THE BIOLOGY OF THE SPIDER, MISUMENOPS CELER (HENTZ), AND STUDIES ON ITS SIGNIFICANCE AS A FACTOR IN THE BIOLOGICAL CONTROL OF INSECT PESTS OF SORGHUM

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PREFACE

In recent years the importance of spiders in biological control has been well realized, and in many laboratories of the world work on this aspect is in progress. During the past five years the Entomology Department of Oklahoma State University has studied their utilization in the biological control of sorghum and other crop pests. Dr. Harvey L. Chada, Professor of Entomology, Oklahoma State University, and Investigations Leader, Entomology Research Division, United States Department of Agriculture, suggested this problem to the author and explained the need to do research on this aspect.

The author expresses sincere appreciation to his major adviser, Dr. Harvey L. Chada, for his advice, competent instruction and guidance, encouragement, helpful suggestions, and assistance in the preparation of this thesis.

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INTRODUCTION

Spiders are well known for their predatory habits. Their significant role in controlling the pests of sorghum, corn, alfalfa, wheat, orchard, and plantation crops, etc., has been realized only very recently.

The economic role of spiders in field crops has been studied to some extent in the United States by W. H. Whitcomb and co-workers in Arkansas cotton; H. L. Chada and co-workers in Oklahoma sorghum; C. D. Dondale and co-workers in Canadian apple and pear orchards; and by S. Hukusima and co-workers in Japanese apple and pear orchards.

Earlier research work at Oklahoma State University has shown that spiders play an important part in the control of insects attacking sorghums. Among them, one of the crab spiders, Misumenops celer (Hentz), was commonly found inhabiting the sorghum whorls and heads where it fed on the insects present. It was also commonly found in alfalfa and corn fields.

To encourage and utilize the beneficial organisms like spiders in cultivated crops, their biology, population dynamics, migration, food preference, etc., must be known. A review of the literature proved that no work has been published on the biology of the spider, M. celer. Hence, the mating behavior, oviposition, incubation, hatching, duration, and measurements of different instars, feeding behavior, and food preference have been studied. Also, techniques were developed for mass rearing this spider in the laboratory. Population dynamics of spiders in alfalfa and corn have also been studied, since these crops are grown adjacent to grain sorghum fields and there is a possibility of spiders migrating between them. The jumping spider, *Phidippus audax* (Hentz), was also tested in the greenhouse for the control of greenbugs on Rogers barley plants.

REVIEW OF LITERATURE

Literature on the association of spiders with crop plants is very limited when compared to the literature available on their taxonomic aspects. The importance of spiders in the field of biological control has been realized only very recently.

Spiders Associated with Cultivated Crops

The spiders associated with sorghum have been listed and studied by Bailey and Chada (1968) in Oklahoma. They reported the presence of spiders in large numbers throughout the growing season, and that they preyed upon many of the insect pests that attack sorghum. Harris (1961) noted that spiders *Thomisus* sp. and *Diaea* sp. prey upon ovipositing female sorghum midges in Nigeria. Everly (1938) observed spiders of the families Salticidae and Thomisidae in sweet corn fields throughout the season.

Hensely, et al. (1961) and Negam and Hensely (1967) found that heptachlor had an adverse effect on the spider fauna in the sugarcane fields of Louisiana. Raatikainen and Huhta (1968) found that *Tetragnatha extensa* (L), *Linyphia pusilla* Sundev., *Xysticus cristatus* (Clerck), and *X. ulmi* (Hahn) were the commonest spiders in oat fields of Finland. The number of spider species per sample depended on the distance of the field from the forest edge, and on weed control. Fluke (1929) observed a number of spiders feeding on the pea aphid in Wisconsin.

In a cotton field of central Texas, Kagan (1943) collected 36 spider species belonging to nine families. Fletcher and Thomas (1943) observed spiders feeding on the first instar larvae of Heliothis armigera (Boddie). Wiesmann (1955) in Egypt, observed three species of spiders as important enemies of Prodenia sp. larvae. The bushy and vigorous plants harbored more spiders than the small plants. He also studied the migration cycle of the predators within a year in cotton, clover, and maize. Hassen, et al. (1960) in Egypt, found sprays of toxaphene, parathion, demeton, phosphamidon, and cotton dust affect the predators including a spider, Chiracanthium isiacum Pickamb in cotton fields.

Clark and Glick (1961) studied the preying of spiders on the pink bollworm moths tagged with radioactive material. Wene and Sheets (1962) observed spiders catching nymphs and adults of lygus bugs, damsel bugs, assassin bugs, Geocoris sp. and Orius sp. in a cotton field in Arizona. Of the 143 species of spiders collected by Whitcomb, et al. (1963b) in a cotton field in Arkansas, 82 were hunting forms, and 61 were web builders. They also found a seasonal succession of species, with some forms abundant early in the season, others later, and some even with two population peaks. Whitcomb and Bell (1964) studied the seasonal abundance of different spiders in an Arkansas cotton field. Lincoln, et al. (1967), Whitcomb (1967), and Lingren, et al. (1968b) found many species of spiders feeding on bollworm larvae, among which the important ones were the hunting and the lynx spiders.

Laster and Brazzel (1968) in Mississippi, compared the predators in cotton fields under different control programs. The spiders were dominant in the mid and late seasons, and 90 per cent of them were the striped lynx, Oxyopes salticus Hentz. A mixture of toxaphene and DDT affected the spiders more than toxaphene alone. Spiders were less affected by phosphates and carbamates than by chlorinated hydrocarbon insecticides. Studies by Ridgway, et al. (1967) showed that spiders in cotton fields were less affected by the sprays of systemic insecticides. Lingren, et al. (1968a) came to the conclusion that spiders were more affected by toxaphene plus DDT and azodrin than by other material sprayed for cotton bollworms in cotton.

Spiders Associated with Horticultural Crops

Chant (1956, 1957) concluded that particularly small species and immature forms fed on phytophagous mites, and the larger species confined their feeding to other orchard insects of southeastern England, like winter moth larvae, apple suckers, and aphids, in preference to predaceous insects. The feeding of spiders on mites increased with the density of the prey. Spiders played a greater role in reducing the population of apple pests than did the other predators in the field.

In Canada, Stultz (1955) reported the spiders Agelenopsis sp., Coriarachne versicolor (Keyserling), Dictyna sp., Misumena calycina (L.), Paraphidippus marginatus (Walckenaer), and Tmarus angulatus (Walckener) feeding on the caterpillars of the Eye-spotted bud moth, Spilonota ocellana (D. & S.) in apple orchards. Dondale (1956, 1958), listed the spider species collected in apple orchards, and also studied the population dynamics of them. He found one peak to appear in June, and the other late in August or early September.

Specht and Dondale (1960) studied the population trend of spiders in sprayed and unsprayed apple orchards in New Jersey. Legner and

Oatman (1964) recorded 24 species of spiders belonging to 17 genera and six families in an apple orchard of northwestern Wisconsin. They found the highest numbers of spiders in a fungicide environment, which was attributed to the more abundant and lush foliage, and extremely low numbers in the insecticide environment.

Dondale (1966) reported a total of 38 species of spiders as suspected predators of the light brown apple moth, Epiphyas postvittana (Walck), in the Australian Capital Territory. Hukusima (1961a) listed the 36 species of spiders found in apple orchards of Gifu University, Japan. Hukusima (1967) studied the seasonal population trends of pests and predators (including spiders) under pesticide treatments in apple orchards.

Putman and Herne (1966) found that some small spiders preyed heavily on phytophagous mites of peach, Panonychus ulmi (Koch), and Bryobia arborea (Morgan and Anderson), in Ontario. However, Putman (1967) reported Philodromus spp. and sometimes Theridion murarium (Emerton) were the abundant spiders in peach orchards. Hukusima and Kondu (1962a, b) studied the effect of different pesticides on the predaceous insects and spiders in pear orchards of Japan.

Dondale (1967) noted spiders as being among the principal predatory groups of the mite, Tetranychus mcdanieli (McGregor) in raspberry.

Spiders Associated with Fall Webworm

Fall webworm, Hyphantia cunea (Drury) is a pest of more than one hundred fruit, shade, and woodland trees. Riley (1887) and Whitcomb and Tadic (1963) observed spiders of the family Salticidae preying on fall webworm larvae. Oliver (1964) found spiders feeding actively on early larval stages of the fall webworm in Louisiana. Warren, et al. (1967) collected 371 spiders representing 41 species and 11 families from 400 fall webworm nests in northwest Arkansas. In Japan, Kayashima (1967) found mostly grass spiders to prey upon fall webworms; however, it was noted that grass spiders were difficult to propagate, and needed to be liberated in the infested area since they were stationary in nature.

Harrison (1968) has given a list of spiders belonging to 36 families in banana plants at Changuinola, Panama. He observed several species of spiders feeding on the larvae of lepidopterous banana pests in the field.

Lovell (1915) reported crab spiders living in the inflorescence of sumac (Rhus), meadowsweet (Spiraea salcifolia), elderberry (Sambucus viburnum, vornus, and the bristly sarsaparilla (Aralia hispida) and feeding on the insects visiting those flowers. Judd (1964) has given a list of spiders and their insect prey from the heads of ox-eye-daisy, Chrysanthemum leucanthemum L. in southwestern Ontario. Miller (1966) recorded eight species of spiders belonging to three families in the stem galls of goldenrod (Solidago sp.).

Spiders Associated with Pasture Lands and Forests

According to Loughton, et al. (1963), Escherich in 1914 stated that spiders were an important biotic control factor for Chermes sp. on spruce, the spruce scale, Tortrix spp., and leaf and needle-eating beetles in Germany. Sweetman (1936) referred to spiders as predators of aphids on spruce and larch in England. Kayashima (1961) proved that the release of the spider Oxyopes sertatus L. in Cryptomeria forests in Japan reduced damage to the trees by the cecidomyiid, Contarinia inouyei (Mani) 53 to 75 per cent.

Loughton and West (1961) used serological tests to study spiders feeding on the spruce budworm, Choristoneura fumiferana (Clem). Loughton, et al, (1963) reported that the spider Grammonota pictilis (O. P. Cambridge) was an important predator of the spruce budworm. They also studied the functional response of spiders to fluctuations in budworm population. Elliott (1930) studied the ecology of spiders in beech-maple forests and listed spiders noted.

Turnbull (1960a) found two peak populations of spiders in an oak forest of Berkshire, England. Whitcomb, et al. (1963a) compared the spider populations in pasture and cultivated fields in Arkansas. A few papers have been published on the ecological aspects and association of spiders to pasture and prairie lands (Barnes, 1953; Barnes and Barnes, 1955; Jones, 1946; Muma and Muma, 1949; and Hansell, 1961).

Life History of Spiders

In general, not much work has been done on the biology of spiders. Only in recent years has the importance of information on the life history of spiders been realized. Knowledge of the life history of spiders is a necessity in initiating further work on the applied aspect.

As early as 1885, Enock studied the life cycle of Atypus piceus (Sulz) in England. Life history of the black widow spider, Latrodectus mactans (Fabr.) , has been studied by Rau (1924), Lawson (1933), and Deevey (1949), and for two other spcies of the same genus by Shulov (1940).

The life histories of the following species have been studied: Teutana grossa Koch. (Branch 1943); Phidippus audax (Hentz), and P. rinater (Walck.)(Snetsinger 1955); Philodromus rufus Walck., Paraphidippus marginatus Walck., and Metaphidippus protervus Walck., all in

Canada (Dondale 1961); Loxosceles reclusa Gertsch, in Arkansas (Hite, et al.1966); Phidippus coccineus Peckham and Peckham, in Nevada (Gardner 1967); Oxyopes salticus Hentz (Whitcomb and Eason 1967); and Phidippus audax (Hentz) in Oklahoma (Bailey 1968).

Mating Behavior

Bristowe (1930 and 1931) observed the mating behavior of many spiders. Kaston (1936) studied the senses involved in the courtship of some vagabond spiders. Rovner (1967) analyzed the reproductive behavior of Lycosa rabida Walck. Hallander (1967) studied the courtship display of Pardosa chelata (Muller). The mating behavior of Gasteracantha minax Thorell. has been studied by Mascord (1967). Whitcomb and Eason (1965) and Exline and Whitcomb (1965) studied the mating behavior of Peucetia viridans (Hentz).

Food Habits

Bilsing (1920) stated that there is no evidence to say that any species of spider has a particular food preference. Savory (1928) stated, "Spiders will eat all kinds of flies, as well as wasps, bees, ants, beetles, earwigs, butterflies, moths, harvestmen, and wood lice, and other spiders whenever the opportunity occurs ---------- they show no trace of discrimination." On the other hand, Bristowe (1941) said, "I have known for many years that a host of invertebrates were rejected by spiders.....discrimination and preference for certain insects is shown....."

Hobby (1930) listed the prey captured by some thomisid spiders, and the same author (1940) listed the different insects captured by spiders available in the Oxford University Museum. Turnbull (1960b) found that most of the prey of Linyphia triangularis (Clerck) were winged adult insects found in the community, and that spiders are not restricted in their prey to any taxonomic group. He attributed the following reasons for rejection of a prey, (1) the spider may be physiologically or psychologically unprepared to feed, (2) the manner of offering the prey may alarm the spider, (3) at the moment of offering the spider may find a particular prey distasteful, or (4) may not recognize it as a potential food.

Feeding trials with the spider Misumena tricuspidata Fab., showed that adult females and males killed the apple leaf-curling aphid, Myzus malisuctus Matsumura, at the rates of 12 to 24, and 25 to 32 per day, respectively, and killed the European red mite, Panonychus ulmi Koch. at about 20 per day (Hukusima 1961b).

Turnbull (1962) studied the food requirement of the various stages of the spider, Linyphia triangularis (Clerck), and found that spiders supplied prey at the lowest rates died in the early stages, usually in the act of molting, but those supplied at higher rates all matured. Thus, all deaths were attributed directly or indirectly to inadequate food supplies. A straight line relationship between the quantity of food consumed per day and the daily growth of the spider was found. Turnbull (1965) reared the spider, Agelenopsis potteri (Blackwall) from egg to adult on Aedes aegypti L. supplied at different daily rates. Mortality varied inversely with feeding rates. Gardner (1964) studied the sequential responses in the hunting behavior of the salticid spider, Phidippus clarus Keyserling, and the same author (1966) studied the characteristics of the prey in the hunting behavior of the spider, Phidippus coccineus.

Young Philodromus praelustris Keyserling eventually died without molting when fed only on European red mite, but the young of Theridion murarium Emerton molted once or twice with very slow development (Putman 1967). Lingren, et al. (1968b) found that Oxyopes salticus did not feed on the eggs of Heliothis zea (Boddie), but the adult males and females consumed 57 and 94 first instar larvae, respectively. Bailey and Chada (1968) in their feeding tests with different spiders came to the conclusion that any insect was satisfactory for food. Bailey (1968), based on his feeding tests with Phidippus audax and Oxyopes salticus, concluded that there was a relationship between the size of the spider and the size of the insect fed upon. The smaller instars of P. audax fed on the small, soft-bodied insects, while the larger spiders preferred the larger insects.

MATERIALS AND METHODS

Source of the Misumenops celer Colony

The *M. celer* colony was built up by collecting the adults and immature forms from alfalfa and sorghum fields near the Insectary, Oklahoma State University, Stillwater, Oklahoma.

Laboratory Room

Much of the work for this dissertation was carried out in a small laboratory room at the Entomology Insectary. Artificial light was provided daily from 6:00 A. M. until 6:00 P. M. by means of fluorescent lights. Temperature was maintained at 78±5°F., and the relative humidity ranged from 30 to 70 per cent.

Rearing, Mating, and Egg-laying Chambers

Different containers were used for rearing different stages of the spider. For rearing the adults, the container described by Peck and Whitcomb (1967) was used. It consisted of half an inch diameter glass tubing cut in 6-inch lengths and plugged firmly but loosely with cotton, allowing diffusion of air (Fig. 1). This arrangement facilitated the easy handling, feeding, and observing the specimen under a microscope. The same container was used for rearing the spiderlings after the third instar.

Small medicine cups were used for rearing the second and third instar spiderlings and for the feeding tests (Fig. 2). The egg masses

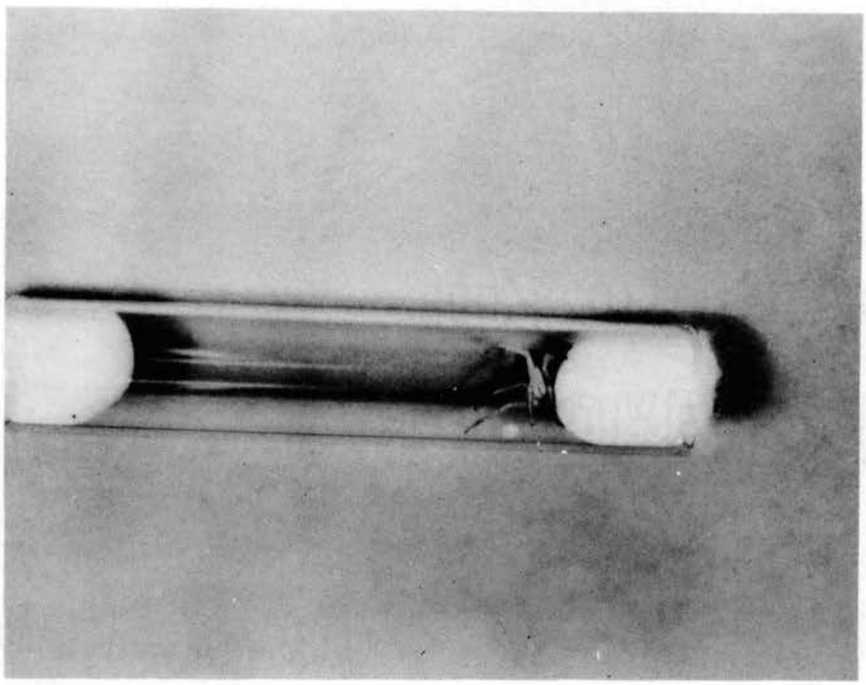

Fig. 1. Cotton-stoppered glass tube rearing chamber for rearing spiderlings from the fourth instar to maturity.

Fig. 2. Medicine cup used as a rearing chamber for second and third instar spiderlings.

were kept in a petri dish, which facilitated easy observation for time of hatching, duration, counting of eggs, measuring of egg size, etc. The first instar spiderlings (when hatched outside the egg sac) and the second instar spiderling were kept in a petri dish with a little cotton in the middle, and a thin coating of vaseline on the rim. This method restricted the movement of the spiderlings, and provided a resting place for them.

The containers with egg masses and spiderlings were kept inside an aquarium tank, which was covered at the top with a polyethylene sheet. A petri dish containing water was placed inside the aquarium. This method helped to keep the spiderlings and the adult spiders, before mating and egg laying, at 80 to 83 per cent relative humidity (Fig. 3, 4). The adult females after the egg laying period were kept in a tray (Fig. 5).

Food Used for Rearing the Spiders

Drosophila, house fly adults, and greenbugs were used as food for the various spider stages. First instar spiderlings did not feed. Greenbugs and *Drosophila* adults were fed to the second instar spiderlings. The third to the sixth instar spiderlings were fed *Drosophila* adults. The seventh instar spiderlings and the adults were fed house fly adults.

Greenbug culture was raised on Rogers barley in the greenhouse. *Drosophila* were reared on banana in one-gallon jars. House fly cultures were raised on CSMA fly medium as described by Bailey (1968). The adult flies were maintained in a screen cage, and fed with condensed milk. The house fly larvae were reared in a mixture of CSMA fly medium two parts, wood shavings one part, water one part, and a teaspoon of

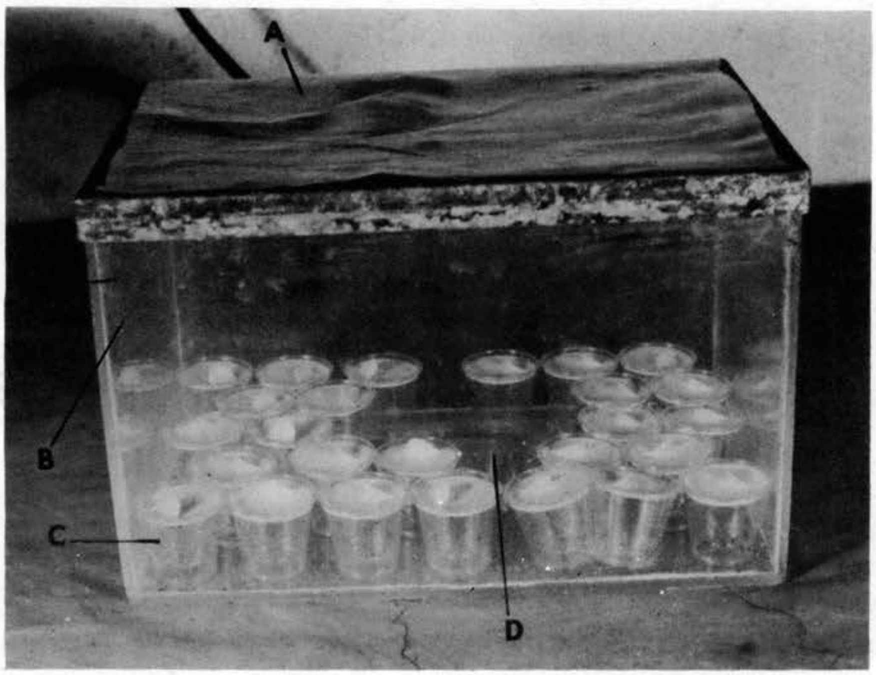

Fig. 3. Plastic cage designed to maintain 80-83 per cent relative humidity for rearing second and third instar spiderlings. A, polyethylene sheet cover; B, plastic cage; C, medicine cups containing spiderlings; and D, petri dish with water.

Fig. 4. Aquarium tank used to maintain 80-83 per cent relative humidity for rearing spiderlings from the fourth instar to maturity. A, polyethylene sheet cover; B, aquarium tank; C, cotton-stoppered glass tube rearing chambers; and D, petri dish with water.

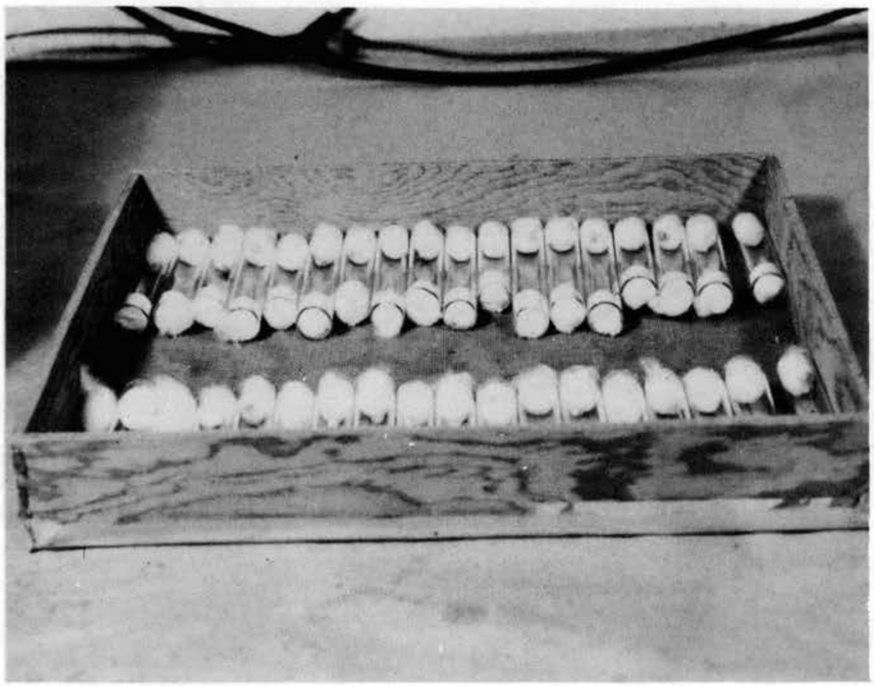

Fig. 5. Tray containing glass tube rearing chambers for spiders after oviposition was completed.

sodium propionate. Whenever needed, the house flies were collected in an ice cream container, anesthetized with carbon dioxide, and fed to the spiders.

Handling the Spiderlings

For capturing and transferring spiderlings, a slightly modified form of the aspirator (pooter) described by Cooke (1966) was used. It consisted of a long piece of rubber tubing having a one-fourth inch diameter glass tube, six inches long, inserted in one end. A filter of finely-woven fabric was placed between the glass tube and the rubber tubing.

Feeding Tests

Feeding tests were conducted in the medicine cups (Fig. 2) for all stages of the spiders, since it was easy to maintain uniform space. The insects used in the feeding tests were the first two larval instars of the fall armyworm and corn earworm, greenbugs, spotted alfalfa aphid, and adults *Drosophila* and house fly.

Life History Studies

Observations were made on the mating, oviposition, hatching, molting, duration of different stadia, and feeding habits of *M. celer*. The length and width of the cephalothorax and tibial and tarsal length of first pair of legs of different instars were also recorded.

Population Dynamics of Spiders in the Alfalfa Field

In an alfalfa field on the southwestern side of the insectary, weekly sweepings were made with a one-foot diameter hand net to study the population dynamics of *M. celer* (Thomisidae), *Oxyopes salticus*

Hentz. (Oxyopidae) and Tetragnathus sp. (Tetragnathidae). Each count consisted of ten sweeps, and this was replicated five times.

Pit-Trap Collection of Spiders in the Corn Field

In the summer of 1968, twenty soil pit-traps were placed at about 20 ft intervals in each row of the corn field on the southern side of the insectary. These pit-traps were a modification of those used by Fenton and Howell (1957), and they were described by Bailey (1968). They consisted of beer cans having the end, which had not been used for the original opening, cut out. A geotome was used to make a round hole in the ground the exact circumference and depth of the can. The can was then placed into the hole with the top even with the soil surface, and the dirt was tightly packed around the top. A plastic "Dixie" cup which fit tightly into the can was placed therein to hold the collection fluid. The collection fluid consisted of 40 per cent formalin one cup, five drops of liquid detergent, and enough water to make one gallon. The pit-trap was filled with fluid to about one-fourth inch from the top. A round plastic cover of five inches in diameter with a six-inch wooden leg pinned to the side was placed over the trap to keep out rain water and debris.

At one-week intervals, the material was collected and put into jars. Then the spiders were picked from the solution and stored in 70 per cent alcohol.

Greenbug Control Studies with Phidippus audax (Hentz)

Rogers barley plants were grown in pots inside the greenhouse. When the plants were about two inches in height they were thinned out to three plants per pot, infested with greenbugs, and then covered with plastic cage tops. Then the second instar spiderlings were placed in the cages to study their effectiveness in controlling the greenbugs.

RESULTS AND DISCUSSION

Life Cycle of Misumenops celer

Most of the specimens of M. celer collected in the alfalfa field during the months of June and July were immature. These were brought to the laboratory and reared in the glass tube containers (Fig. 1). Since sexual dimorphism is very distinct in M. celer, male and female spiders could be easily recognized based on their color and size. The males were somewhat smaller and darker, with reddish bands on the legs. The mature females could be easily distinguished from the immature females by the presence of the two distinct atrial openings in the epigynal plate.

Mating Behavior

Mating behavior in spiders is characteristic and distinct for each species (Dondale 1964, 1967). According to Whitcomb and Eason (1965), no life history of a spider is complete without a description of its mating habits.

The mating behavior of M. celer in the laboratory was watched closely under a dissecting binocular microscope during the month of July 1968, when a large number of specimens reached maturity. The males charged their palpi with seminal fluid one day after the last molt. Even though a triangular web was built by the male inside the mating chamber, the whole process of the sperm induction could not be watched *in toto*, but the male's readiness to mate attested to the fact that sperm induction had taken place. The female was ready to mate soon after the last molting. In many cases the mating was observed to occur an hour after the last molting, after the cuticle had hardened. There was very little pre-mating activity in the case of *M. celer* in comparison to that observed for spiders in the families Salticidae and Oxyopidae.

When the male was placed in the container with the female, it easily recognized the presence of the opposite sex. The male demonstrated its awareness of the presence of the female by vibrating the abdomen and moving its first two pairs of legs and palpi, and also gradually approaching the female. Then he touched her legs with his first and second pairs of legs. When she was in a receptive mood, she raised her legs and allowed herself to be hung in the silken threads which had been spun. In this condition the female accepted the male for mating, but when a male was introduced into the container of a nonreceptive female, he was able to realize the nonreceptive condition and did not approach her.

When the female was in a receptive condition, the male climbed over the female's dorsal side and reached to the opposite lateral side, where he remained in a slanting, inverted position. The male's head remained close to the female's epigynal plate. If the male approached from the right side of the female, then mating took place between the left embolus and the left atrium, and vice versa.

On the other hand, in some cases no pre-mating behavior was observed, and the male mounted directly on the female. In some cases the male licked the epigynal plate before inserting the emoblus, or rested for some time, keeping his chelicerae over the epigynal plate.

During copulation a transparent vesicle (the fundus) in the palpi was found dilating and collapsing at 5½-second intervals, signifying the action of pumping the seminal fluid into the female. The spines on the tarsi of the first two pairs of legs in the male were observed flickering in synchronization with the pumping of the seminal fluid from fundus in the palp. Sometimes the male lubricated the embolus by passing it in between the chelicerae.

The time taken for copulation on each side is shown in Table I. The total time of actual coupling varied from three minutes thirty seconds to nine minutes thirty-one seconds, with an average of six minutes, nineteen seconds. Table I shows only the actual time taken for coupling, or the time taken for transferring seminal fluid observed under a binocular dissecting microscope. It was also noticed that the male remained on the female for a long time after copulation, until the female became active and kicked him off. When the male was allowed to remain in the same container after copulation, the female eventually killed and devoured the male.

The male was able to mate with more than one female, but before each mating it needed to charge its palpi with seminal fluid. This usually took about 12 hours. However, the female did not mate more than once. A waxy or oily coating found over the atrium in the epigynal plate of the mated female probably prevented a second mating. This was also observed by Exline and Whitcomb (1965) in Peucetia viridans (Oxyopidae).

Egg-sac Construction and Oviposition

About four to ten days before egg-laying, the female started

TABLE I

TIME TAKEN FOR COPULATING BY *Misumenops celer*

Observation Number	Date (1968)	Side of first mating	Time taken for mating: Left min. sec.	Right min. sec.	Total min. sec
1	6- 4	left	2 - 53	3 - 30	6 - 23
2	6- 5	left	2 - 29	4 - 08	6 - 37
3	6- 5	left	3 - 05	4 - 22	7 - 27
4	6- 7	right	2 - 29	2 - 15	4 - 44
5	6- 7	left	-	-	6 - 34
6	6-10	right	2 - 52	-	-
7	6-10	left	4 - 22	5 - 09	9 - 31
8	6-10	left	3 - 38	5 - 08	8 - 46
9	6-10	left	3 - 30	2 - 47	6 - 17
10	6-10	right	3 - 10	2 - 58	6 - 08
11	6-10	right	4 - 40	3 - 38	8 - 18
12	6-11	right	1 - 02	2 - 44	3 - 46
13	6-12	right	3 - 50	3 - 22	7 - 12
14	6-12	right	3 - 32	2 - 51	6 - 23
15	6-14	right	1 - 30	2 - 00	3 - 30
16	6-14	left	2 - 30	2 - 25	4 - 55
17	6-14	right	2 - 40	6 - 20	9 - 00
18	6-17	left	2 - 36	2 - 52	5 - 28
19	6-18	right	1 - 56	2 - 02	3 - 58
20	6-20	right	2 - 00	3 - 19	5 - 19
Average			2 - 55	3 - 26	6 - 19

constructing a white sheet of web, and it was slowly enlarged into a concave sac. Then she moved to the middle and strengthened the sac with more silk. Oviposition took place in the middle of the sac, and the egg mass was covered with silk. Oviposition took place mostly during the night, and it could not be observed. The time taken from mating to oviposition varied from 11 to 43 days, with an average of 23.1 days (Table II). In most cases the egg sac was found attached to the corner of the cotton plug and the glass tube. The completed spherical, white egg sac was found attached to the surface of the tube by means of silken threads. After oviposition, the female remained near the egg sac until the spiderlings were ready to leave.

The eggs were yellow and globular, with a diameter of 0.75 mm, as shown in Fig. 6. Eggs remained inside the sac in a mass, but could be easily separated. Fig. 7 shows an egg mass in a slightly opened egg sac. The number of eggs per sac varied from 55 to 234, with an average of 144.9 (Table V). Removal of eggs from the egg sac did not affect the hatchability of the eggs, provided that they were given the proper relative humidity. The relative humidity of 80 to 83 per cent was quite satisfactory for the normal hatching of the eggs.

There was no apparent change in the color of the egg from the time of oviposition to the time of hatching. The incubation period ranged from five to eleven days, with an average of 7.1 days (Table II). A few hours before hatching, the chorion of the egg was slightly wrinkled. Then there was a split in the chorion at the region of the cephalothorax of the spiderling, which enabled the cephalothorax to emerge first, followed by the cephalothoracic appendages. After the emergence of the abdomen, the chorion remained attached to the posterior tip near the

TABLE II

DURATION IN DAYS OF THE VARIOUS DEVELOPMENTAL STAGES OF *Misumenops celer*.[a]

Developmental stage	Number of individuals	Duration of different instars Range	Average
Mating to oviposition	20	11-43	23.1
Incubation period	20	5-11	7.1
Post embryo	20	1- 2	1.4
First instar	20	5- 9	6.5
Second instar	20	13-42	27.1
Third instar	20	15-71	41.8
[b]Fourth instar	20	19-80	50.4
[b]Fifth instar	10	11-65	43.7
[c]Sixth instar	10	17-74	45.1
[c]Seventh instar	10	15-22	17.0
Adult male	20	35-64	52.0
Adult female	--	-	-
Egg to adult male	20	85-169	-
Egg to adult female	20	118-311	-

[a]Reared during the winter and early spring of 1968-69 in the the laboratory.

[b]Spiderlings reached the adult male stage after the 4th or 5th instars.

[c]Spiderlings reached the adult female stage after the 6th or 7th instars

Fig. 6. Individual egg of Misumenops celer, greatly enlarged.

Fig. 7. Egg mass inside the egg sac of Misumenops celer.

spinnerets. The newly-emerged spiderling is known as the "post embryo," since the appendages (legs, mouth parts, and pedipalp) are kept close to the body and are enclosed in a transparent membrane with the chorion attached at the posterior end (Fig. 8). The motionless post embryo stage lasted one to two days with an average of 1.4 days (Table II). The chorion was shed off with the exuvium of the post embryo (Fig. 9).

The first instar spiderling with a white to transparent cephalothorax and legs and yellowish abdomen, emerged from the post embryo. They did not feed and were not able to stand or walk on a plain surface, but they could walk and remain on cotton fibers. Hence, the first instar spiderlings were kept in a petri dish with a small amount of cotton in the middle of the dish. The first instar spiderlings were smooth-bodied and possessed no pigments, hairs, or setae (Fig. 10). These spiderlings remained inside the egg sac if they were not disturbed. Fig. 11 shows the first instar spiderlings when the egg sac was opened.

The second instar spiderlings were quite active, and at this stage came out of the egg sac (from the normal egg sac). They fed rapidly on small insects such as aphids and Drosophila. These spiderlings were somewhat yellow, with setae scattered profusely over the body. An average of 23 days elapsed between oviposition and emergence of second instar spiderlings from the egg sac.

Data on the duration of the several spider instars are presented in Table II. Cephalothoracic width and length of tibial and tarsal length data are presented in Table III. There were four or five instars for male, and six or seven instars for female spiders. The

Fig. 8. Post-embryonic stage of Misumenops celer with the chorion attached.

Fig. 9. Chorion attached to the exuviam of the post embryo of Misumenops celer.

Fig. 10. First instar spiderlings of Misumenops celer.

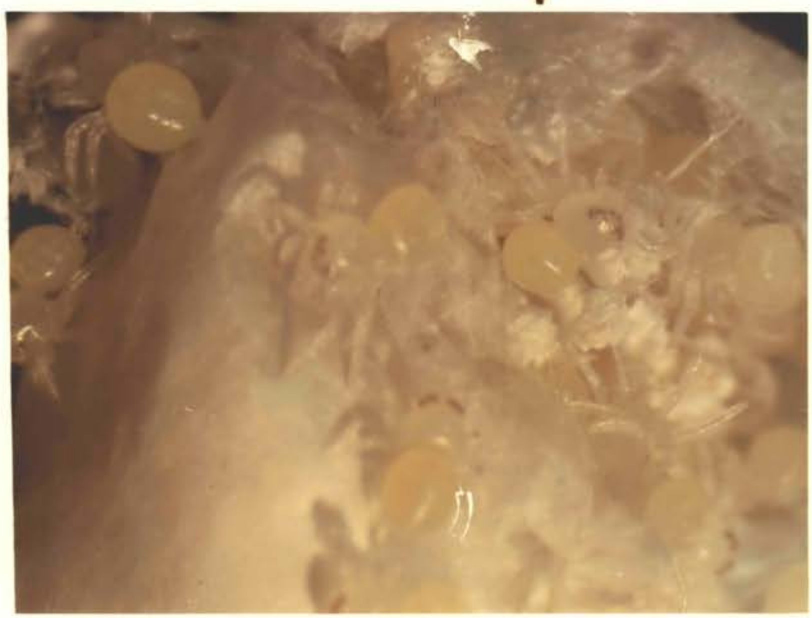

Fig. 11. First instar spiderlings of Misumenops celer in an opened egg sac.

TABLE III

MEASUREMENTS IN mm OF THE VARIOUS STAGES OF *Misumenops celer*

Instars	No.	Cephalothorax: Length Range	Cephalothorax: Length Avg.	Cephalothorax: Width Range	Cephalothorax: Width Avg.	First pair of legs: Tibial Length Range	First pair of legs: Tibial Length Avg.	First pair of legs: Tarsal Length Range	First pair of legs: Tarsal Length Avg.
First	10	0.42-0.45	0.43	0.42-0.45	0.43	0.15	0.15	0.12	0.12
Second	10	0.45-0.48	0.46	0.45-0.51	0.47	0.24-0.27	0.25	0.21-0.24	0.22
Third	10	0.63-0.72	0.64	0.66-0.72	0.68	0.33-0.52	0.44	0.27-0.45	0.35
Fourth	10	0.84-1.02	0.95	0.90-1.05	0.99	0.72-0.84	0.79	0.54-0.72	0.62
Fifth	10	1.05-1.20	1.19	1.08-1.20	1.18	0.96-1.15	1.07	0.75-0.99	0.81
Sixty	10	1.20-1.47	1.33	1.20-1.47	1.49	1.18-1.35	1.22	1.05-1.14	1.27
Seventh	5	1.42-1.71	1.62	1.45-1.74	1.65	1.44-1.62	1.50	1.35-1.55	1.44
Adult male	10	1.12-1.35	1.24	1.12-1.35	1.28	1.75-2.10	2.04	1.75-2.10	2.04
Adult female	10	1.80-2.55	2.32	1.80-2.58	2.38	1.50-2.40	1.95	1.50-1.80	1.74

variation in instar numbers has also been observed for other spiders (Bailey and Chada 1968).

None of the immature stages or adults of this spider constructed a web, except for egg sac construction by the female at the time of oviposition. The males died 35 to 64 days after reaching the adult stage, but some were eaten by the females after copulation. The females lived more than a year after oviposition.

In general, differences in the duration of the several instars of this spider may be attributed to the genetic variance existing in the population, and part of it may be due to environmental factors, such as variation in temperature. A temperature ranging from 70 to 80^{o}F. was found to reduce the length of the instars. The high relative humidity of about 80 per cent reduced the mortality rate considerably.

In the laboratory it is possible to rear two to three generations in a year by carefully controlling the temperature and relative humidity.

Mass Rearing

The egg sac production varied from one to three per female, with an average of 2.1 (Table V). Even though there were no egg sacs produced in the laboratory during the months of November, December, January, and February (Table IV), egg sac production is possible by proper manipulation of temperature and humidity. As shown in Table V, life cycle duration varied from 128 to 347 days.

M. celer spiderlings required a relative humidity of 80 to 83 per cent for normal development (Table VI). In the early stages of this study there was a high rate of mortality of the second and third instar spiderlings when they were kept at the existing laboratory relative humidity (about 30 to 50 per cent). Relative humidity was increased,

TABLE IV

EGG SACS PRODUCED DURING THE YEAR BY *Misumenops celer* IN THE LABORATORY

Month	Number of egg sacs produced
January	0
February	0
March	2
April	3
May	4
June	7
July	24
August	6
September	3
October	1
November	0
December	0

TABLE V

DATA ON EGG SACS, EGGS, AND SPIDERLING PRODUCTION OF *Misumenops celer*

	Range	Average
Eggs per sac	55 - 234	144.9
Egg sacs per female	1 - 3	2.1
Spiderlings per sac	0 - 217	114.3
Number of days for life cycle	128 - 347	-

TABLE VI

MORTALITY OF THE VARIOUS INSTARS OF *Misumenops celer* WHEN REARED AT RELATIVE HUMIDITY VARYING FROM 80 TO 83 PERCENT[a]

	Instar						
	1	2	3	4	5	6	7
Percent mortality	4	16	6	2	-	-	-

[a]Based on a sample of 50 spiderlings.

and this situation was corrected, as described in the materials and methods section, and as shown in Fig. 3 and 4.

Jones (1941) reported that a low humidity of less than 50 per cent caused high mortality in Agelina naevia Walcknaer. She also reported that the temperature had a definite effect upon the length of the instars, and a wide daily range caused a slow growth.

The first instars of M. celer were reared in mass numbers in a petri dish, the second and third instars were reared in small medicine cups, and all other instars and the adults were reared in glass tubes, as described by Peck and Whitcomb (1967). The main difficulty in mass rearing this spider was the need to keep spiderlings in individual containers after the second instar, because of their cannibalistic habit.

Feeding Tests with Misumenops celer

The thomisid spiders, in general, catch and prey on insects by the sense of touch. They have acquired the habit of frequenting flowers and foliage of plants for the purpose of preying on the insect visitors. Lovell (1915) noted the crab spiders lurking in the inflorescence of the sumac (Rhus), meadow sweet (Spiraea salicifolia), elderberry (Sambucus), viburnum, cornus, bristly sarsaparilla (Aralia hispida), and rose. He also observed them capturing bumble bees, honey bees, butterflies, dragonflies, and other insects. Judd (1964) found more than half the total spider population on ox-eye daisy consisted of thomisid spiders. He also reported that these spiders fed on tettigoniid nymphs; bugs of the family Coreidae and Miridae; flies of the families Anthomyiidae, Agromyzidae, and Calliphoridae; and wasps of the family Chalcidae.

When Misumenops celer spiders were collected from the alfalfa field during the spring and summer of 1968, they were observed feeding on small grasshopper and treehopper nymphs, mirid and coreid bugs, cicadellids, aphids, small wasps, flies, and small butterflies and moths. This spider did not construct a web, as do most other spiders, or jump to capture prey, as do the salticids. It captured prey by stealth and ambush. When a fly was introduced into the rearing chamber of a hungry spider, it prepared itself for the attack by raising its first pair of legs. In capturing the prey, the spider pierced it with its chelicerae. After the prey was paralyzed, the spider started to feed on it by inserting its chelicerae at the posterio-dorsal part of the head. After feeding on the head, it fed on the abdomen, and finally on the thorax and legs.

The various stages of the spider, M. celer, were fed house flies, Drosophila, greenbugs, spotted alfalfa aphid, first and second instars of corn earworm and fall armyworm to study food preference. First instar spiderlings did not feed. The second and third instars preferred smaller insects, such as Drosophila and aphids, while the other instars and the adult spiders preferred somewhat larger prey, such as house flies. The results of the feeding trial are given in Table VII. The adults of M. celer preferred to feed on larger insects in the test, rather than on small insects such as greenbugs and the spotted alfalfa aphid. However, Hukushima (1961b) reported that Misumena tricuspidata Fabricius adult females fed on the apple leaf-curling aphid, Myzus malisuctus Matsumura, at the rate of four to 38 individuals per day in the rearing tubes, and 35 to 143 in outdoor cages. It also consumed about 20 European red mits, Panonychus ulmi Koch. per day. Hukusima and Kondo (1962b) found that M. tricuspidata consumed an average of 15 pear

TABLE VII

AVERAGE NUMBER OF INSECTS EATEN PER DAY BY THE SEVERAL *MISUMENOPS CELER* INSTARS[1]

Instars	*Drosophila*	Green-bug	Spotted alfalfa aphid	Fall armyworm 1st instar	Fall armyworm 2nd instar	Corn earworm 1st instar	Corn earworm 2nd instar	House fly
1	-	-	-	-	-	-	-	-
2	1.5	2.6	1.4	4.6	3.1	2.8	1.2	-
3	1.8	2.2	1.6	-	-	-	-	-
4	3.1	1.5	1.3	9.3	-	7.0	3.8	1.5
5	3.3	1.7	1.5	10.5	-	7.2	5.4	2.9
6	4.1	1.2	1.3	-	-	8.3	-	3.3
7	4.7	-	-	-	-	-	-	3.1
Adult male	1.9	0.7	1.1	9.2	-	7.6	4.5	1.9
Adult female	5.6	1.3	1.9	12.3	-	14.2	9.8	4.8

[1]Observations for 3-day feeding period.

aphids, *Toxoptera piricola* Matsumura, per day.

All stages of this spider fed well on the first and second instars of corn earworm and fall armyworm. *Drosophila* was preferred by all stages of the *M. celer*. The adults and the fourth, fifth, sixth, and seventh instars preferred house fly. According to Turnbull (1962) the rate of development of spiderlings of *Linyphia triangularis* Clerck, varied at different daily rates of food. The lowest rate of food supply in the early stages of the spiderlings caused death during the act of molting. He attributed all deaths of spiderlings to inadequate food supply.

The adult males of *M. celer* were not as effective predators as were the females. The females killed at least 2½ times more house flies than the males. The females were more effective as predators because of their longer life span.

To determine the amount of food extracted from a fly, four adult *M. celer* of each sex were starved for 12 hours and then were fed one house fly each. At the same time, four other flies were kept in separate containers as a check. At the end of feeding, the dead flies were weighed individually. The check flies were killed with CO_2 and weighed. The results are given in Table VIII. The results show that the adult female extracted about 71.1 per cent of the weight from the house fly, whereas the adult male extracted only 32.9 per cent. Turnbull (1962) stated that the quantity of food extracted per captured fly varied widely and depended at least in part on the ease with which the additional prey could be captured.

TABLE VIII

FOOD MATERIAL EXTRACTED FROM THE HOUSE FLY BY THE ADULT MALE AND FEMALE *Misumenops celer* SPIDER

Spider number	House fly weight in grams After spider feeding Female	 Male	 No feeding-check flies
1	0.0073	0.0178	0.0123
2	.0017	.0095	.0105
3	.0083	.0100	.0212
4	.0011	.0102	.0167
Average	.0044	.0102	.0152
Average percent reduction in weight	71.1	32.9	

Population Dynamics of Spiders in Alfafla Field

In the spring of 1968, sweeping were made with a hand net to collect spiders in alfalfa and to study their biology. It was found that alfalfa supported a surprisingly large population of spiders. As there is a possibility of spiders migrating from alfalfa to nearby sorghum, corn, and wheat fields, the present study was undertaken to note the population fluctuations of spiders in alfalfa during the summer of 1968. It was observed in pre-survey collections that *Misumenops celer*, *Oxyopes salticus*, and *Tetragnathus* sp. made up the major proportion of the total population. Data were recorded on the numbers of females, males, and young of *M. celer*, *O. salticus*, and *Tetragnathus* sp. The population trend of the above sampling is shown in Fig. 12. Weekly samples were made from June to September, 1968. The weekly collection data shown in Fig. 12 represent the total number of spiders collected in 50 sweeps.

From Fig. 12 it is seen that there are two peak populations of spiders, one in late June, and the other in late August. The late June population peak is due to overwintering population of spiderlings reaching the adult stage and migrating to the crop. The second peak is due to the summer generation reaching maturity. In the case of the young of *M. celer* and *O. salticus*, the population peaks in early July are due to the young produced by the overwintering generation. Dondale (1958) also noted the same kind of fluctuation of spiders in apple orchards of Nova Scotia.

Periods of decline in spider populations were observed in mid-July and mid-September. The decline in male spiders in mid-July and mid-September was thought to be due to the death of males after mating

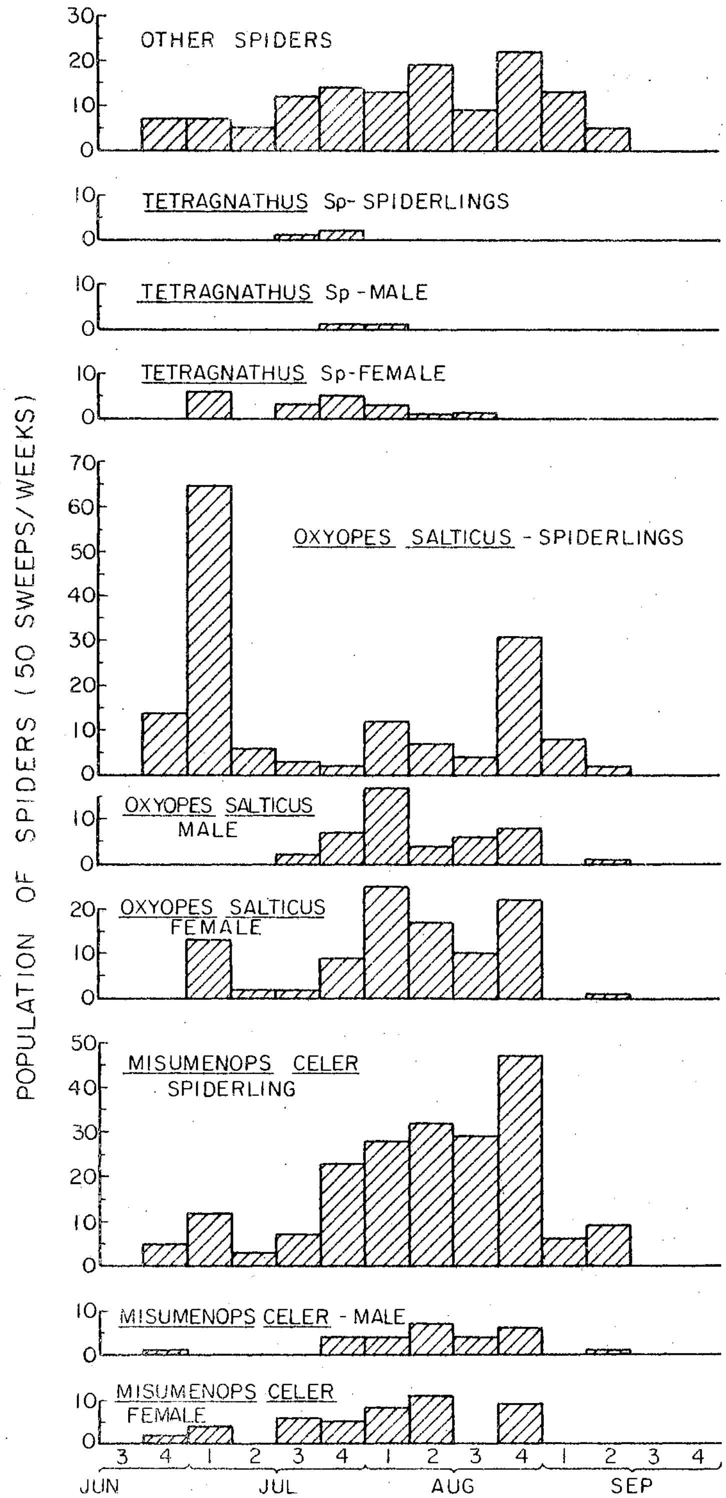

Fig. 12. Population dynamics of *Misumenops celer*, *Oxyopes salticus*, *Tetragnathus* sp., and other spiders in the alfalfa field during the summer. Stillwater, Okla. 1968.

(Kaston 1948). However, the decline was noted not only in male, but also in females and young populations. The mid-July decline seemed to be due to some environmental influence, probably interaction with other predators, and the September decline could be associated with the movement of spiders to overwintering niches (Dondale 1958). Even though the data collected on spiders from the alfalfa field coincided with views of Dondale (1958), the decline in population in mid-July and mid-September may also be attributed to the harvest of the crop during that period.

Pit-Trap Collection of Spiders in Corn Field

From the middle of July to the middle of September, 1968, ten pit-traps were placed in the corn field, and the spiders were collected at weekly intervals to study their population dynamics. Since it was not possible to have the spiders collected in the pit-traps identified, only the total spider population fluctuation during the period of sampling is shown in Fig. 13. From this figure it is evident that spiders were present even in the early stages of the crop development, and that populations increased to the maximum in late August, when the crop was in the nearly-matured or matured stage. This trend in the population was also noted by Bailey and Chada (1968) in grain sorghum at Stillwater, Oklahoma.

Everly (1938) studied the spiders associated with sweet corn, and reported that families Salticidae and Thomisidae were abundant throughout the season. During the latter part of August, the web-spinning spiders were most numerous. He reported nine families of spiders that were associated with sweet corn. Even though the pit-trap collection

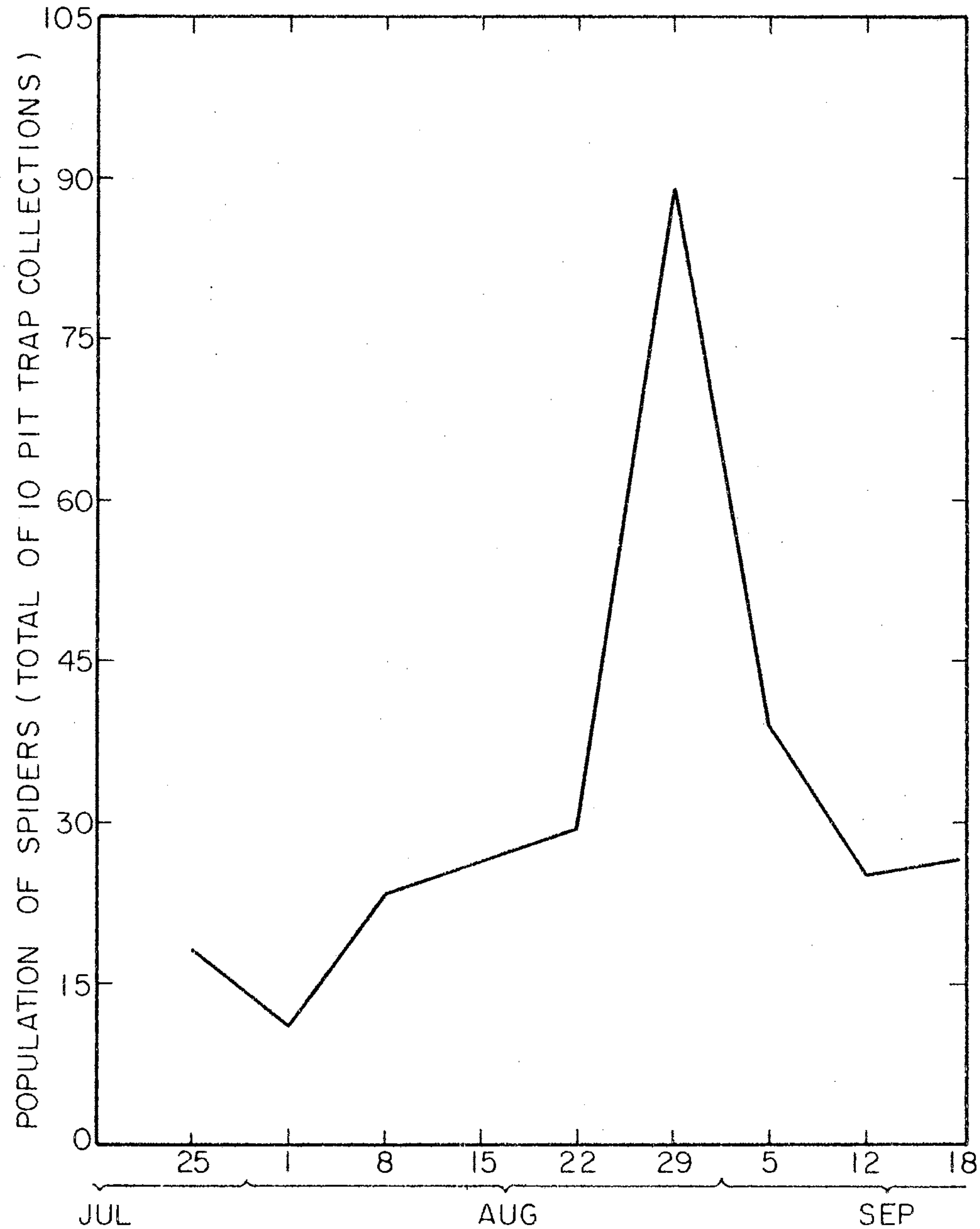

Fig. 13. Population trend of spiders in a corn field sampled by means of pit-traps during the summer, Stillwater, Oklahoma, 1968.

showed a general trend of spider population in this study, the data presented do not represent total spider populations because they do not include populations of spiders living on the plant.

According to Bailey (1965), in pit-trap collection of spiders in grain sorghum, the families Erigonidae, Lycosidae, Dictynidae, Salticidae, Oxyopidae, Theridiidae, Nesticidae, and Gnaphosidae were the most commonly collected. Families such as Thomisidae, Arigiopidae, Agelenidae, Clubionidae, and Anyphaenidae were not commonly found in pit-traps, because they are mainly plant inhabitors. However, in the present study, the spider population was found to increase with the growth of the crop, and reached a peak when the crop was at full maturity. Since this increase in population might have coincided with the increase in crop pests, most of which attack in the mature stage of the crop, the spiders might have played a valuable role in reducing the insect pest population.

Use of Phidippus audax for the Control of Greenbugs

Kayashima (1961) in Japan reported releasing 45,000 lynx spiders of the species Oxyopes sertatus L. Koch. in a plot of Cryptomeria forest for the control of the cryptomerian leaf fly, Contarinia inouyei Mani. He stated that larvae that dropped to the ground for pupation in the treated and untreated plots were 2,075 and 8,593, respectively. It was also estimated that the damage to the trees was about 75 per cent less in the treated plots. By continuously conducting the experiment from 1957 to 1961, the results showed that in 1961 there was about 53 per cent less damage in the treated plot than there was in 1957. The above experiment of Kayashima clearly shows the economic role of spiders in cultivated crops. The present study was made to test the effectiveness of P. audax in controlling greenbugs infesting caged barley plants in the greenhouse.

For this purpose, Rogers barley was planted in six pots. When the plants were two inches in height, they were thinned to three plants per pot and infested with 50 greenbugs per pot. Then three of the six pots were infested with three second instar spiderlings each. The other three greenbug-infested pots were not infested with spiderlings. Then periodic observations were made on the condition of the plants in the pots. In the first two or three days, greenbug injury was noticed on the plants of all of the pots, but on the sixth day after spider inoculation, plants in the pots without the spiderlings turned yellow in color. On the ninth day, plants in two of the three pots which were not infested with spiderlings, died completely (Fig. 14), and the plants in the third pot died on the eleventh day. Plants in the pots that were infested with spiderlings showed little or no damage on the eleventh day and were free of greenbugs, except for a few in one pot, but these, too, disappeared by the fourteenth day.

This laboratory experiment shows that the spiderlings of P. audax may be of importance in the biological control of greenbugs in small grains.

Fig. 14. Biological control of the greenbugs infesting barley in the laboratory. L - three pots each infested with 50 greenbugs. R - three pots similarly infested, but greenbugs controlled by infestation with three Phidippus audax spiderlings per pot.

SUMMARY AND CONCLUSIONS

The life history of the crab spider, Misumenops celer (Hentz) (Thomisidae) was studied in the laboratory. Various data in the life cycle were recorded, such as mating behavior, egg sac construction, hatching, and characteristics of different instars. Sexual dimorphism was quite evident in M. celer; the male was half the size of the female. There was little pre-mating activity. The male needed sperm induction on the palpi before mating, but the female mated soon after molting. Males mated with more than one female, but the female mated only once. A waxy covering was noticed over the epigynal plate of the mated females, and this may account for the fact that they did not mate a second time. Eggs were laid inside a white silken cocoon-like egg sac. The female remained near the egg sac until the young emerged and dispersed. The incubation period of the eggs averaged 7.1 days. The number of egg sacs per female varied from one to three, with an average of 2.1. The number of eggs per sac varied from 55 to 234, with an average of 144.9.

Males reached maturity after four or five moltings, while the adult female required six or seven moltings. The actual time of sperm transfer varied from three minutes and 30 seconds to nine minutes and 31 seconds. The total number of days to complete the life cycle varied from 128 to 347 days.

For normal development and reduced mortality, a relative humidity of about 80 per cent was needed. Temperatures ranging from 70 to 80°F. were optimum for spider development. It was also thought that there is a possibility of genetic variability existing in the population, contributing to the variation in the length of the different instars and as a whole to the life cycle.

In the feeding trial it was found that the smaller spiderlings preferred to feed on small insects, and the larger spiderlings and the adults on the large insects. In general they preferred quick-moving insects. Adult males were found to be less effective predators than adult females.

In pit-trap collections of spiders in a corn field during the summer of 1968, it was found that spiders were present even in the early stages of the crop, and the increase in spider population coincided with the development of the crop.

Misumenops celer, *Oxyopes salticus*, and *Tetragnathus* sp. were very common in alfalfa during the summer of 1968. There were two population peaks, one in late June and the other in late August. Soon after each spider population increase there was a decrease in the population, which might be attributed to the influence of biotic and abiotic factors, and also to harvesting of the crop.

Second instar *Phidippus audax* spiders effectively controlled infestation of greenbugs on potted barley plants.

This study indicates that *Misumenops celer* in particular, and spiders in general, are of economic importance as predators on insect pests of crop plants. Additional information is needed on the biology, ecology, and mass rearing of spiders.

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