops (watermelon and cantaloupe) in subplots. The treatments were replicated five times. Watermelon ('Allsweet') was transplanted into beds on 22 June and cantaloupe ('Perlita') was direct seeded on 4 June in plots measuring 6.7 m by 1.4 m with 6 plants (0.6-m plant spacing) in a row in each plot. A 3.7- and 4.7-m buffer was kept between rows and between plots in a row, respectively. The Oklahoma State University Cooperative Extension Service recommendations were followed for fertilization and irrigation. Irrigation was applied as needed using a surface level trickle system. Benlate DF (Benomyl, Du Pont Company) (0.56 kg/ha) and Dithane DF (Mancozeb, Rohm and Haas Company) (3.36 kg/ha) were sprayed alternately at 1-week intervals from 7 July throug 18 August to control fungus diseases. Weeds were mechanically controlled.

From 1 July through 5 September, melon aphid and coccinellid abundance were estimated at 5-day intervals. Samples were taken between 9:00 and 15:00 hours. Five plants were surveyed in a plot. For aphid census, two leaves, one from the central and another from the outer area, were randomly taken from each plant. Numbers of apterous and alate aphids were recorded. A quadrat approach was used for surveying coccinellids. A 930-cm^2 steel wire frame (30.5 x 30.5 cm) was placed randomly in a central and peripheral area of each plant. Within each quadrat, the numbers of coccinellid adults and other predators were recorded. The weight of watermelon and cantaloupe fruits from plots receiving different treatments were measured so that a yield comparison could be made.

Insect and yield data were subjected to analysis of variance using SAS General Linear Models (GLM) with mean separation determined with Ryan-Einot-Gabriel-Welsch multiple F test (REGWF) at $\alpha=0.05$ level of probability (SAS Institute, 1988). Data from the non-chemical treatment (control) plots were further used for a regression analysis (SAS Institute, 1988) to examine the relationship between the densities of aphids and adult coccinellids. Data from watermelon and cantaloupe were analyzed separately to determine the possible difference in the aphid-coccinellid interactions. Three regression analyses were performed. First, densities of coccinellids were regressed on the densities of melon aphid on the same date. Next, densities of coccinellids were regressed on the densities of melon aphid five days previously. Finally, densities of coccinellids were regressed on the percentage infestation of plant leaves.

Results

During the 1993 growing season, *H. convergens* and *C. maculata* were the predominant coccinellid species on both watermelon and cantaloupe, composed of 92% of the total number of coccinellids observed during the experiment. Other predators occasionaly detected included *Coccinella septempunctata* L., *Geocoris spp.*, *Orius spp.*, *Scymnus spp.*, *Cycloneda spp.,* and *Chrysopa spp.*. These predators were detected during sampling or obtained from sticky traps established in the field.

Results from analysis of variation (ANOVA) indicated that the mean numbers of melon aphid and coccinellids were not significantly different among treatment plots until 20-25 days after the start of the treatments. After that, the mean numbers of melon aphid per leaf and coccinellids per square foot were consistently different among treatment plots. There were significant differences between the the numbers of melon aphid on watermelon and cantaloupe. However, no significant difference existed between the numbers of coccinellids on watermelon and those on cantaloupe on most of the dates (Table 1). As there were significant differences in the numbers of melon aphids on different crops, the data were reanalyzed separately to examine the relationship of coccinellid and aphid populations on watermelon and cantaloupe, respectively.

The seasonal abundance of melon aphid on watermelon and cantaloupe on the sampling dates are described in Figs. 1 & 2, and Tables 2 & 4. On both crops aphid numbers increased more rapidly in carbaryl-treated plots than in plots receiving no insecticide application. On watermelon, aphid density in the carbaryl-treated plots increased steadily and reached a peak on 5 August when the mean number of aphids per leaf was 37 times that of the control plots. Following a slight decline between 5 August and 15 August, melon aphids attained another peak on 30 August with a density of 32.6/leaf, 68 times the density in the control plots. After the second peak, melon aphid population drastically declined. The densities of melon aphids from the control plots were very low throughout the experiment and usually comparable to the densities from the bifenthrin-treated plots. On cantaloupe, aphid numbers in both chemical-treated and untreated plots were much lower than on watermelon, and no significant differences were present between the population densities of melon aphid in chemical-treated and control plots on most of the survey dates (Table

4).

Coccinellid adults was rare in carbaryl- and bifenthrin-treated plots on watermelon and cantaloupe alike. On most of the sampling dates no coccinellids were detected in chemical-treated plots. However, an appreciable number of coccinellids were present in control plots for most of the the growing season. Before mid-July,the numbers of coccinellids were low (0.01-0.03 adults/930 cm^2). Following the growth of melon aphid populations, coccinellid numbers increased steadily and remained relatively abundant and constant from mid-July until the end of August when melon aphids almost disappeared from watermelon and cantaloupe. The abundance of coccinellids on watermelon and cantaloupe usually was not significantly different (Tables 1, 3, & 5, Figs.3 & 4).

The results of regression analyses for the coccinellid-aphid relationship indicated that the coccinellid complex followed aphid population through an immediate response. The coefficients of determination (R^2) were greater for immediate responses than lag responses on both watermelon and cantaloupe (watermelon R^2 = 0.47 vs. 0.28; cantaloupe R^2 = 0.36 vs. 0.16), which suggests that the densities of coccinellids were more closely associated with the aphid densities at the time when sampling was taken than the densities 5 days before the sampling occurred. The results of regression of coccinellid adult densities on percentage infestaion of leaves indicated that numbers of coccinellids appeared to be closely related to the percentage infestaion of leaves by melon aphid. The coefficients of determination were greater for watermelon than for cantaloupe ($R^2 = 0.68$ vs. 0.48). The immediate numerical responses of the coccinellids are depicted in Figs. 5, 6, 7, & 8.

Despite the prominent difference in the abundance of coccinellids and melon aphid among plots receiving different treatments, yields per unit area of watermelon or cantaloupe were not significantly different (Table 6). Honeydew contamination by melon aphid was not serious in the experiment plots, therefore no further comparison was conducted.

Discussion

Previous studies have provided varible conclusions about the effectiveness of coccinellids as aphid control agents. Most field experiments demonstrated that coccinellids can play an active role in delaying or suppressing the growth of aphid populations for at least a portion of the growing periods of the crops in various agroecosystems (Neuenschwander et al. 1975, Michelbacher 1975, Wright & Laing 1980). Frazer (1987) gave a definition of "effective" as this: Effective means that the pattern of abundance in time or density of an aphid population would be different if the coccinellids were not present, with the difference being demonstrated by field experimentation or simulation modeling. According to this standard, our experiment provided evidence that the three coccinellid species can be effective predators of melon aphid. Melon aphids were always at lower population levels in insecticide-free plots than in plots receiving carbaryl applications. This difference should be first of all ascribed to the difference in predator activities, for the most distinctive consequence from the treatments was that coccinellids were present in insecticide-free plots but eliminated in the carbaryl- or bifenthrin-treated plots during the study.

In untreated plots, coccinellids held the melon aphid populations in check throughout the growing season by numerical response which is defined as "a change in predator density brought about by a change in prey abundance" (Grawley 1975). In our study, we found that coccinellids respond to aphid density in an immediate numerical response instead of a lag response. This is coincident with the conclusion of Wright and Laing (1980), who conducted a similar investigation in corn. Although a complex of predators occurred in the watermelon and cantaloupe field during the experiment, coccinellids were by far the most abundant predators. Other predators such as chrysopids, lygaeids and anthocorids were only occasionally observed. As coccinellids were present in the untreated plots consistently during most of the growing season, their predation must have played a dominant role in repressing the aphid population.

Carbaryl application itself might have been partially responsible for the rapid increase of melon aphid. The development of pesticide resistance in *Aphis gossypii* has become a principal factor confounding chemical control on cotton (Slosser et al. 1989, O'Brien & Graves 1990). Apparent resistance in this species has not been confirmed on watermelon, but the control difficulties in some cases implies that a certain degree of tolerance may exist (Cartwright, unpublished data).

Cantaloupe sustained a lower numbers of melon aphids than watermelon, but the numbers of coccinellids observed on cantaloupe were not significantly different from those on watermelon. Several factors might account for this. First, the true difference in the abundence of coccinellids on these two crops might have been obscured by sampling protocol we used. Coccinellids are very mobile predators and have a intrinsic tendency to leave a given plant substrate. Aphid densities have little influence on the duration of a coccinellid on a plant, for individual coccinellids are constantly moving onto and off the plants, and into and out of the field (Frazer & Raworth 1985, Frazer & Gilbert 1976). Based on the results of a comparative study on the responses of coccinellids to aphid densities at three hierarchical scales, Ives et al. (1993) concluded that the underlying responses of coccinellids to the densities of aphids should be viewed at a large scale. The response pattern of coccinellids to the variation in aphid densities on watermelon and cantaloupe might have been clearer if a larger-scale sampling scheme had been adopted. Second, the coccinellids observed on cantaloupe might be associated with some nutrients which the coccinellids needed and happened to encounter on cantaoupe plants. Coccinellids are "opportunists" in searching for food. They can not deliberately select plants with aphid colonies, nor do they have the ability to detect the existence of aphids at long distance (Hodek 1973). The primary coccinellid species occurring in the field, *C. maculata, H. convergens,* and *C. septempunctata,* are all polyphagous predators. They not only prey on aphids but also feed on other insects. Most coccinellids use plant pollens and nectar as sources of supplementary nutrition. *C. maculata* even has a preference for pollens (Andow & Risch 1985). The field used for our experiment was adjacent to plots of tomato, cabbage, sweet corn, bell pepper, strawberry, etc. Sweet corn pollen could have drifted and been deposited on cantaloupe. Some lepidopteran insects such as corn earworm, *Heliothis zea* (Boddie) and cabbage looper, *Plusia brassicae* L., might have invaded the experimental area to lay eggs on cantaloupe.

Cantaloupe pollens may also serve as a good food source for coccinellids. These possibilities should be be investigated in future studies.

When carrying out this experiment, we tried to record the occurrence of coccinellid predators of all stages but never observed any egg masses or larvae. We surmise that the length of retention of adult coccinellids might be too short for them to have enough time to lay eggs, or some special environments or conditions for oviposition were not met in our watermelon or cantaloupe plots.

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Table 1. ANOVA for the average numbers of melon aphid and coccinellids on watermelon and cantaloupe

Date	Source of Variance	df	p	
			Aphid	Coccinellids
1 Jul	Treatment	2	0.8663 NS	0.7903 NS
	Crop	1	0.2940 NS	1.0000 NS
	Treatment X Crop	2	0.3558 NS	0.6154 NS
5 Jul	Treatment	2	0.4108 NS	0.4096 NS
	Crop	1	0.3572 NS	0.5870 NS
	Treatment X Crop	2	0.7619 NS	0.4096 NS
10 Jul	Treatment	2	0.5543 NS	0.0013 *
	Crop	1	0.0886 NS	0.0204 *
	Treatment X Crop	2	0.4117 NS	0.0161 *
15 Jul	Treatment	2	0.1613 NS	0.0001 *
	Crop	1	0.7749 NS	0.3792 NS
	Treatment X Crop	2	0.7961 NS	0.5378 NS
20 Jul	Treatment	2	0.2831 NS	0.0008 *
	Crop	1	0.6233 NS	0.1384 NS
	Treatment X Crop	2	0.3440 NS	0.4325 NS
25 Jul	Treatment	2	0.0275 *	0.0001 *
	Crop	1	0.1502 NS	0.0751 NS
	Treatment X Crop	2	0.3161 NS	0.0287 *
30 Jul	Treatment	2	0.0021 *	0.0002 *
	Crop	1	0.0693 NS	0.7292 NS
	Treatment X Crop	2	0.0125 *	0.6136 NS
5 Aug	Treatment	2	0.0002 *	0.0001 *
	Crop	1	0.0081 *	0.1206 NS
	Treatment X Crop	2	0.0006 *	0.0617 NS
10 Aug	Treatment	2	0.0012 *	0.0001 *
	Crop	1	0.0109 *	0.0993 NS
	Treatment X Crop	2	0.0045 *	0.0728 NS

Table 1. Continued

15 Aug	Treatment	2	0.0001 *	0.0013 *
	Crop	1	0.0077 *	0.4050 NS
	Treatment X Crop	2	0.0015 *	0.4570 NS
20 Aug	Treatment	2	0.0081 *	0.0008 NS
	Crop	1	0.0029 NS	0.4263 NS
	Treatment X Crop	2	0.0012 *	0.4893 NS
25 Aug	Treatment	2	0.0026 *	0.0002 *
	Crop	1	0.0001 *	0.5457 *
	Treatment X Crop	2	0.0001 *	0.6618 NS
30 Aug	Treatment	2	0.0002 *	0.0002 *
	Crop	1	0.0011 *	0.4144 NS
	Treatment X Crop	2	0.0001 *	0.4713 NS
5 Sept	Treatment	2	0.0036 *	0.4096 *
	Crop	1	0.0027 *	0.3739 *
	Treatment X Crop	2	0.0010 *	0.4096 *

NS Not significantly different at $\alpha = 0.05$ level.

* Significantly different at $\alpha = 0.05$ level.

Table 2. Mean numbers of melon aphid on watermelon plants receiving different insecticide treatments

Date	Mean No. Aphids/Leaf (±SE)[a]		
	Carbaryl 0.56 kg ai/ha	Bifenthrin 0.04 kg ai/ha	Untreated
1 Jul	0.36 ± 0.15A	0.68 ± 0.37A	0.46 ± 0.23A
5 Jul	0.70 ± 0.50A	0.32 ± 0.17A	1.43 ± 0.50A
10 Jul	2.28 ± 0.67A	1.36 ± 0.34A	0.16 ± 0.11A
15 Jul	3.04 ± 0.98A	0.98 ± 0.39A	1.87 ± 0.40A
20 Jul	1.82 ± 0.50A	2.66 ± 0.59A	2.06 ± 0.31A
25 Jul	2.94 ± 0.45A	1.42 ± 0.32A	2.21 ± 0.31A
30 Jul	12.72 ± 2.17A	1.30 ± 0.32B	1.41 ± 0.16B
5 Aug	21.08 ± 3.91A	1.54 ± 0.32B	0.57 ± 0.11B
10 Aug	17.52 ± 3.01A	1.52 ± 0.31B	0.69 ± 0.15B
15 Aug	11.38 ± 2.05A	1.82 ± 0.30B	0.81 ± 0.15B
20 Aug	13.64 ± 2.27A	5.40 ± 0.83B	0.90 ± 0.18B
25 Aug	16.04 ± 2.96A	7.20 ± 1.04B	0.96 ± 0.23C
30 Aug	32.62 ± 5.56A	5.16 ± 0.88B	0.48 ± 0.12B
5 Sep	8.20 ± 0.98A	3.84 ± 0.53B	0 ± 0 C

[a] Means for each row with the same letter are not significantly different at $\alpha = 0.05$ level (REGWF multiple comparison procedure).

Table 3. Mean numbers of coccinellids on watermelon plants receiving different insecticide treatments

	Mean No. Aphids/930 CM^2 (±SE)[a]		
Date	Carbaryl 0.56 kg ai/ha	Bifenthrin 0.04 kg ai/ha	Untreated
1 Jul	0.02±0.02A	0 ± 0A	0.02 ± 0.02A
5 Jul	0±0A	0.02 ± 0.02A	0.01 ± 0.01A
10 Jul	0.04±0.03B	0.18 ± 0.05B	0 ± 0A
15 Jul	0±0B	0 ± 0B	0.19 ± 0.05A
20 Jul	0±0B	0 ± 0B	0.34 ± 0.06A
25 Jul	0±0B	0 ± 0B	0.54 ± 0.07A
30 Jul	0±0B	0.02 ± 0.02B	0.29 ± 0.06A
5 Aug	0±0B	0 ± 0B	0.23 ± 0.04A
10 Aug	0.02±0.02B	0.08 ± 0.04B	0.24 ± 0.05A
15 Aug	0±0B	0 ± 0B	0.26 ± 0.05A
20 Aug	0±0B	0 ± 0B	0.17 ± 0.04A
25 Aug	0±0B	0 ± 0B	0.22 ± 0.04A
30 Aug	0±0B	0 ± 0B	0.10 ± 0.03A
5 Sep	0±0A	0 ± 0A	0 ± 0A

[a] Means for each row with the same letter are not significantly different at $\alpha = 0.05$ level (REGWF multiple comparison procedure).

Table 4. Mean numbers of melon aphid on cantaloupe plants receiving different insecticide treatments

Date	Mean No. Aphids/Leaf (±SE)[a]		
	Carbaryl 0.56 kg ai/ha	Bifenthrin 0.04 kg ai/ha	Untreated
1 Jul	0.18 ± 0.09A	0.06 ± 0.03A	0.38 ± 0.16A
5 Jul	0.18 ± 0.13A	0.34 ± 0.34A	0.59 ± 0.41A
10 Jul	0.16 ± 0.11A	0.10 ± 0.06A	0.28 ± 0.16A
15 Jul	2.70 ± 0.97A	0.46 ± 0.18A	2.25 ± 0.47A
20 Jul	2.46 ± 0.54A	0.84 ± 0.34A	4.87 ± 1.71A
25 Jul	1.02 ± 0.29A	0.68 ± 0.41B	1.49 ± 0.39A
30 Jul	7.28 ± 1.64A	0.32 ± 0.24B	1.70 ± 0.35B
5 Aug	5.86 ± 1.45A	0 ± 0A	0.58 ± 0.17A
10 Aug	3.28 ± 0.56A	0 ± 0B	0.57 ± 0.16B
15 Aug	0.38 ± 0.19A	0.12 ± 0.09A	0.35 ± 0.14A
20 Aug	1.88 ± 0.87A	0 ± 0A	1.80 ± 0.52A
25 Aug	1.84 ± 0.81A	0.08 ± 0.05A	0.33 ± 0.13A
30 Aug	2.36 ± 0.88A	0 ± 0A	0.20 ± 0.15A
5 Sep	0.64 ± 0.27A	0 ± 0A	0.04 ± 0.03A

[a] Means for each row with the same letter are not significantly different at $\alpha = 0.05$ level (REGWF multiple comparison procedure).

Table 5. Mean numbers of coccinellids on cantaloupe plants receiving different insecticide treatments

	Mean No. Aphid/930 CM^2 (±SE)[a]		
Date	Carbaryl 0.56 kg ai/ha	Bifenthrin 0.04 kg ai/ha	Untreated
1 Jul	0 ± 0A	0.02 ± 0.02A	0.02 ± 0.02A
5 Jul	0 ± 0A	0 ± 0A	0.01 ± 0.01A
10 Jul	0 ± 0A	0 ± 0A	0.03 ± 0.02A
15 Jul	0 ± 0B	0.02 ± 0.02B	0.27 ± 0.06A
20 Jul	0.14 ± 0.05B	0 ± 0B	0.53 ± 0.06A
25 Jul	0 ± 0B	0 ± 0B	0.34 ± 0.05A
30 Jul	0 ± 0B	0 ± 0B	0.33 ± 0.05A
5 Aug	0.10 ± 0.05B	0 ± 0B	0.44 ± 0.07A
10 Aug	0.06 ± 0.03B	0.06 ± 0.03B	0.46 ± 0.08A
15 Aug	0 ± 0B	0 ± 0B	0.22 ± 0.05A
20 Aug	0 ± 0B	0 ± 0B	0.14 ± 0.04A
25 Aug	0 ± 0B	0 ± 0B	0.17 ± 0.04A
30 Aug	0 ± 0B	0 ± 0B	0.16 ± 0.05A
5 Sep	0 ± 0A	0 ± 0A	0.02 ± 0.01A

[a] Means for each row with the same letter are not significantly different at $\alpha = 0.05$ level (REGWF multiple comparison procedure).

Table 6. Yields of watermelon and cantaloupe in the experimental plots receiving different treatments

Treatment	Yield (Kg/Plot) (Mean ± SE)[a]	
	Watermelon	Cantaloupe
Carbaryl 0.56 kg ai/ha	49.3 ± 11.5 A	44.8 ± 5.3 A
Bifenthrin 0.04 kg ai/ha	6.4 ± 5.5 A	53.5 ± 3.2 A
Untreated	47.3 ± 5.6 A	42.8 ± 2.5 A

[a] Means within a column followed by the same letters are not significantly different at $\alpha = 0.05$ level (REGWF multiple comparison procedure).

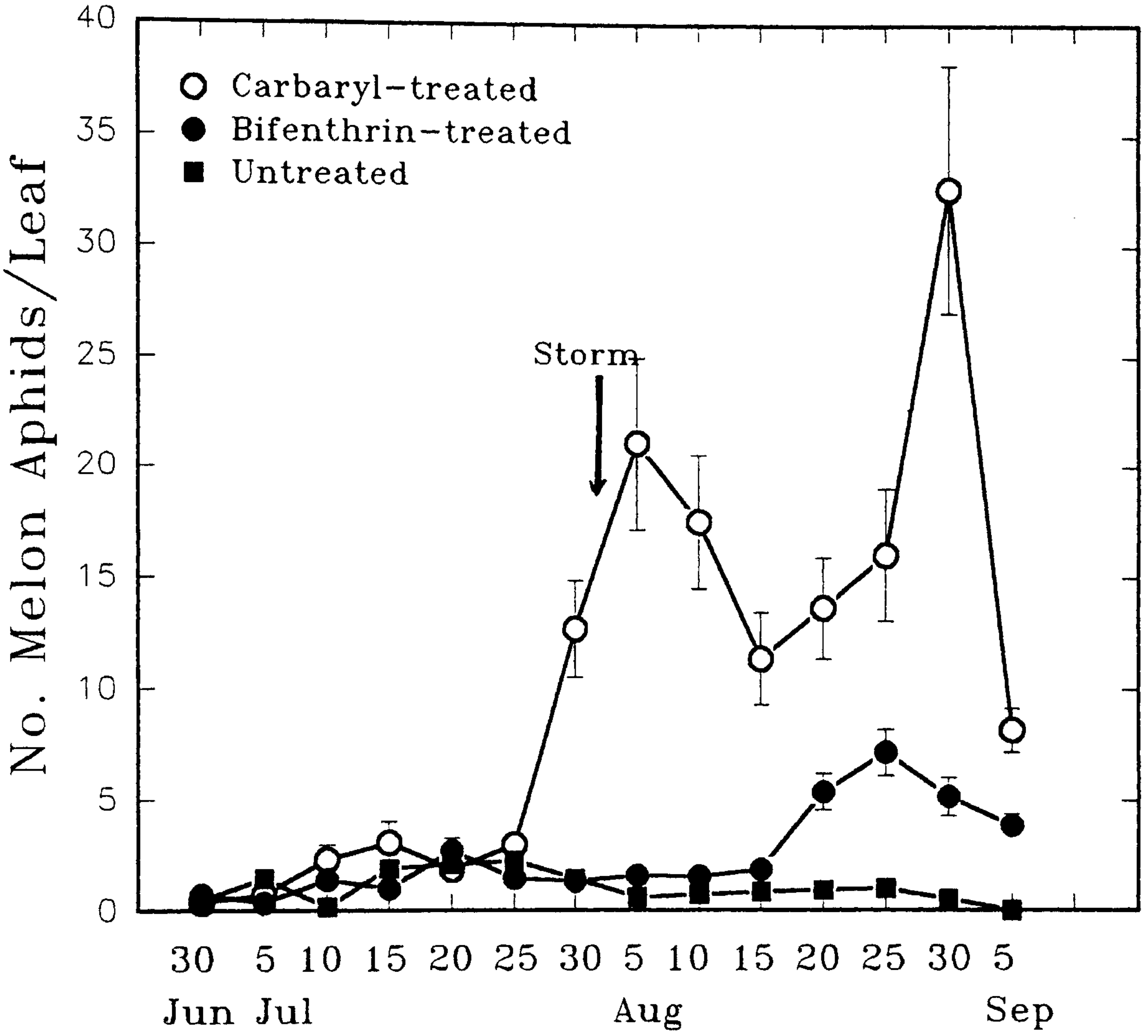

Fig. 1. Population dynamics of melon aphid on watermelon

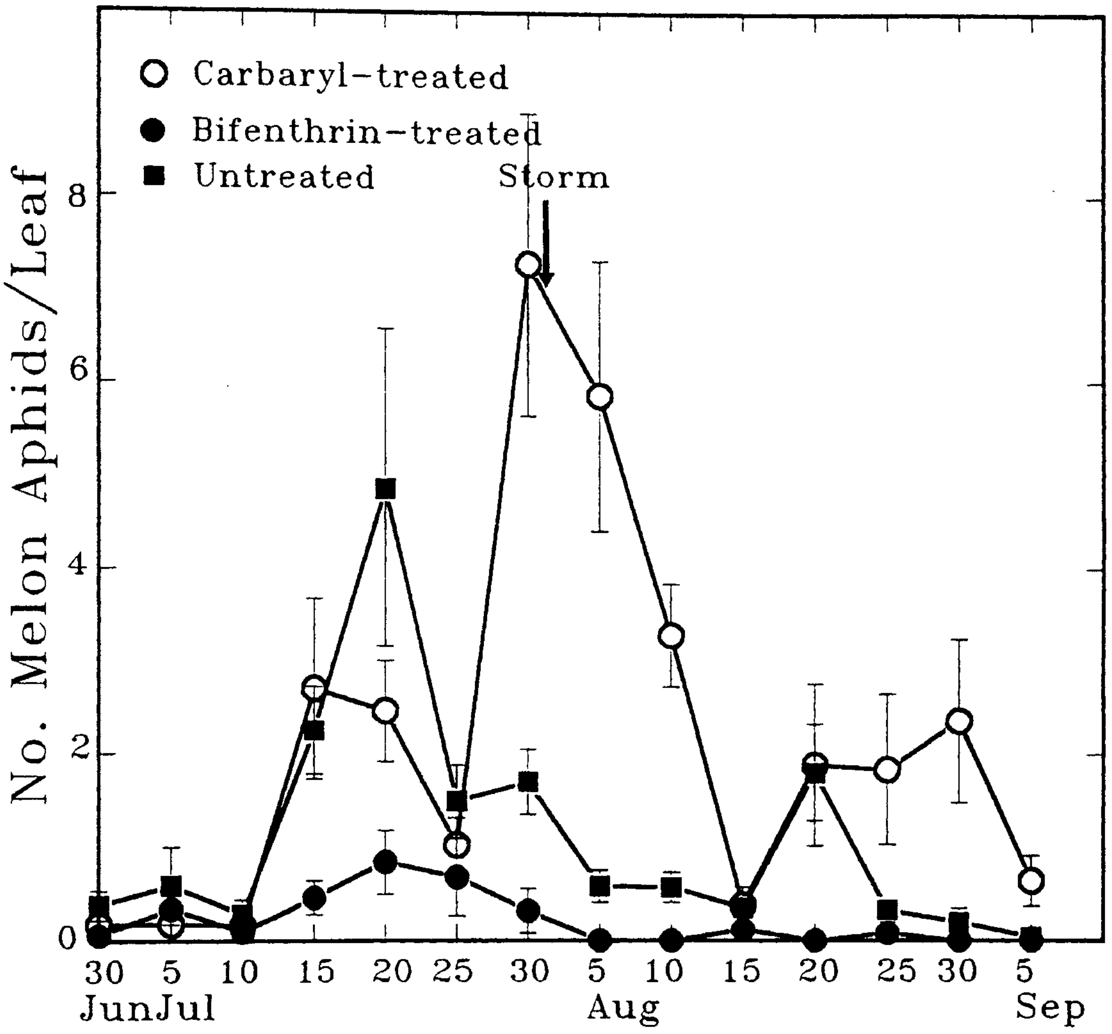

Fig. 2. Population dynamics of melon aphid on cantaloupe

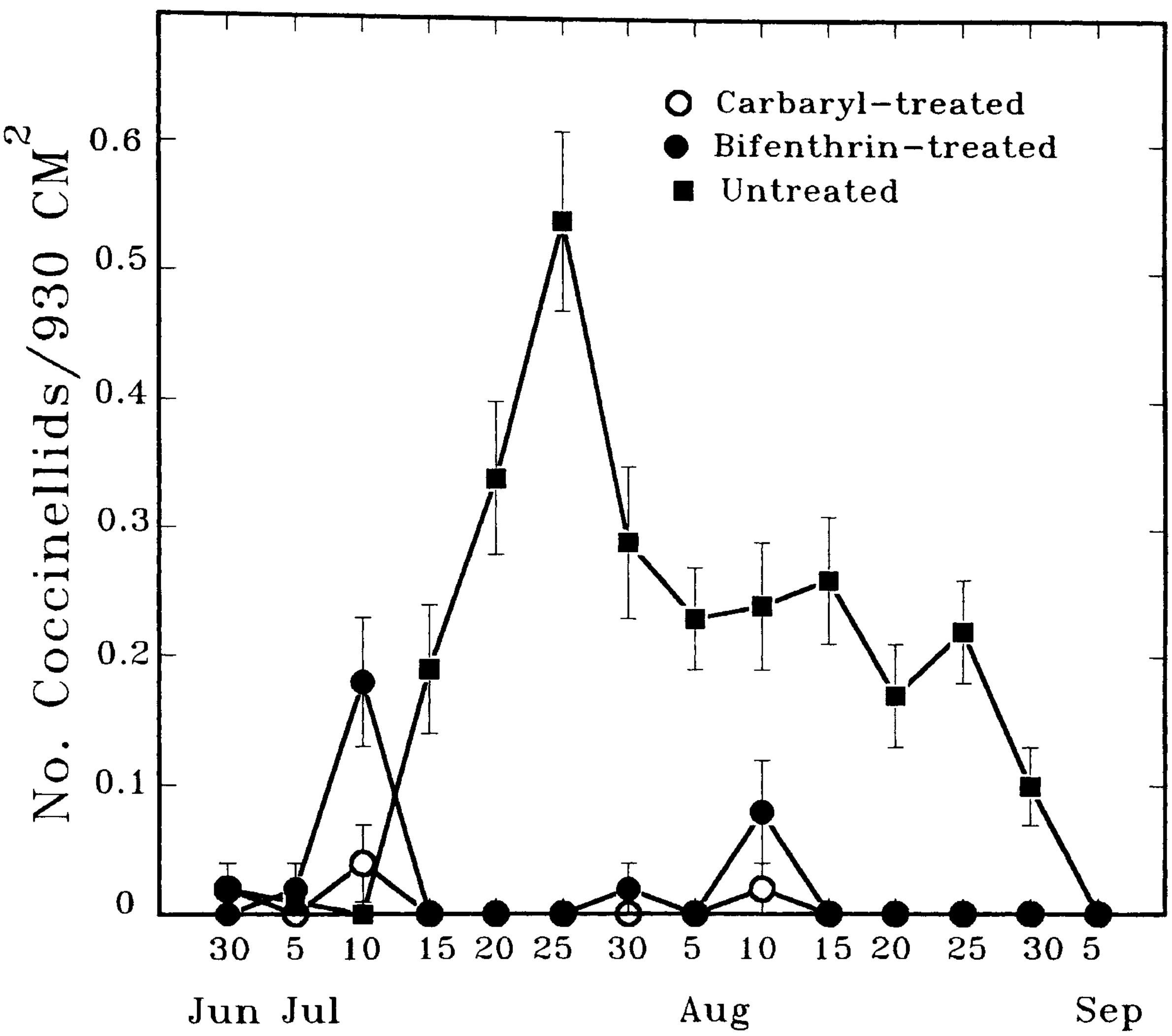

Fig. 3. Seasonal abundance of coccinellids on watermelon

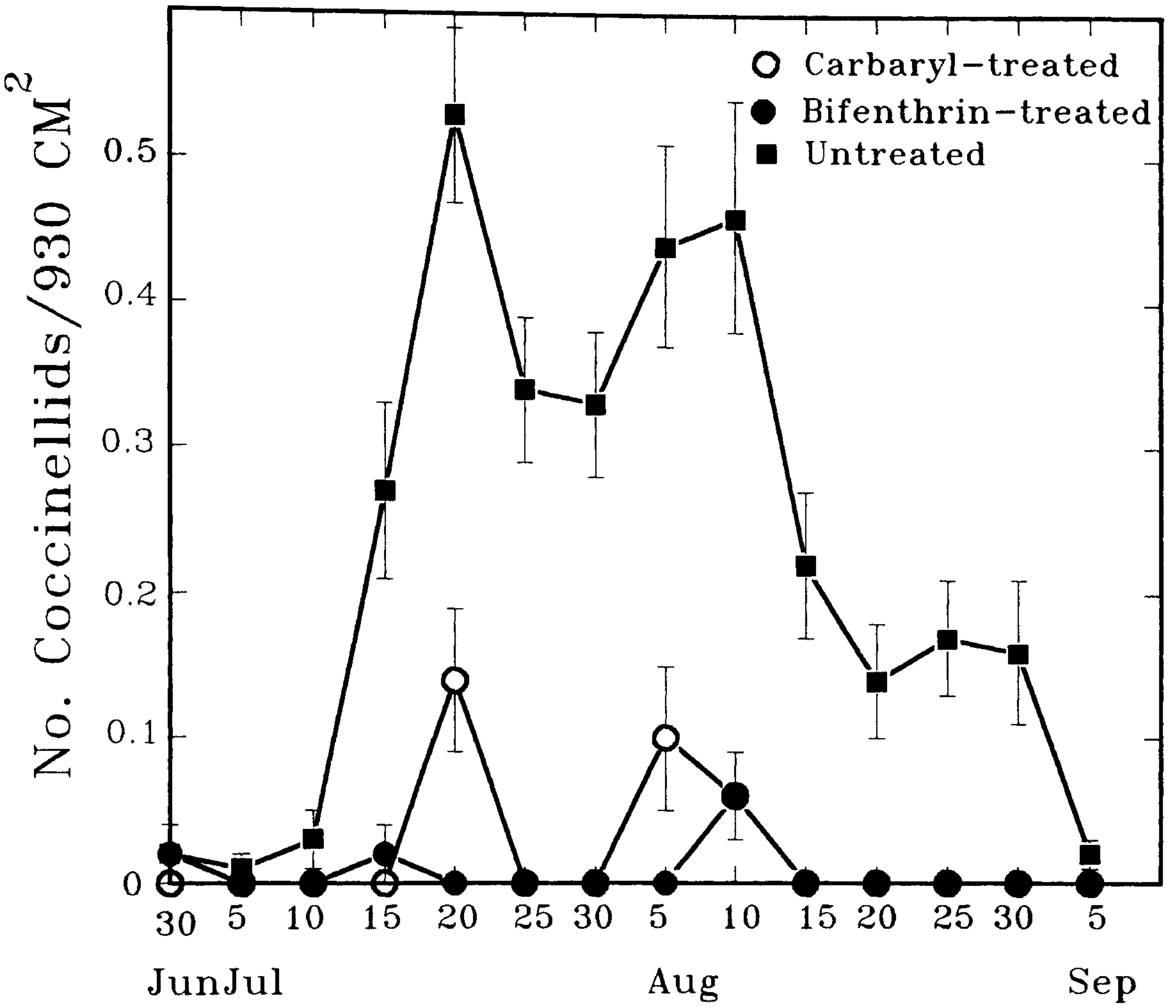

Fig. 4. Seasonal abundance of coccinellids on cantaloupe

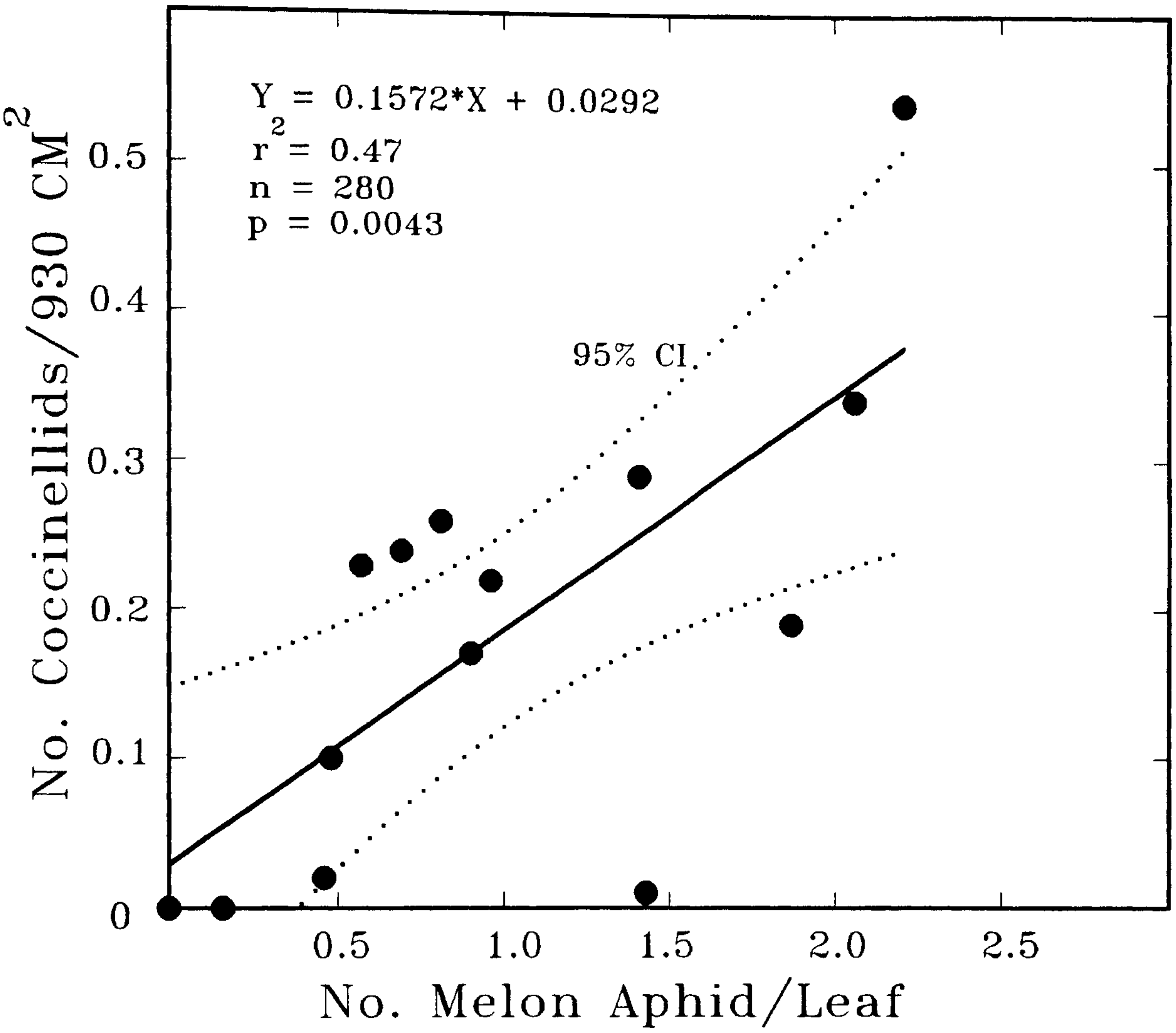

Fig. 5. Relationship between the density of melon aphid and the density of coccinellids on watermelon

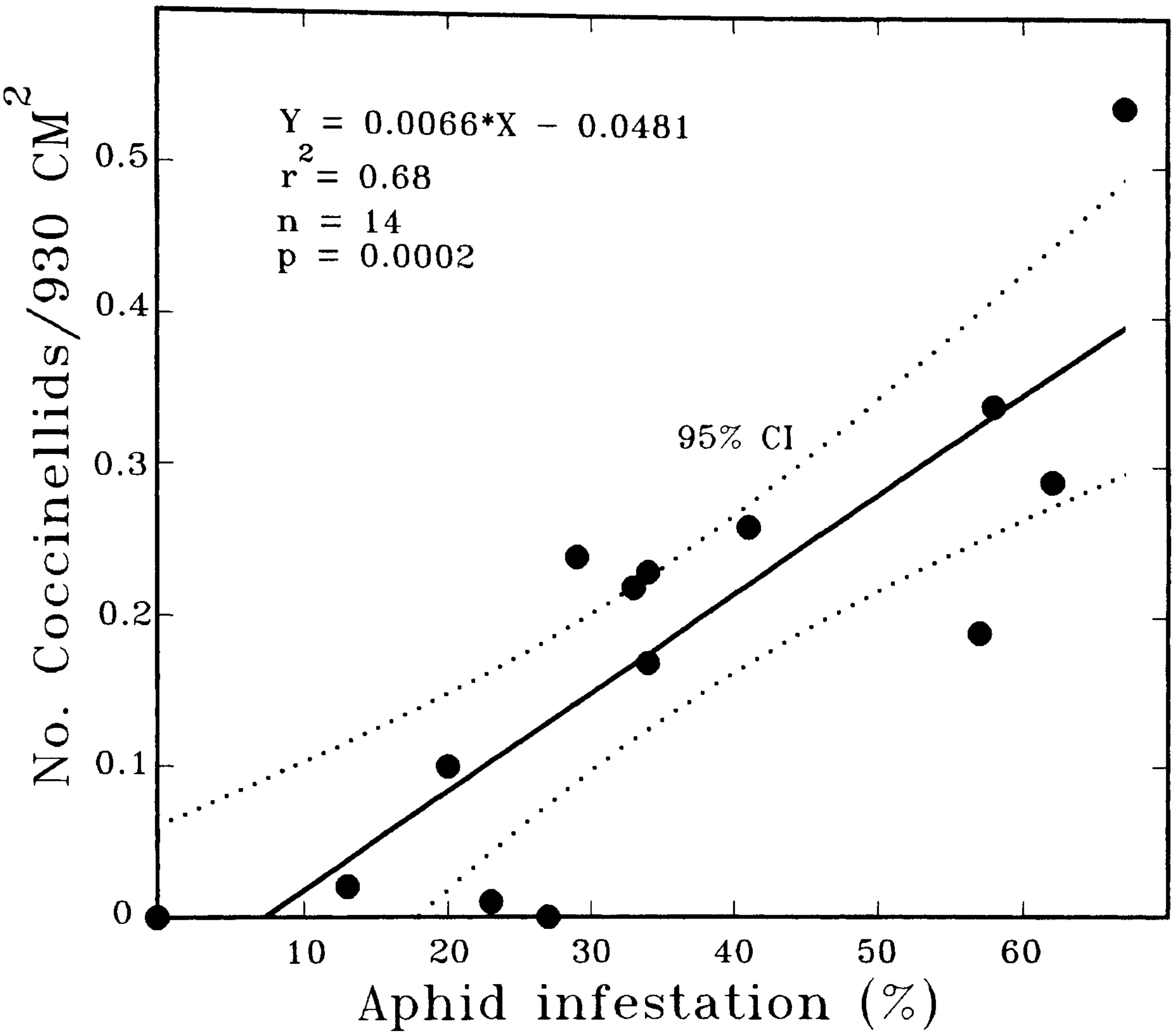

Fig. 6. Relationship between the proportion of watermelon leaves infested with melon aphid and the density of coccinellids

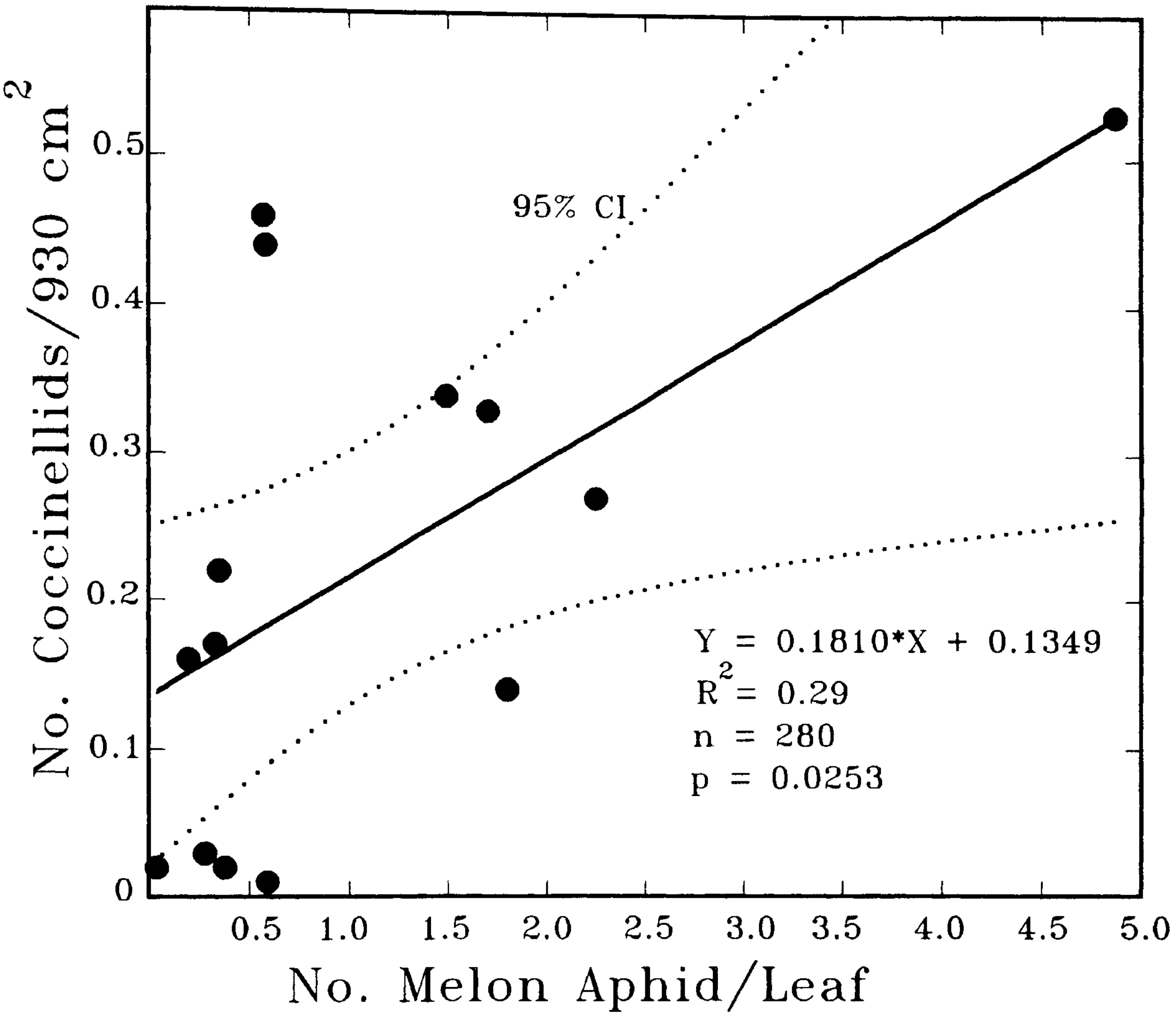

Fig. 7. Relationship between the density of melon aphid and the density of coccinellids on cantaloupe

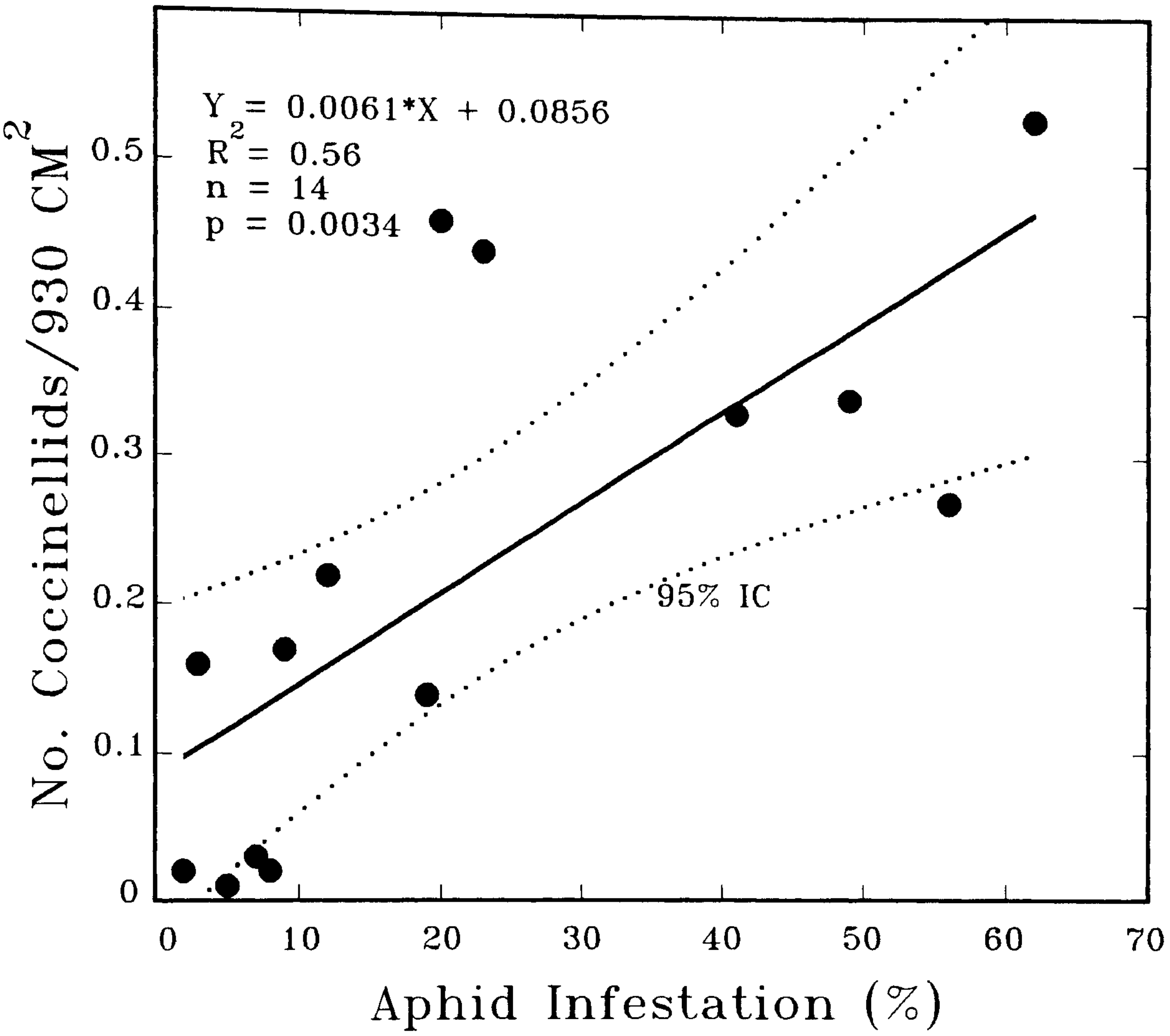

Fig. 8. Relationship between the proportion of cantaloupe leaves infested with melon aphid and the density of coccinellids

VITA

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Master of Science

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