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A Study of *Neoscona oaxacensis* (Araneae: araneidae) in Commercial Avocado Orchards in San Diego County, California

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SUMMARY

To determine the role of spiders in avocado orchards, the biology of the dominant spider, *Neoscona oaxacensis* (Keyserling), was studied in six commercial avocado orchards near Fallbrook, San Diego County. Direct visual observations were made weekly, from November, 1978 to October, 1979, to determine the spiders' behavior, life history and prey. Window and light traps were used to monitor the flying insect populations.

Neoscona oaxacensis spiderlings appeared in the avocado trees in the first week of March and increased in number until April, after which they decreased in number until late October. After October only a few individuals remained in the orchards. *Neoscona oaxacensis* did not overwinter in the orchards as adults. Daily activity patterns showed evenings to be the active period for orb repair, feeding and mating, though these activities were also observed at other times during the day. Psocoptera, Diptera, Coleóptera and Lepidoptera were the main prey items. Psocoptera and Coleóptera were a larger portion of the spider's diet than they were a portion of the total flying insect population. Lepidoptera and Diptera were a smaller portion of the spider's diet than they were a portion of the flying insect population. Behavior of spider and prey, and characteristics of the spider's orb, are possible explanations for the unequal composition of the spider's diet. Spiders other than *Neoscona oaxacensis* were uncommon in the orchards.

INTRODUCTION

Avocados are an important part of the agricultural economy of San Diego County. In 1978 San Diego County produced 59,015 tons of avocados for a total value of $44,084,000, making avocados the fourth most important agricultural commodity in the county (San Diego County Department of Agriculture 1978). Fortunately for the growers in this county, avocado trees seldom need pest control treatment, as beneficial organisms usually control the pest populations (Fleschner 1954, Ebeling and Pense 1957). However, occasional outbreaks of lepidopteran pests cause economic damage. To manage the pests in the most intelligent manner the California Avocado Advisory

Board and the California Avocado Society initiated the development of an integrated pest management program. To implement such a program, knowledge of the biology of the pests and their natural enemies is necessary (DeBach 1974).

The biology of the two lepidopteran pests of avocado, the omnivorous looper, *Sabulodes caberata* Guenee and the amorbia moth, *Amorbia essigana* Busck is well known (Ebeling 1950, Ebeling *et al.* 1959). Looper damage can be seen in most avocado groves in California, yet this pest seldom causes serious damage to foliage (Ebeling 1950). The amorbia moth is also widespread in California. The larval stage of both pests feeds on the leaves, especially skeletonizing young leaves. Two or three leaves are usually webbed together to provide a retreat for hiding during the day or pupation. Although these larvae are usually present, the avocado tree can sustain a large amount of leaf damage before the following year's crop is decreased (Ebeling 1950). Larval populations seldom reach a density great enough to do such damage. Economic damage also occurs when pest populations are high and young fruit is attacked. The damage to young fruit becomes more conspicuous as the fruit enlarges, making the fruit unsuitable for market. The larvae of both species are active at night and cling to the undersides of leaves during the daylight hours. The life cycle of the looper requires about six weeks in the summer in coastal San Diego County and there are usually five to six generations per year. The life cycle of the amorbia moth is slightly longer, taking about two months in the summer and having four to five generations per year (Ebeling 1950). During the summer months the populations of the moths may build up to a density which can cause economic damage.

The avocado brown mite, *Oligonychus punicae* (Hirst), and the greenhouse thrips, *Heliothrips haemorrhoidcdis* (Bunche), are also potentially serious pests of avocados. However, they were not serious problems during the course of this study and were not considered.

The biology of the parasites of the lepidopteran pests has received some attention (Fleschner *et al.* 1957) and is currently under intensive investigation by Workers from the University of California at Riverside. Unlike the pests and their parasites, the biology of the spiders, the dominant predators in avocado orchards, was not known. This thesis investigates the biology of spiders, specifically orb weaving araneids of the genus *Neoscona,* which were found to be the dominant predators in commercial avocado orchards in San Diego County.

Spiders are among the dominant predators in all terrestrial ecosystems (Gertsch 1979). Bristowe (1941) calculated the number of spiders present on an acre of undisturbed grassy habitat to be 2,265,000. Despite the dominance and possible importance of spiders as agents of community regulation and biological control, there are very few quantitative studies of spider prey (TurnbuU 1973).

Arachnologists have taken the first step in evaluating the role of spiders in agricultural situations by listing the spider species which are present on various crops. Such lists include the spiders on alfalfa (Howell and Pienkowski 1971, Yeargan and Cothran 1974), cotton (Leigh and Hunter 1969, Whitcomb and Bell 1964, Whitcomb *et al.* 1963), apples (Dondale 1958, Legner and Oatman 1964, Specht and Dondale 1960) and peaches (Herne and Putman 1966, Putman 1967). None of these workers have attempted to examine the impact of the spiders on the pests of the crop. Spider prey data is either lacking or consists of casual observations, and no attempt has been made to compare Ufe cycles of the spiders and pests.

The few studies which have attempted to determine the effect of spiders on pest species are those of Ito *et al.* (1962), Whitcomb (1967), Kiritani *et al.* (1972), Putman (1967) and Mansour *et al.* (1977). Ito *et al.* (1962) showed that insect pest populations on rice increased at a much faster rate in plots treated with insecticides than in untreated plots. This difference was attributed to the destruction of spider populations by the insecticide. Whitcomb (1967) found spiders, particularly *Oxyopes salticus* Hentz, to be effective predators on the second instar bollworms, *Heliothis zea* (Boddie), on cotton. Kiritani *et al.* (1972) discovered that the green leafhopper, *Neophotettix cincticeps* Uhler, and other homopteran pests of rice made up more than half of the diet of the spiders in the rice. Putman (1967) used paper chromatography to detect mite pigments in spiders of peach orchards, and suggested that spiders may have an important role in controlling mites at lower population levels. Mansour *et al.* (1977) showed that spiders, especially *Chiracanthium mildei* Kock, played an important role as natural enemies of *Spodoptera littoralis* (Boisd.) larvae in apple orchards.

Though information on the impact of spiders in agricultural ecosystems is scarce, detailed observations and quantitative data on spider prey have been obtained for spiders in natural ecosystems (Kajak 1965a, 1965b, Robinson and Robinson 1970, Turnbull 1960). In these studies observations were made on what the spiders were eating over a given period of time. Their results indicate that the exact diet of the spiders varies depending on the species of spider and method of capture as well as prey population size and prey behavior. Spiders may exhibit a functional response to prey populations; that is, the proportion of the spider's diet which an individual prey species comprises, increases with an increase in the prey's population. However, the spider's low reproductive rate does not allow the spiders to exhibit a strong numerical response to pest outbreaks. Also, spiders deal with a wide variety of prey and only with experience develop prey-specific capture techniques, leading to an S-shaped functional response curve. Such a response results in an initial lag in predator response to pest outbreaks (Riechert 1974).

Despite weak numerical responses, spiders may show an aggregative response which consists of the movement of predators into areas of increased insect density (Riechert 1974). Such movements can reflect similar reactions of predator and prey populations to some external factor or the movements may be a response to prey numbers. Turnbull (1966) concluded that the spiders in a pasture moved from an area of decreasing prey density to an area of greater prey density because of the gradual desiccation of the plot from which emigration was occurring. However, Riechert (1974) and Turnbull (1964) made observations which demonstrated that spiders are capable of responding to prey stimuli by movement towards areas of increased prey activity. Unfortunately, the aggregate response may not occur at a rate fast enough to check pest outbreaks in agricultural situations. The spider's generalist nature and success in maintaining itself through periods of low insect densities indicates that the spider's role may be as a stabilizing influence in the invertebrate community. This role may be one factor in reducing natural species populations and inhibiting the increase in pest populations during an outbreak until the more specific predators or parasites exhibit a numerical response. Breymeyer (1966) and Kajak (1965a) found spiders to be most abundant and to apply the most pressure on insect prey species just beginning to increase their densities. Though no studies have demonstrated that spiders will dampen increases in pest species in agricultural situations, their presence and feeding behavior indicate that spiders serve as stabilizing agents. Any attempt to develop an integrated pest management program for avocados must determine the role spiders have in the ecosystem. This thesis investigates the spider's role by determining the biology, including behavior, life cycle and prey, of *Neoscona oaxacensis* (Keyserling) in commercial avocado orchards during the 1978-79 season.

MATERIALS AND METHODS

To determine the role of spiders in avocado orchards, spiders and their potential prey were studied in six commercial avocado orchards. These orchards were located in the Fallbrook area of San Diego County (Figure 1).

Primary and Secondary Sites

At two of the six orchards, Atkins Nursery and the Von Essen Ranch, the flying insect and spider populations were monitored and the spider's prey and activity were observed. These two sites, the primary sites, were observed on a regular basis.

Atkins Nursery (3129 Reche Rd., Fallbrook) is located one and a half kilometers east of Interstate 15 and approximately four kilometers north of the intersection of Interstate 15 and State Highway 76. The nursery contains approximately 40 acres of avocados. The study site at the nursery was approximately one acre with 81 avocado trees, mostly of the Fuerte variety, planted six meters from each other in rows six meters apart. This is a mature avocado grove (15 years old) and the trees were three to eight meters in height. The study site was bordered on all sides by a dirt road and then at least 60 meters of avocados. The ground cover was of avocado leaf litter seven to twenty centimeters deep over sandy soil. The trees in this primary site, despite their large size, did not have the canopy typical of older avocado orchards in which branches are seldom seen on the lower two meters of the trunk and the higher branches intermingle between adjacent trees. The study site and surrounding trees were sprinkler irrigated and were not treated with insecticides during the course of this study.

FIGURE 1. Location of study sites.

The second primary site was the Von Essen Ranch (3464 Reche Rd., Fallbrook), approximately one kilometer east of Interstate 15 and four kilometers north of the Interstate 15 and State Highway 76 junction. The site contained 108 trees (84 Hass and 24 Fuerte). This was also a mature orchard, 14 years old with the same type of ground cover as Atkins Nursery. This site was on a ridge running east to west. The north facing slope of the ridge had no canopy but the south facing slope had a typical canopy. This site was also sprinkler irrigated and not treated with insecticides. The north boundary of the Von Essen site was a paved road. To the north of this road were several acres of chaparral. The west side of the plot was bordered by a paved driveway and the William Von Essen residence, which was surrounded by many ornamental plants. The south and east sides of the site were bordered by a dirt road and in both directions avocado trees extended on the other side of the road for at least 100 meters. All the trees in the primary sites were assigned numbers for identification.

The other four commercial avocado orchards, the secondary sites, were sampled on an irregular basis. These four were the Lindberg orchard (6461 La Paloma Lane, San Luis Rey), the Robinson orchard (10489 Camino del Venado, Valley Center), the Krekorian orchard (9511 Circle R Dr., Valley Center) and Atkins Nursery Via Loma (Via Loma Rd., Fallbrook). The secondary sites differed in age and included many avocado varieties. All four are in the Fallbrook area of San Diego County (Figure 1). The secondary sites were observed in the same manner as the primary sites to determine if the observations in the primary plots were typical for avocado orchards in the area. The Krekorian and Via Loma groves were younger (less than 10 years old) and had smaller trees with no canopy. The Robinson and Lindberg groves were older with mature trees and canopies.

Insect Populations

Two methods were used to monitor the flying insect populations. Window traps were employed for the duration of the study to monitor populations of all flying insects and ultraviolet lights were used during the warmer months to supplement the window trap's record of moth populations. Also, Lepidoptera larval populations were surveyed at Von Essen's Ranch by workers from the University of California, Riverside who were investigating Lepidoptera parasites.

The window trap was a clear glass pane (50x75 cm) mounted upright on a wooden frame with the longer sides horizontal and the bottom edge 1.2 m above the ground. Directly under the glass pane a galvanized steel pan (75 cm long; 50 cm wide; and a sloping bottom 7.5 to 12 cm deep) was mounted on the wooden frame. The pan was filled with water and 10 ml of liquid detergent. A mesh-covered outlet near the top of the metal pan allowed excess water to drain without losing insects. Flying insects do not detect the glass and after hitting the pane drop into the fluid-filled pan where they are trapped. The insects were collected from the trap with a fine-mesh nylon net. The water could be emptied through a capped opening at the bottom of the sloping pan and the water was changed weekly during the warmer months and twice a month the rest of the year. After the insects were collected from the window traps they were placed in a labeled jar with alcohol and were later identified. Two of these window traps, spaced approximately 40 m apart, were placed at each primary site. In each orchard one of the two traps was placed in a shady area close to a large tree and the other window trap was placed several meters from the closest tree in an open area. The four window traps were labeled A, B, C and D. Traps A and D were the traps in clearings at Atkins' and Von Essen's, respectively. Traps B and C were the shaded traps at Atkins' and Von Essen's, respectively. Window traps were selected and used instead of other insect population monitoring devices, such as sticky traps, for three reasons: they were easier to maintain, trapped large as well as small insects and like a spider's orb were nearly invisible to the flying insects. The possibility of wind affecting the efficiency of the window traps (Chapman and Kinghorn 1955, Juillet 1963) was not a problem due to the shielding effect of the surrounding trees.

To monitor the moth populations even more accurately ultraviolet collecting lights were employed. A permanent collecting light set-up was used at Von Essen's and a portable unit was used at Atkins Nursery.

The collecting light at Von Essen's ("Luralight", Onamia Manufacturing, Inc.) was a circular ultraviolet light bulb (G.E. FC12T10-BL) with an incandescent 100 watt bulb in the center. Behind the bulbs was a hollow metal tube (20 cm diameter) with a fan blade in it. When the unit was running the insects attracted to the light were sucked in by the fan and blown into a water filled bucket where they were killed. This set-up was run for three consecutive days per week for four hours each night. The light was hooked up to a timer and set to start the four hour collecting period one half hour after sunset. The light was run weekly from April through August, when the moth populations were largest.

At Atkins Nursery a portable collecting light (BioQuip, Series 2800 Collecting Light) was used. This was a straight ultraviolet light (15 watt) which was run from an automobile 12 volt battery. The light was run for three hours per night starting a half hour after *dusk.* With the light placed against a white sheet tied vertically to the side of the car, insects which were attracted to the light would then be collected by hand.

Spider Biology

The data on the spider's prey and activity was collected by direct visual observations. Although time consuming, this was the most direct and accurate method. Kajak (1965a, 1965b), Turnbull (1960), and Robinson and Robinson (1970) also used this method and found it to be the most accurate for determining numbers and size of spider prey. The most abundant spider during this study was an orb weaver, family Araneidae. This spider eats its prey in the hub of its orb. The spider and its prey may be easily observed during the approximate two hours it takes the spider to complete the meal on an average size insect. Also facilitating visual observation is the poor eyesight of this spider which allows observation of it and its prey at very close range without disturbance. Araneid spiders normally do not physically damage the external cuticle of the prey. The normal feeding method of araneids is to puncture the body of the insect with their weak fangs and then feed by alternating injections of digestive fluid and sucking up the digested tissues, until only the empty shell remains. From this empty shell the meal may be identified even after the meal is completed. The araneid spider often wraps its prey in silk before feeding and after the meal the spider drops the wrapped carcass to the ground. However, if the spider has several prey items in the orb at once or if the spider is disturbed, the wrapped carcass is not cut loose and may be observed several hours after the meal has been completed. Small, soft prey is not wrapped in silk and is soon destroyed by even the weak jaws of the araneids, making identification difficult.

The prey census was taken at Atkins Nursery and Von Essen's Ranch every two weeks from November, 1978, to the end of February, 1979, after which the census was taken weekly until the end of September, 1979, when sampling every two weeks was resumed until October, 1979, when sampling was terminated. A census involved randomly selecting (using a table of random numbers) ten of the numbered trees in each study plot and observing the prey found in the orbs on the trees. Each tree was sampled by working around the outside of the tree and then, if space allowed, around the inside of the tree, allowing as many of the spiders as possible to be observed. In making the census, the captured prey was not removed or the spider disturbed. The prey was carefully examined in the orb and a taxonomic determination was made to the lowest taxon possible (usually to the family level). Using a small metric ruler the length of the prey was measured without touching the orb. In this manner the prey in all the orbs from ground level to two and a half meters in height was recorded.

In addition to the prey in the orbs, the species of spider, number of spiders per tree, size of the spiders, sex of the spiders (if possible), height of the orb from the ground, diameter of the orb, condition of the orb and activity of the spiders was recorded.

The number of spiders per tree was determined by adding up the total number encountered at each tree. Spiders which had orbs spanning two trees were counted as one half of a spider for each tree.

The length of the spider from the front of the cephalothorax to the back of the abdomen was determined by holding a ruler behind the spider in its web. The length was measured to the nearest millimeter except in the case of spiders less than three millimeters, which were measured to the nearest 0.25 millimeter.

The height of the orb from the ground to the hub of the orb was measured to the closest centimeter using myself as a metric ruler. By measuring the height of anatomical landmarks on the body (e. g. knee or waist) the observer could stand next to the orb and determine its height above ground level. Only orbs lower than two and a half meters were observed and measured.

The diameter of the orb was measured using a metric ruler. Most of the orbs were symmetrical and the diameter was measured across the horizontal axis of the orb. If the orb was asymmetrical, both vertical and horizontal measurements were made and then averaged. The condition of the orb was also noted. Characteristics such as general appearance, completeness, damage, whether or not the orb was being repaired, and where the spider was located were recorded. The orb was considered to be complete and recorded as in "excellent" condition if at least 90 per cent of the orb structure was intact. Otherwise the completeness was recorded as greater or less than 50 per cent whole (recorded as "good" and "poor" condition, respectively). If the spider was hanging from a branch or trunk without an orb or in a leaf retreat without an orb, the completeness was noted as "no orb."

The activity of the spiders fell into one of six categories: feeding, hunting, resting, web constructing, hanging and, rarely, mating. A feeding spider was defined as any spider in the process of wrapping, biting or feeding on a prey item. A hunting spider was defined as a spider hanging upside down in the hub of the orb. A resting spider was defined as a spider, with or without an orb, found in a retreat. The retreats were of two kinds: those formed from leaves or those in hollows in the bark of the trunk or branches. The activity of web constructing was defined as a spider destroying an old orb, constructing a new orb or repairing an existing orb. A hanging spider was one which was dangling on a silk thread from a branch or trunk. A mating spider was defined as either a female spider copulating or otherwise interacting with a mature male spider in her orb, or a male spider copulating or waiting for the female at the edge of a female's orb.

The observations of the spiders and their prey were made both during daylight hours and after sunset. During the observations made in the dark, a flashlight was used to illuminate the spiders and their prey. The light did not appear to affect the spider's behavior. However, the light tended to attract moths and other night flying insects and the light could only be used sporadically when close to an orb or the attracted insects became entangled in the orb and made the condition and activity of the spider difficult to determine.

During the search of 10 trees for the above data, any spiders other than the orb weavers were also observed. Their size, activity and prey were recorded.

RESULTS AND DISCUSSION

Neoscona Biology Studies

During the summer and autumn of 1978, preliminary observations were made of several avocado groves in the Fallbrook area of San Diego County. These observations revealed that the dominant invertebrate predator in the avocado groves was an orb weaving spider (Araneae: Araneidae). To determine the species, mature males and females were collected the following year (1979) and keyed to species with the key in Herman and Levi (1971). Fifteen mature spiders were collected from each primary site. All the spiders collected were determined to be *Neoscona oaxacensis* (Keyserling). All the Araneidae from the secondary sites were this same species. *Neoscona oaxacensis* populations were studied through 1979 in both primary and secondary sites.

Neoscona oaxacensis did not overwinter in the adult stage. Instead, the next year's generation overwintered in the egg stage in egg sacs hung by the mature females in the foliage of the avocado trees in late September or October. The spiderlings began to appear in the avocado trees during the beginning of March, 1979 (Figure 2). The spiderlings were still emerging as late as the end of April. There is only one generation per year and the spiders present at any time during the year are all of the same generation, except for an occasional overwintering female seen in the spring.

The average number of *Neoscona* per tree increased through April but began a decline in May which did not end until the winter when, with few exceptions, the *Neoscona* populations disappeared. Thus, araneids were absent from the study sites from the middle of November, 1978, to the beginning of March, 1979. During the winter the populations did not completely die out, as an occasional mature female was spotted in avocado trees bordering the study sites. The spiders apparently die due to climatic conditions or old age. No parasitism of the spiders was observed and predation (by a sphecid wasp) on the spiders was observed only once. Figure 2 shows that throughout 1979 the average *Neoscona* per tree was much lower at Atkins Nursery than at the Von Essen site. This was due to a combination of factors. The first factor was that *Neoscona* are more common near the edges of the groves or in open, uncanopied areas. This is due to the greater abundance of transient flying insects providing more prey. Thus, the north face of the Van Essen site, being uncanopied and facing chaparral had a higher spider population than the south facing slope at Von Essen's, Atkin's site or any of the secondary sites throughout the study. The spiderlings were slower to emerge at Atkins Nursery (Figure 2). During the last two weeks in April the trees at the Atkins study site were pruned. This resulted in a decline in the number of spiders in the study site at a time when the populations were becoming established in the other sites. The *Neoscona* populations at Atkins study site did not recover until August, 1979, at which point it closely matched the Von Essen population. Orchards pruned are therefore apparently without the impact of spider predation until late in the year. The increase in the *Neoscona* population at Atkins study site seen from May, 1979, to August, 1979, was probably due to an influx of spiders from the trees surrounding the study site as the avocado trees surrounding the study site were not trimmed and spider populations not disturbed. This is an indication that larger araneids, and not just dispersing spiderlings, may have the potential to move to an area where prey is available.

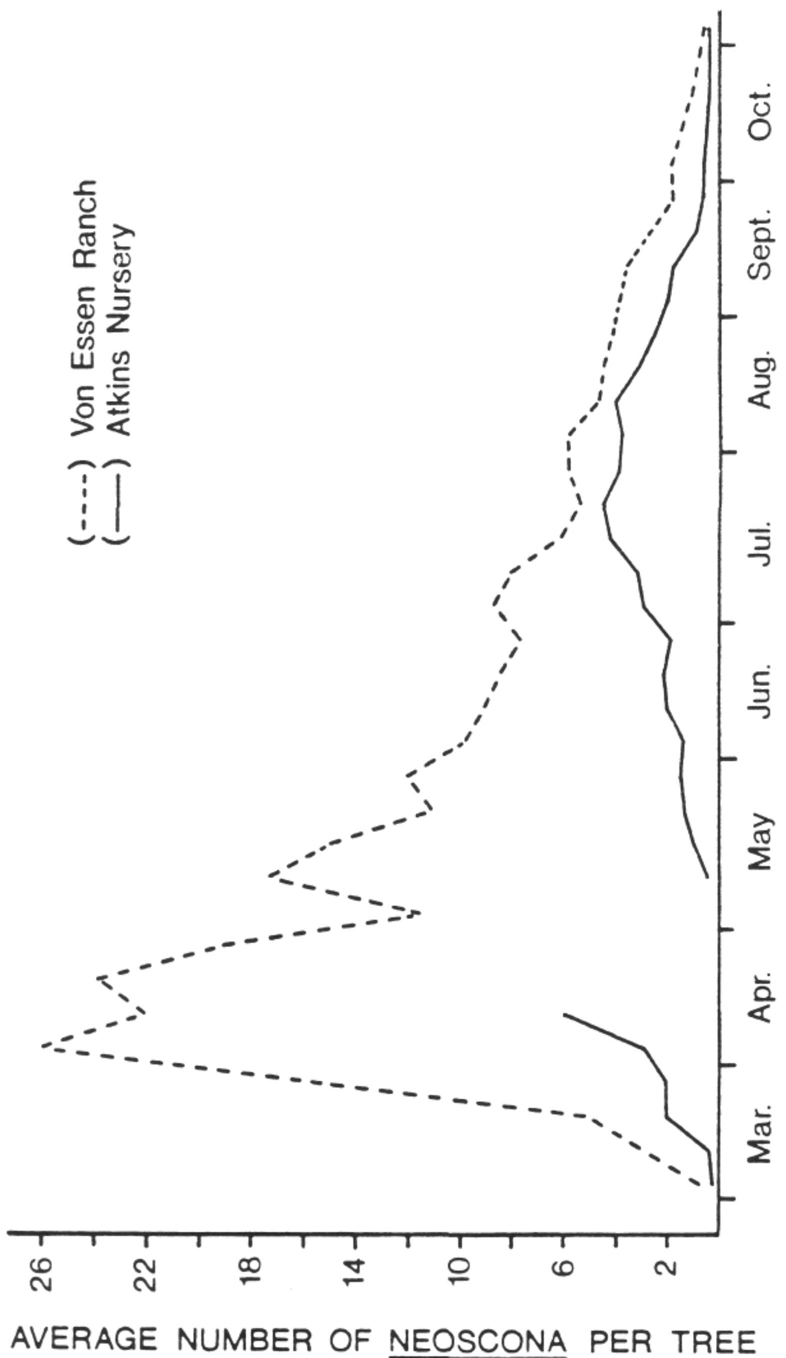

FIGURE 2. Average number of Neoscona oaxacensis per tree at the Von Essen Ranch and Atkins Nursery, Fallbrook, San Diego Co., California, in 1979.

The spiders increased in size throughout the summer and matured in the early autumn (Figures 3 and 4). Sexually mature *Neoscona* were observed from the end of August through October when the study was concluded. The male *Neoscona* at maturity are smaller than the females, being 12-15 mm in length and the mature females were 14-17 mm in length. The males matured first, usually by the beginning of September, at which time they wander in search of females. During this time mature males are often found without orbs of their own. When the male comes to an orb of a female he plucks the female's orb in an attempt to get her attention (Gertsch 1979). In this way he avoids becoming a meal for the female. If his attempts are successful, mating occurs in the female's orb. The matings observed were all in September. It was not unusual during late August and through September to see one and sometimes two mature males waiting at the edge of an immature female's orb, apparently waiting for the female to molt to maturity *so* they might mate.

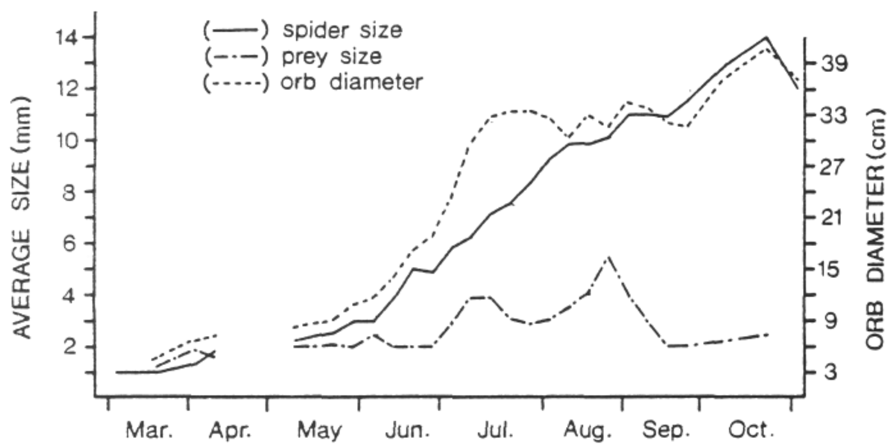

FIGURE 3. Average Neoscona oaxacensis size, prey size and orb diameter at Atkins Nursery, Fallbrook, San Diego Co., California, in 1979.

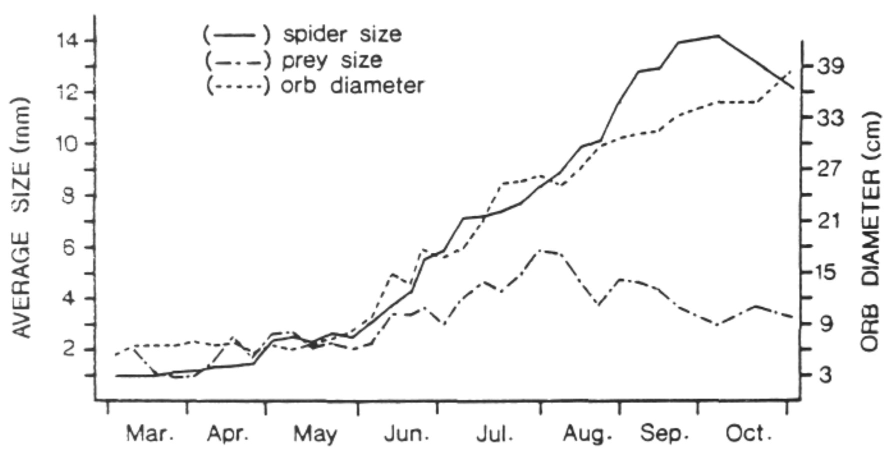

FIGURE 4. Average Neoscona oaxacensis size, prey size and orb diameter at the Von Essen Ranch, Fallbrook, San Diego Co., California, in 1979.

As the average size of the *Neoscona* increased from March through October, the average size of the orbs also increased (Figures 3 and 4). The average size of prey caught also increased slightly but leveled off in July and August.

As the *Neoscona* increased in size the average height of their orbs did not change greatly (1.3-1.7 meters). The height of the orbs was, however, influenced by the structure of the trees in the groves. In the younger, uncanopied trees, with branches near ground level, the young spiders were often found close to ground level. In the mature trees with a canopy, the younger spiders (1-4 mm) were seldom found close to the ground. The small orbs of the younger *Neoscona* were not large enough to span the branchless areas. As the spiders matured and built larger orbs they were able to produce orbs of sufficient size to reach from the ground to the branches of even the canopied trees. On the canopied south side of the Von Essen study site the *Neoscona* were not very common (less than three per tree) until July, when the spiders were spinning much larger orbs.

Daily activity patterns of *Neoscona* are presented in Figures 5 and 6. The spiders repair their orbs at any time during the day, though the most active periods of repair are in the early morning and evening. Climatic conditions may influence this pattern as cold, damp mornings lead to inactive spiders, causing postponement of the repair. Also, often the morning dew covers the orbs making repair difficult. On cool overcast afternoons the spiders often construct new orbs early. Exactly what stimulates the spiders to construct a new orb was not determined, but it appears not to be solely the condition of the orb in which the spider is hanging, as *Neoscona* were seen hunting in orbs which were nothing more than a single thick silk strand.

If the *Neoscona* were not repairing their orbs, they were usually hunting or feeding. When hunting, the spiders hang upside down in the hub of the orb with their legs outstretched. When prey becomes trapped in the orb, the spider senses the vibrations and can locate the prey through the vibrations. Once the prey is located araneid spiders use different sequences of behavior to subdue the prey depending on the type and size of the prey (Robinson and Robinson 1970). The most active feeding time for the spiders is between dusk and midnight. Thus, night flying insects are favorite prey items.

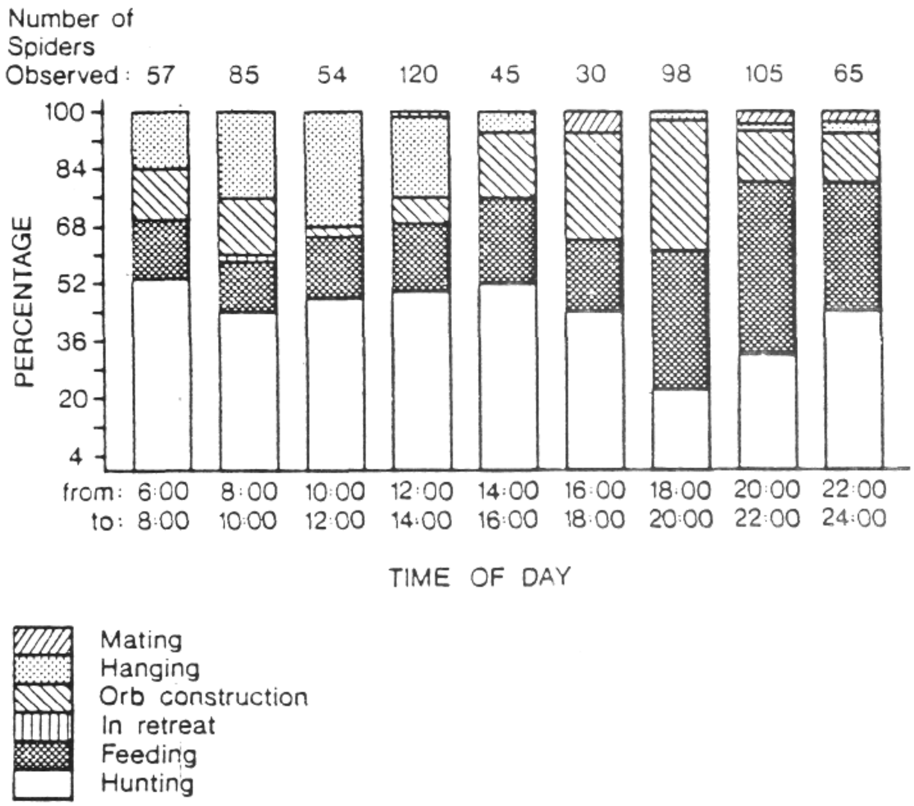

FIGURE 5. Neoscona oaxacensis daily activity pattern at Atkins Nursery, Fallbrook, San Diego Co., California.

Mornings and middays are the peak times for hanging. Hanging, like mating, is an age-limited activity. Hanging is most common when the *Neoscona* are less than five mm and seldom occurs in older spiders until maturity when some males were observed to hang (Figures 7 and 8). Hanging from the end of an attached silk thread is done for one of three reasons. The first is the spider may be knocked off its orb and it hangs momentarily from a silk thread before pulling itself up to the orb again. Araneids also use a line to pull themselves back to the orb when they drop from the orb after being disturbed. Being knocked off the orb may happen to any age spider (and did not appear to be the main cause of the hanging). The second reason for hanging is that the spider is attempting to disperse. A normal behavior for Araneidae and other families of spiders is to let out long threads of silk in the breeze and be carried away on the breeze. This is termed "ballooning." However, the hanging behavior observed in this study was unlike ballooning. The spiders were observed to be suspended at the end of an attached silk thread rather than remaining attached to the substrate and feeding out silk into the breeze. By hanging from a silk thread, the spiders may still disperse to different areas and levels of an avocado tree and even to different trees within the orchard. This is a good technique for limited dispersal as Araneidae have poor locomotor ability when not in their orb. If dispersal was the main reason for hanging, one would expect to see hanging more frequently in newly emerged spiders. These young spiders must disperse to avoid cannibalism. Figure 7 illustrates that it was the younger, smaller spiders which did most of the hanging. The slight increase in number of hanging spiders in August is due to mature males wandering in search of females. A third possible explanation for the hanging is predator avoidance. However, the only animal observed preying on a *Neoscona* spider was a sphecid wasp, seen once at Lindberg's, which attacked and carried off a medium size (8-9 mm) *Neoscona. Neoscona* also hang from a short line while molting but this behavior differs from hanging as described above in the line being shorter and the spider remaining immobile for long periods of time.

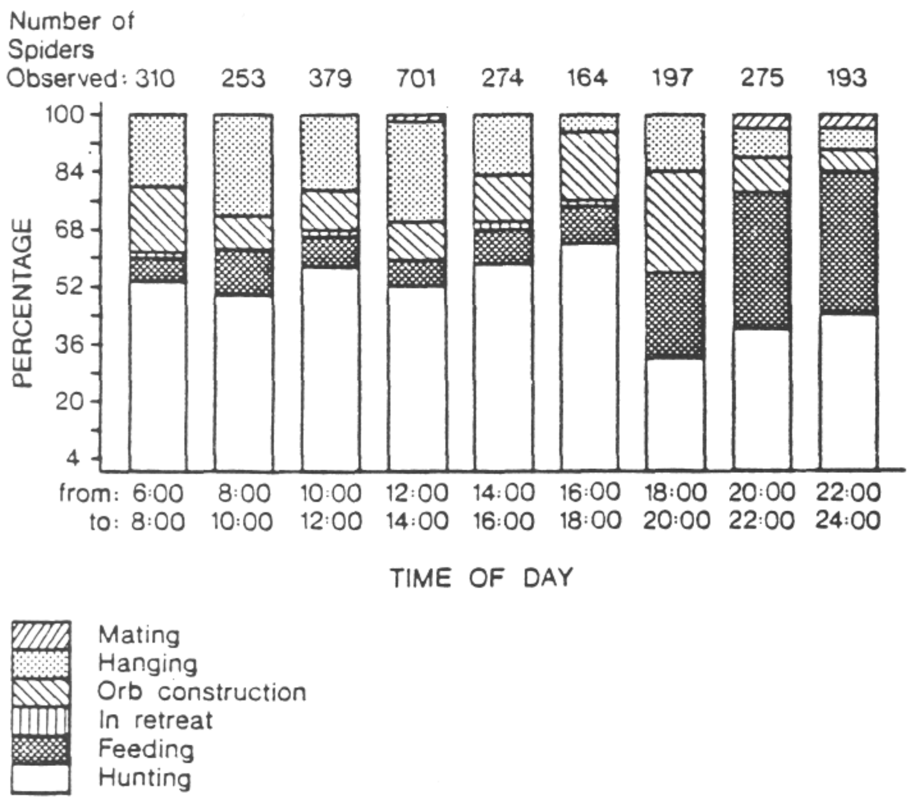

FIGURE 6. Neoscona oaxacensis daily activity pattern at the Von Essen Ranch, Fallbrook, San Diego Co., California.

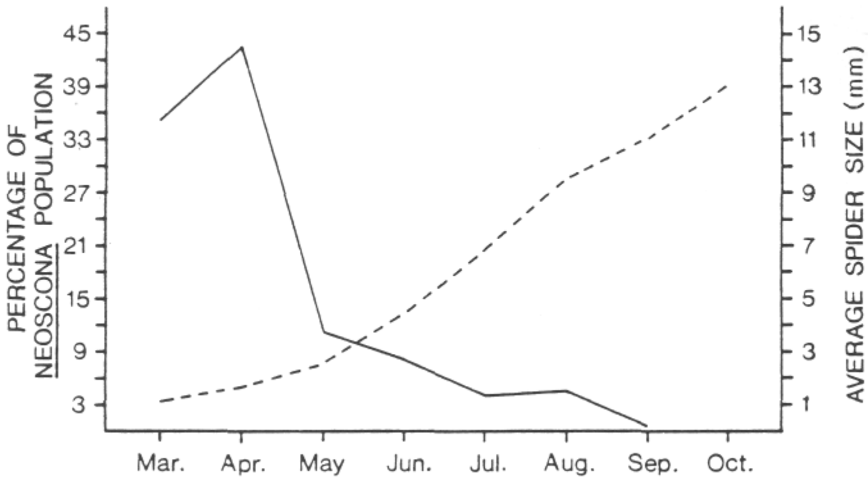

FIGURE 7. Average monthly Neoscona oaxacensis size and average monthly percentage of the population "hanging" at Atkins Nursery, Fallbrook, San Diego Co., California, 1979.

(——) percentage of population "hanging"
(- - -) average Neoscona size

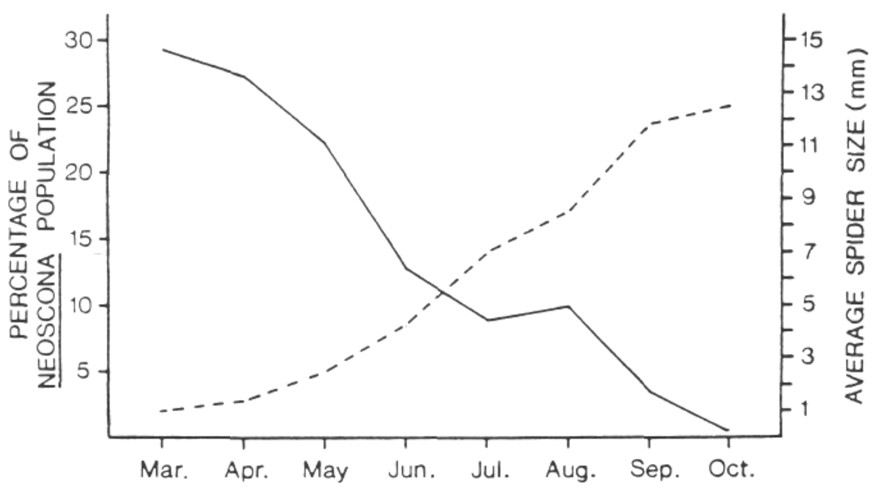

FIGURE 8. Average monthly Neoscona oaxacensis size and average monthly percentage of the population "hanging" at the Von Essen Ranch, Fallbrook, San Diego Co., California, 1979.

Neoscona do not spend much time in a retreat. The few times *Neoscona* were observed in a retreat, it was during extreme climatic conditions, such as the warm part of a hot day or an early morning when the web was nonfunctional as a result of a heavy dew. In the retreat the *Neoscona* maintain contact with their orb by several silk strands which run from the spider to the hub of the orb. These lines allow the spider to sense and respond to prey vibrations in the orb.

Mating was most common in the evenings and at night (Figures 5 and 6), though males were observed at the edge of the female's orb in the mornings and afternoons. In the latter case it was usually mature males waiting for an immature female to molt to maturity.

As expected from the spiders' daily activity patterns (early morning and early evening active periods for orb reconstruction), the most fresh webs are found in the later morning and evening (Figures 9 and 10). The number of orbs in poor condition are large at midday but dramatically decrease after sunset. The *Neoscona* with no orb, either hanging or rarely in a retreat without an orb, are again most common at midday and less prevalent in the evening and night. Thus, *Neoscona* seem especially adapted to catch evening-flying prey.

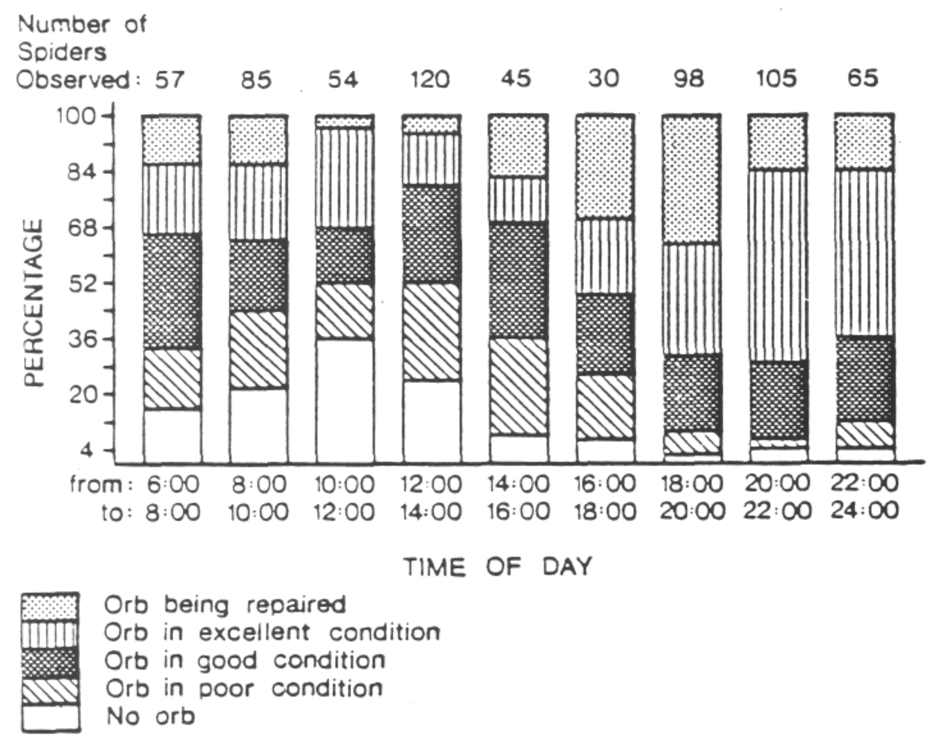

FIGURE 9. Daily orb condition of Neoscona oaxacensis at Atkins Nursery, Fallbrook, San Diego Co., California.

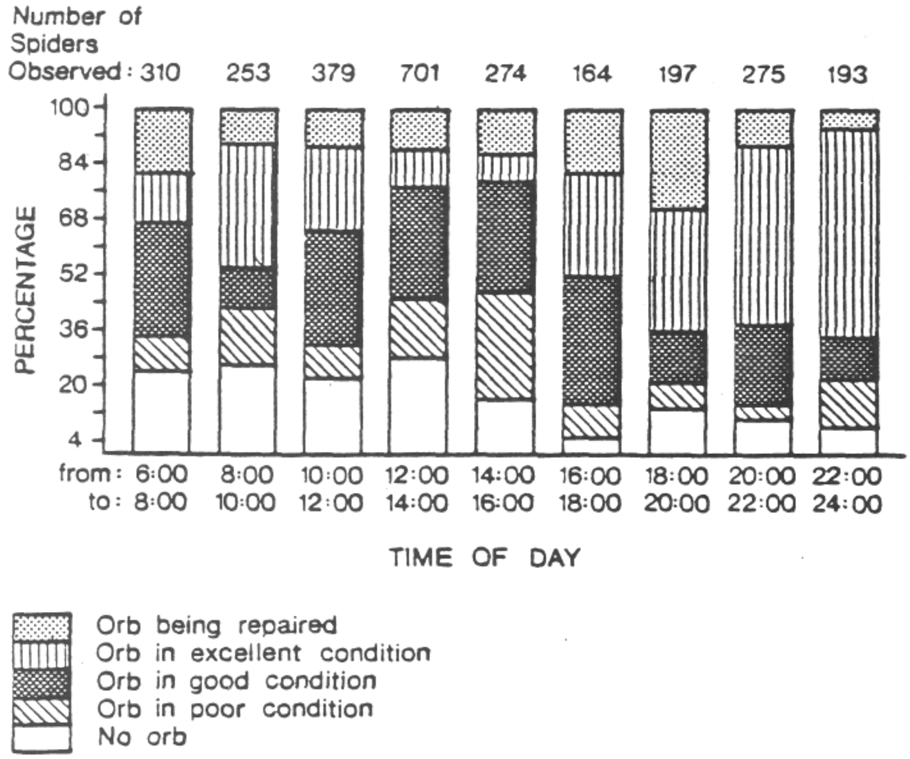

FIGURE 10. Daily orb condition of Neoscona oaxacensis at the Von Essen Ranch, Fallbrook, San Diego Co., California.

Insect Populations and Spider Prey

The window and blacklight traps indicated a diversity of insect populations in the primary sites during the study (Appendix A; Tables 13). The window traps proved especially effective for Coleóptera, Lepidoptera, Diptera and Hymenoptera. Even the small (1-3 mm) insects of the heavier bodied type (Coleóptera and Hymenoptera) were trapped in large quantities. Large numbers of microdiptera were also trapped. However, this was a passive trap (as are the *Neoscona* orbs) and did not attract insects which resulted in relatively low numbers of some groups (e. g. Lepidoptera). The ultraviolet light is an attractant for moths and other night-flying insects which were caught in high numbers (Appendix; Tables 5 and 6).

Neoscona appears to feed more upon night-flying insects (Figures 11 and 12). Night-flying Psocoptera and Coleóptera were preyed upon at a much higher frequency than would be expected from their population size. Psocoptera were common inhabitants in both the primary and secondary sites, living in the litter. Unfortunately, because of their small size and weak flight the window trap probably did not accurately monitor the population. Figures 13 and 14 show some correlation between the Psocoptera population and the portion of the *Neoscona* prey the Psocoptera comprise. Though the Psocoptera population size was probably not accurately monitored by the window trap, it is obvious that Psocoptera are a significant portion of the *Neoscona* diet. There is no correlation between spider size and ability to catch the Psocoptera (Figure 15).

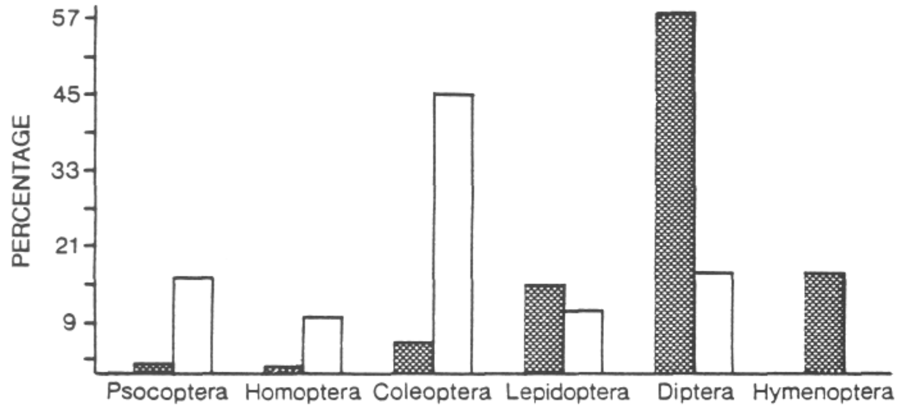

FIGURE 11. Percentage of each order of insect in the window trapcatch and Neoscona oaxacensis prey at Atkins Nursery, Fallbrook, San Diego Co., California.

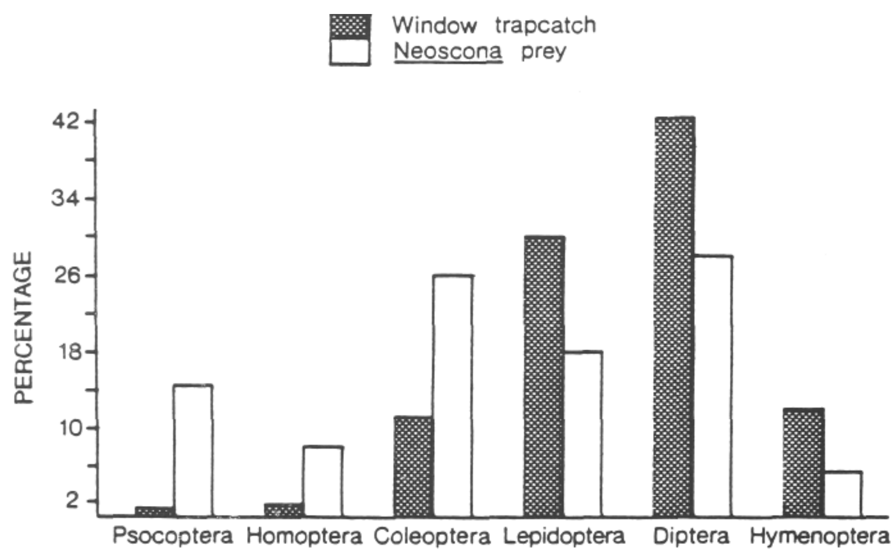

FIGURE 12. Percentage of each order of insect in the window trapcatch and Neoscona oaxacensis prey at the Von Essen Ranch, Fallbrook, San Diego Co., California.

The Coleóptera populations in the primary sites were composed principally of Staphylinidae, Nitidulidae, Coccinellidae, Curculionidae and Silphidae. The first four are all tiny beetles (less than 6 mm), but the Silphidae were 20-28 mm in length. Silphidae were never taken, and Coccinellidae were seldom taken, by the *Neoscona,* Nitidulidae, Curculionidae and occasionally Staphylinidae comprised the Coleóptera portion of the spiders' diet (Figures 16 and 17). The larger spiders appear better able to capture Coleóptera (Figure 15). This may be due to orb location, as the larger orbs span open flight paths used by the less accurate fliers. At one of the secondary sites (Robinson), Elateridae made a significant portion of the spiders' diet in September.

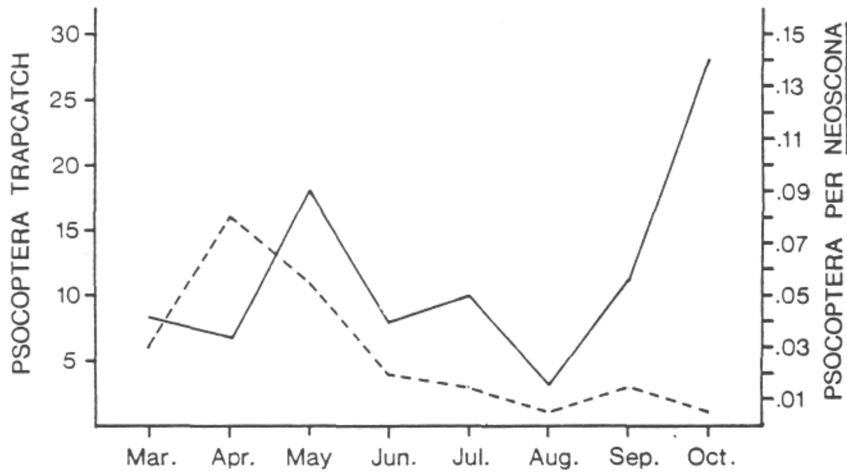

FIGURE 13. Pscocoptera monthly trapcatch and Neoscona oaxacensis predation on Psocoptera at Atkins Nursery, Fallbrook, San Diego Co., California, 1979.

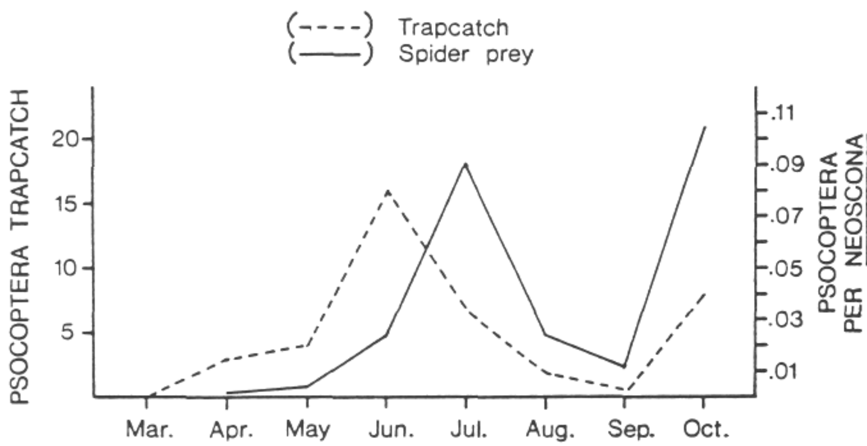

FIGURE 14. Psocoptera monthly trapcatch and Neoscona oaxacensis predation on Psocoptera at the Von Essen Ranch, Fallbrook, San Diego Co., California, 1979.

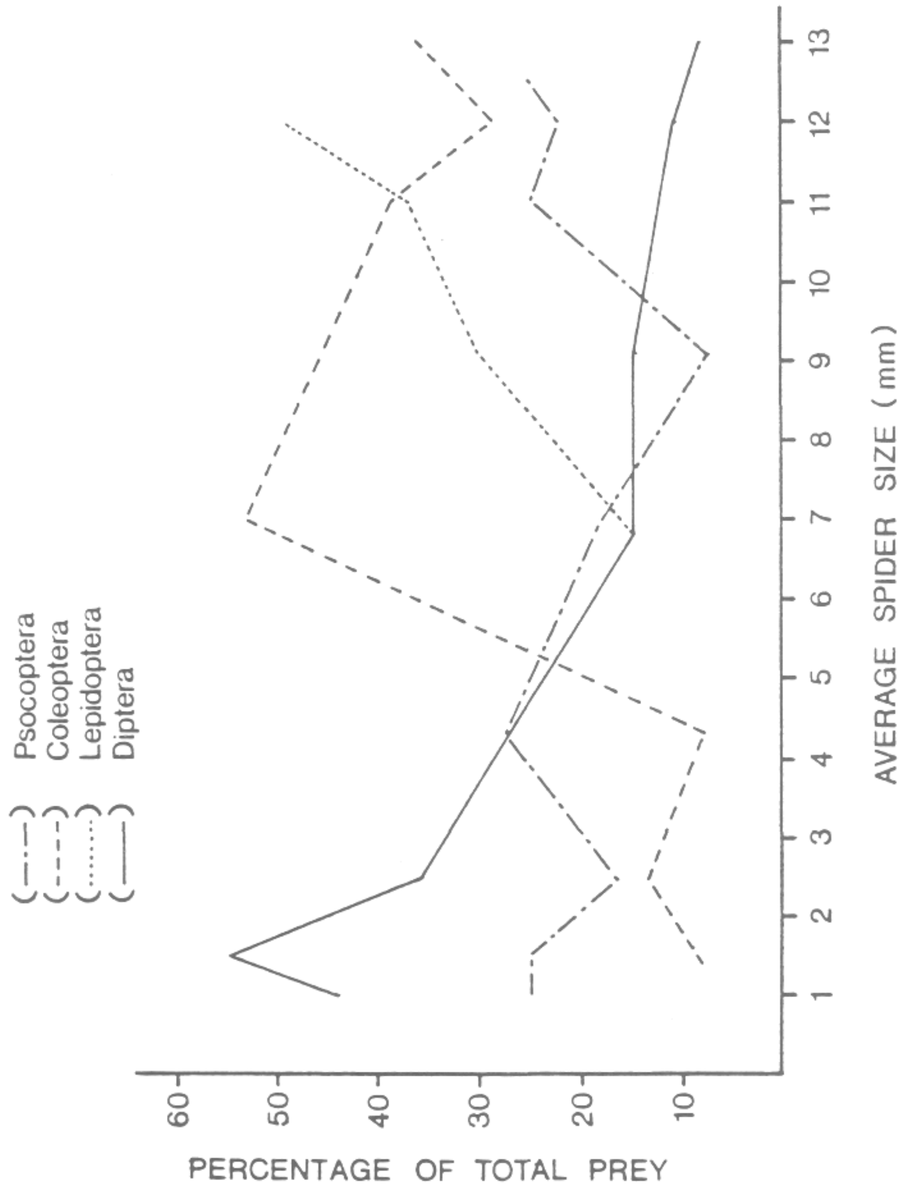

FIGURE 15. Comparison between common prey groups and size of Neoscona oaxacensis from Atkins Nursery and the Von Essen Ranch, Fallbrook, San Diego Co., California.

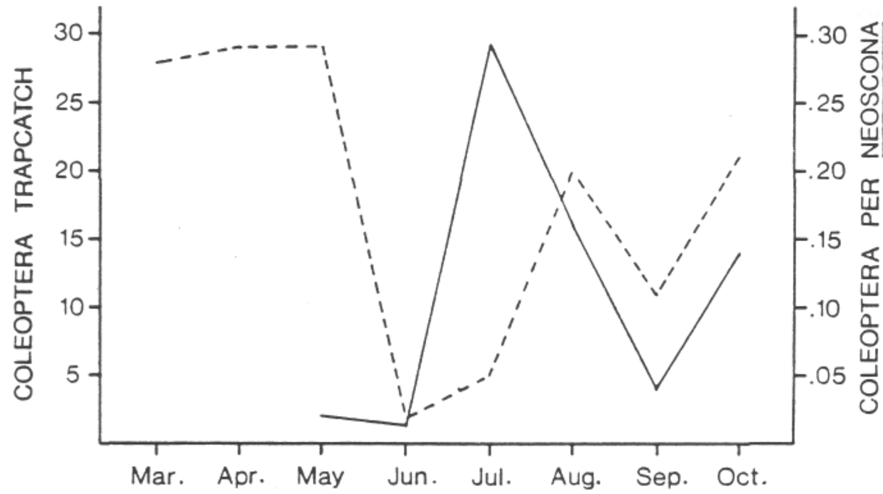

FIGURE 16. Coleoptera monthly trapcatch and Neoscona oaxacensis predation on Coleoptera at Atkins Nursery, Fallbrook, San Diego Co., California, 1979.

(- - - -) Trapcatch
(———) Spider prey

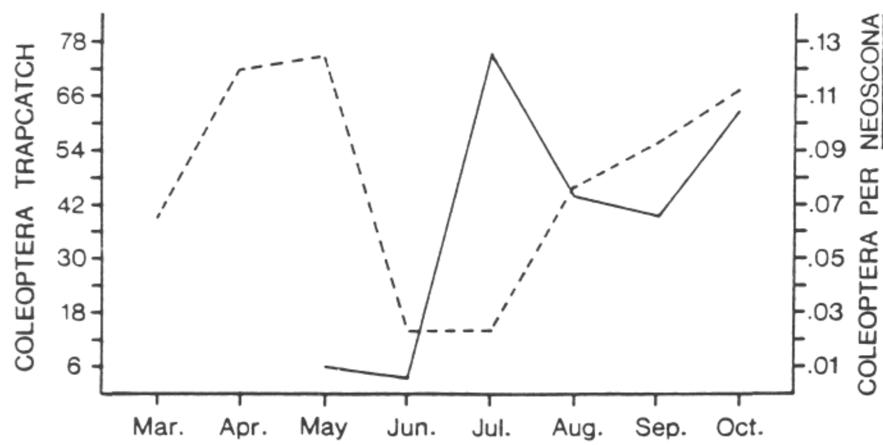

FIGURE 17. Coleoptera monthly trapcatch and Neoscona oaxacensis predation on Coleoptera at the Von Essen Ranch, Fallbrook, San Diego Co., California, 1979.

Diptera and Hymenoptera, both primarily day-flyers, were much smaller parts of the total prey than they were parts of the total of the flying insect populations (Figures 11 and 12). The Diptera populations in the primary sites were composed mainly of microdiptera, though Muscidae, Tachinidae and Calliphoridae were also common, along with a great variety of less common families (Appendix; Tables 1 and 2). The high Diptera population in March through May (Figures 18 and 19) was composed primarily of microdiptera. The apparent decrease in ability of larger spiders to capture flies is probably due to the scarcity of flies later in the summer when the spiders are larger.

The Homoptera (mostly day-flying aphids) were trapped by the spiders more often than the aphid's population size would cause one to expect. This may have been due to window trap inefficiency in trapping smaller, lighter insects, such as aphids.

For night-flying Lepidoptera, there was less predation than the population size would indicate (Figures 11 and 12). The small Lepidoptera representation in the prey sampling is probably due to the fact that lepidopterans, by virtue of their wing scales, are able to escape rather easily from the *Neoscona* webs (Eisner *et al.* 1964).

During the study there were very few lepidopteran pests in the primary sites. Dr. McMurtry at the University of California, Riverside, working on lepidopteran pest parasites, noted that even the larval populations of omnivorous looper and amorbia moth were very low during 1979 (McMurtry 1979). In the primary study sites there were two lepidopteran population peaks in 1979, both due mainly to Tineidae. It was only during the latter peak in which the spiders were observed preying upon the Tineidae (Figures 20 and 21). There are three possible explanations for the lack of spider predation on the moths early in the year. One is that as the spiders mature, they gain in strength and agility and can react faster to the moth hitting the orb. The second is, as Tumbull (1960) has observed, that with increasing frequency of exposure to a prey species the spiders get Tietter at capturing it. Perhaps it is only after the orbs are large enough, late in the summer, to be hit regularly by the moths that the spider develops the fast reaction necessary to feed successfully on lepidopterans before they escape. The third alternative is that the spiders and their orbs are not large enough to hold even the smaller Tineidae during the early months of the summer. The scales on the wings and body of Lepidoptera come off very easily. Thus, when the moth hits the orb, the moth struggles and rolls down the orb, losing scales. The sticky threads of the orb become covered with scales and are no longer adhesive, allowing the moth to fly free. Such silk-laden threads ("moth scars") were often encountered at night on the *Neoscona,* orbs in the avocado orchards. In a smaller orb, the moth would easily roll off the orb and be only momentarily detained before flying off. But in a larger orb, enough scales might be lost so the moth might eventually stick to the orb long enough for the spider to capture it. On five occasions, the use of the flashlight at night attracted moths to the orbs being observed. On four out of the five occasions, the moths hit and slid 5-10 cm and escaped or merely bounced off. However, on one occasion the moth slid 12 cm, leaving a 12 cm moth scar, and stopped in the orb. The *Neoscona* spider captured the moth immediately. If these limited observations are an indication of the normal events, then the successful capture of even small moths would require an orb of a minimum of approximately 12 cm. The average size of a *Neoscona* orb did not approach 12 cm until the end of June, by which time the first peak of the Lepidoptera population was over. For successful capture of omnivorous looper moths, the spiders would require an even larger orb.

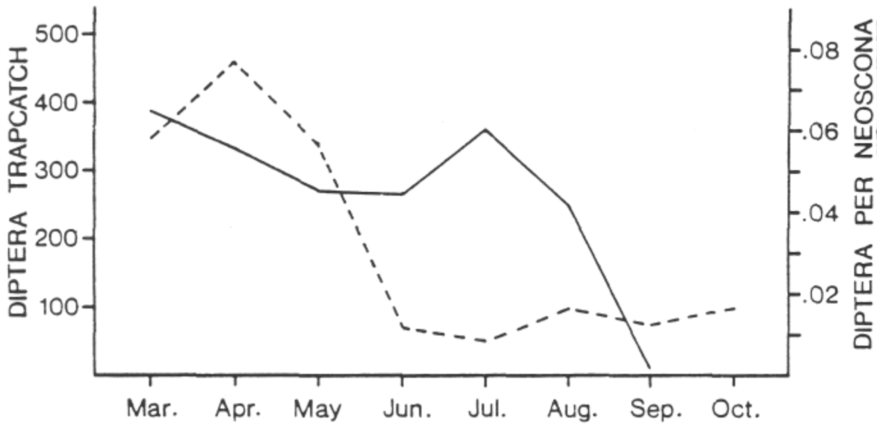

FIGURE 18. Diptera monthly trapcatch and Neoscona oaxacensis predation on Diptera at Atkins Nursery, Fallbrook, San Diego Co., California, 1979.

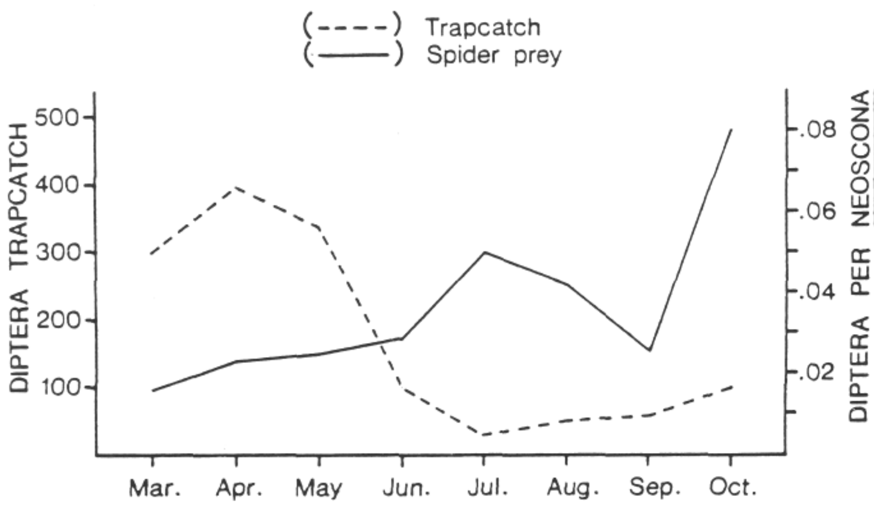

FIGURE 19. Diptera monthly trapcatch and Neoscona oaxacensis predation on Diptera at the Von Essen Ranch, Fallbrook, San Diego Co., California, 1979.

During 1979, not a single amorbia or omnivorous looper moth or larva was ever found in a *Neoscona* orb. However, in July, 1978, when the looper populations were much higher than during 1979, an omnivorous looper moth was observed in the orb of a large *Neoscona* (11 cm in length; orb diameter was 35 cm). On five other occasions during July and August of 1978, large looper larvae (3-4 cm) were observed in the orbs of *Neoscona.* The capture of the larvae required many bites (8-12) to inject venom and nearly fifteen minutes to subdue the struggling larvae. In all five cases the larvae were eventually subdued and eaten. The lack of looper moth and larvae prey during 1979 was due to the low population levels at the primary and secondary sites. The population levels were especially low during the late summer and early autumn when the *Neoscona* are large enough to successfully capture them.

Importance of *Neoscona oaxacensis* as a Natural Enemy of Lepidoptera Pests

In the absence of large lepidopteran populations, the spiders fed mainly on harmless species of moths, beetles and flies which are either casual entrants into the orchard or which are living in the decaying material in the avocado leaf litter. The orb weaver's ability feed and survive on these on these non-pest insects insures the growth and survival of the spiders so that they will be in residence in the orchards in the event that large pest populations develop. The impact of spiders on large populations of Lepidoptera pests would be evaluated more thoroughly in a year of much higher pest populations.

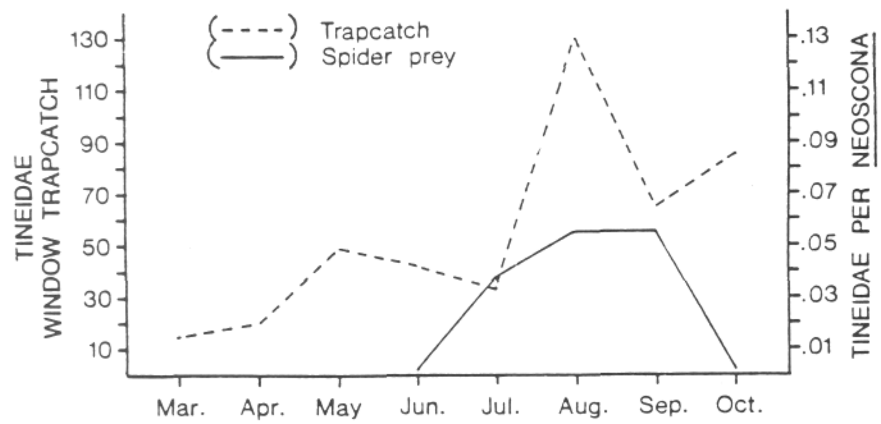

FIGURE 20. Tineidae monthly trapcatch and Neoscona oaxacensis predation on Tineidae at Atkins Nursery, Fallbrook, San Diego Co., California, 1979.

Adult Lepidoptera find it relatively easy to escape from the araneid orbs. However, the Lepidoptera (specifically the Tineidae, which probably inhabit the leaf litter) were a significant portion of the prey taken by the spiders. Eisner *et al.* (1964) observed that smaller moths are more likely to escape than the larger moths. The smaller moths contact fewer sticky threads than the larger moths and may escape with less effort. The smaller moths may even pass through the orb of a large araneid which has wider spaces between its threads. Thus, the loopers, which are much larger than the Tineidae moths (2 cm vs. 8 mm), may actually be easier for the spiders to trap in their orbs.

If the spiders are effective predators, preying significantly on the lepidopteran pests, it is only at higher population levels and only during the later part of the season. At the low population levels of the pests during 1979, omnivorous looper and amorbia moths were never observed being preyed upon by *Neoscona.* If the orb weavers do take many Lepidoptera pests as prey at higher pest population levels, it is not until later in the year when the spiders and their orbs are large enough to capture the moths. Dr. Blair Bailey and Michael Hoffman (Bailey and Hoffman 1979) sampled loopers with a blacklight at the Lindberg orchard (Figure 1) during 1978 and 1979. Their sampling showed high looper populations in May and June with much lower peaks in August and October.

Thus it may be concluded that the significance of the orb weaving *Neoscona* in avocado orchards is probably not that they prevent dramatic population increases in the pest population or control the pests through the year. Instead, the presence of spiders, even in years of low pest populations, may dampen the increases in pest species during the later months of the season and serve as stabilizing agents to restrain the pest outbreaks during the interval between pest population increases and the numerical response of more specific parasites.

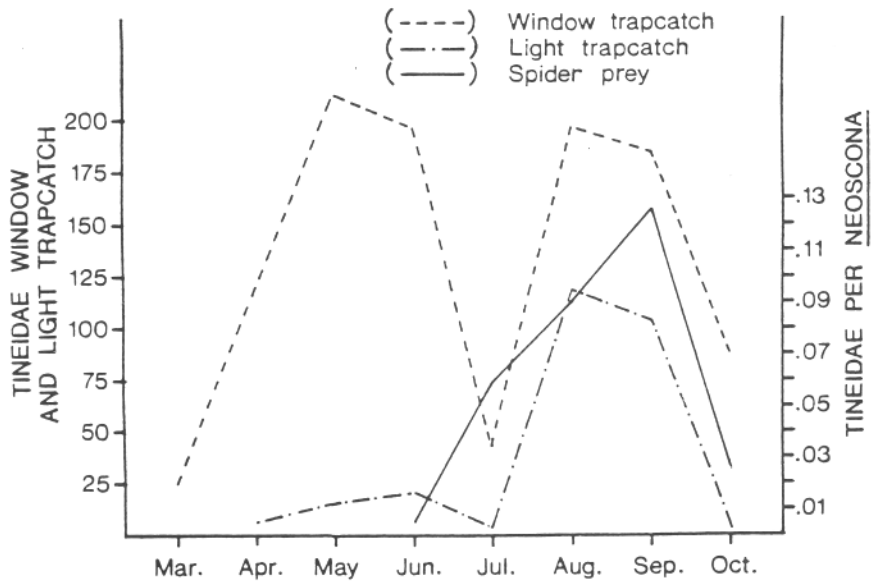

FIGURE 21. Tineidae monthly window and light trapcatch and Neoscona oaxacensis predation on Tineidae at the Von Essen Ranch, Fallbrook, San Diego Co., California, 1979.

TABLE 1. Spider fauna of avocado trees (other than **Neoscona oaxacensis**).

Spider	Abundance in Avocado Trees	Prey Items
Theridiidae-**Achaearanea Tepidariorum** (Koch)	Common	Psocoptera
Theridiidae	Uncommon	Elateridae Looper larvae
Linyphiidae-**Frontinella pyramitela** (Walckenaer)	Rare	Diptera
Micryphantidae	Uncommon	——
Araneidae (**Metepeira**)	Uncommon in spring; rare by late summer	——
Araneidae (**Cyclosa**)	Uncommon in spring; rare by late summer	——
Tetragnathidae	Rare	——
Agelenidae	Common	Diptera Lepidoptera (**Amorbia**) Lepidoptera (looper) Lepidoptera (undetermined) Lepidoptera (Tineidae) Psocoptera Aleyrodidae
Gnaphosidae	Rare	——
Clubionidae (**Chiracanthium**)	Rare	——
Thomisidae	Uncommon in spring; rare by late summer	——
Salticidae (**Thiodina**)	Uncommon in spring; rare by late summer	Tipulidae
Salticidae (**Phidippus**)	Uncommon in spring; rare by late summer	——

Common—observed at all the study sites at each visit.
Uncommon—observed at more than one study site.
Rare—observed once or twice at one study site.

Additional Spider Species in Avocado Orchards

Spiders other than *Neoscona* were seldom seen in the study sites (Table 1). The scarcity of running spiders (Gnaphosidae, Clubionidae, Thomisidae and Salticidae) in the avocado trees may be due to the lack of hiding spaces. The bark of avocado trees is smooth and seldom peels. The leaves are large and flat. Thus, the spiders, such as the salticids, which might hide under the bark, or clubionids, which make leaf retreats when the leaves are suitable for such manipulation, find it difficult to live in avocado trees.

The web-spinning families are probably outcompeted by the araneids which can span the large areas between trees to prey on the transient insects. In general, very few insects live on the avocado trees. The majority of the spider's flying prey is from the leaf litter. Two araneids, *Metepeira* and *Cyclosa,* both of which build small orbs, were seen in the trees in the spring and early summer, but were seldom seen later in the year.

Other than *Neoscona,* the only spiders regularly found during this study were threidiids and agelenids. The Theridiidae build tangled webs on the underside of the junction of branches, often where the branches join the trunk. The agelenids build sheet webs in the foilage, usually in the branches low to the ground. Agelenidae webs higher than 1.5 m were rare. The agelenids and theridiids may be surviving in the avocados by preying on occasional non-flying insects which wander up the trees from the leaf litter below. The araneids, with vertical orbs, seldom capture non-flying insects.

In the leaf litter Lycosidae and Micryphantidae were common and Agelenidae, Gnaphosidae and Clubionidae were present. Lycosidae were never seen in the trees and Micryphantidae were only rarely seen in the trees. The only Gnaphosidae and Clubionidae observed in the trees were mature males searching for females. The leaf litter spider fauna has little or no impact on the lepidoptera pests of the avocado trees.

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APPENDIX

TABLE 1. Monthly totals of insects comprising the window trapcatch at Atkins Nursery, Fallbrook, San Diego County, from November, 1978 to October, 1979.

Order	Family	Month											
		11	12	1	2	3	4	5	6	7	8	9	10
Isoptera	Kalotermitidae	6	2				5	1		2			
Psocoptera	undetermined	2			11	6	16	11	4	3	1	3	2
Hemiptera	Miridae	2		2	3		6	3					
Homoptera	Aphididae				1	1	23	9	4	2			
Coleptera	Silphidae	11	1			4	4						
	Staphylinidae	17	8	4	24	16	16	9	1		2	6	11
	Histeridae							2		1			
	Anobiidae	2		1	5	3							
	Nitidulidae	4	6	5	7	3	3	4	1	3		3	6
	Coccinellidae			3	3	1	5	12					
	Curculionidae	3					1			1	18	2	4
Lepidoptera	Tineidae	74	10	6	13	14	21	48	42	34	133	63	87
	Tortricidae		1	2									
	Noctuidae		1			3	1	2					
	miscellaneous	6			1	3		6	4				1
Diptera	Tipulidae				2	1							
	Bibionidae				4	24	151	93	3				
	Mycetophilidae	1	5	13	34	41	5						
	Therevidae				1	1							
	Drosophilidae	79	10		4	7						2	9
	Dolichopodidae	4	2			7	2	3			2		
	Platypezidae	2	9	5	6	3							
	Phoridae	2			3		2	1					2
	Anthomyiidae	2	6		42	4	7	1					1
	Muscidae	17	8	19	61	57	25	45	11	6	10	3	7
	Tachinidae	6	3	5	18	41	20	48	7	4	7		
	Calliphoridae	21	3	5	18	31	40	26	4	1			5
	Sarcophagidae	1			3	1	1	2			3		
	miscellaneous microdiptera	110	42	34	125	131	213	97	42	33	80	69	83
Hymenoptera	miscellaneous microhymenoptera		5	10	10	16	11	23			23	5	14
	Proctotrupidae	107	21	8	10	2							8
	Formicidae		1	22	198	26				8			3
	Ichneumonidae	3		3	4	5	2	6	1	1	4		
	Tiphiidae	1	1										
	Sphecidae	1						1					2
	Vespidae	1						1					
	Apidae	2			3	3	27	38	1	4			
Neuroptera	Chrysopidae												1

TABLE 2. Monthly totals of insects comprising the window trapcatch at the Von Essen Ranch, Fallbrook, San Diego County, from November, 1978 to October, 1979.

Order	Family	Month											
		11	12	1	2	3	4	5	6	7	8	9	10
Isoptera	Kalotermitidae	2				1	4			2		10	3
Psocoptera	undetermined	3			2		3	4	16	7	2		8
Orthoptera	Acrididae						1			1			
Hemiptera	Pentatomidae				1			1	1				
	Miridae				3	4	12	1	5	3			
Homoptera	Amphididae			13	15	32	14						
Coleoptera	Carabidae												1
	Dytiscidae						2		1				
	Histeridae										1		
	Silphidae	1						1					
	Staphylinidae	6		1	16	16	30	18	1		11	47	18
	Elateridae						1	1					
	Nitidulidae	5	2		12	15	12	17	2	7	33	8	40
	Coccinellidae					3	20	37					
	Anobiidae				2	5			3	2			1
	Scarabaeidae								2				
	Cerambycidae						1		1	2			
	Curculionidae	1					5	1	2	2	1	1	10
Lepidoptera	Tineidae	37		4	20	25	109	219	203	45	204	193	86
	Noctuidae				4	5	13	4					
	Geometridae				3	2		3	2				
	miscellaneous	3				3		11	7				5
Diptera	Tipulidae				2	2	3	10					
	Bibionidae					1		2					1
	Mycetophilidae		1	4	4	10	13	2					
	Rhagionidae					1							
	Dolichopididae							3	3				2
	Phoridae					1							1
	Platypezidae	1											2
	Syrphidae					3		1					
	Drosophilidae				1	3	9						
	Anthomyiidae				6	7	2	4					
	Muscidae	6	1	3	41	32	39	36	7	2	3		3
	Calliphoridae	10		1	39	82	57	60	12	5	8	5	9
	Sarcophagidae					1		1					
	Tachinidae				6	25	50	47	4		1		
	miscellaneous microdiptera	89	20	20	87	127	224	177	78	24	37	51	82
Hymenoptera	miscellaneous microhymenoptera	8		1	7			13	8	7	10	5	13
	Braconidae						4					1	
	Ichneumonidae			1	1			3			1		2
	Prototrupidae	12											28
	Formicidae	2		46	208	12			11	17	2	5	11
	Vespidae												1
	Pompilidae						1						
	Sphecidae												
	Apidae				4	8	16		3				
Neuroptera	Hemerobiidae				1				2	1			
	Chrysopidae				1								

TABLE 3. Catch from light trap run 3 consecutive nights each week for 4 hours each night at the Von Essen Ranch, Fallbrook, San Diego County, 1979. The numbers under the month indicate the number of weeks the light trap was run during that month.

Insect	Feb. (1)	Mar. (1)	Apr. (4)	May (4)	June (4)	July (4)	Aug. (2)	Sept. (2)	Oct. (1)
Neuroptera									
Chrysopidae						5		3	
Corydalidae							1		
Myrmeleontidae						2			
Coleoptera									
Carabidae						10	2		
Cantharidae			4	1					
Elateridae			1			14		15	
Silphidae			3	1					
Heteroceridae						28	3		
Nitidulidae			1					8	
Scarabaeidae						65	2		
Cerambycidae						3			
Curculionidae						6		6	
Diptera									
Tipulidae	3	2	106	26					1
Muscidae			10					3	
Hymenoptera									
Ichneumonidae			1			5			
Formicidae								3	
Lepidoptera									
Sphingidae	5	1	2	1	2	20		1	
Arctiidae		2	74	1	113	87	3		
Noctuidae	16	22	85	76	102	125	28	60	
Geometridae									
Sabulodes caberata	2	11	111	27	91	60	6		
Tortricidae									
Amorbia essigana			2						
Tineidae	3			7	38	2	31	186	
miscellaneous lepidoptera	13	23	103	82	141	96	28	19	12