LIFE HISTORY OF THE SPIDER, PHIDIPPUS AUDAX (HENTZ), IN RELATION TO BIOLOGICAL CONTROL OF GRAIN SORGHUM INSECTS

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LIFE HISTORY OF THE SPIDER, PHIDIPPUS AUDAX (HENTZ), IN RELATION TO BIOLOGICAL CONTROL OF GRAIN SORGHUM INSECTS

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PREFACE

I have been interested in biological control of field crop insects since 1962, when I was an insect checker in cotton and realized some of the problems associated with controlling insects with insecticides. Only since 1965 has my interest been primarily concerned with spiders and biological control. It was Dr. Harvey L. Chada, Professor of Entomology at Oklahoma State University and Investigations Leader, Entomology Research Division, United States Department of Agriculture, who called to my attention the need to do research with spiders in connection with biological control of insects.

I am indebted to my major adviser, Dr. Harvey L. Chada, for making this study possible, for his competent instruction and guidance, generous encouragement, helpful suggestions, and assistance in the preparation of this manuscript.

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INTRODUCTION

Grain sorghums are frequently subject to yield losses due to insect attack, and since there are dangers from toxic residues resulting from treatment with insecticides, other control methods, such as biological control, should be investigated. The role of spiders in the control of destructive insects of field crops has had very little attention, except for the work by W. H. Whitcomb and co-workers in Arkansas cotton and Bailey and Chada in Oklahoma grain sorghum.

In work conducted by Bailey and Chada (1968), it was found that certain spider species were the most important in controlling destructive insects. Therefore, two of the most common spiders of Oklahoma grain sorghum that were found on all parts of the plants, but primarily in the sorghum head, and were observed feeding on destructive insects in the field, were chosen for further investigations. These two species are _Phidippus audax_ (Hentz) (Salticidae) and _Oxyopes salticus_ Hentz (Oxyopidae).

In order to understand the role of a spider in controlling insects, its biology must be known. From a review of the literature very little information was available on the life history of _P. audax_. Therefore, studies on the oviposition, incubation, hatching, molting, mating, feeding habits, aerial dispersal, and longevity were initiated. Food preference observations were also made, using some destructive and beneficial insects of grain sorghum. Techniques were developed in the laboratory for rearing this spider in large numbers for testing purposes.

Feeding and aerial dispersal studies were conducted with the spider *Oxyopes salticus*.

REVIEW OF LITERATURE

Spiders associated with cultivated crops

There is not much literature dealing with spiders associated with cultivated crops or with the economic importance of spiders in cultivated crops. Everly (1938) in studies on the insects and spiders in sweet corn reported that the families Salticidae and Thomisidae were abundant throughout the season, but he did not report on their importance as control factors. Kagan (1943) collected 36 spider species among 9 families from cotton in Central Texas. Specht and Dondale (1960) found that spider populations were reduced following spraying when they made studies in sprayed and unsprayed orchards. In Louisiana sugarcane fields, Hensley et al. (1961) collected 18 spider families following insecticide applications. Whitcomb, Exline, and Hite (1963), in comparing ground strata spider populations in an Arkansas pasture and adjacent cotton field, found a higher population in the cotton field. They collected 64 species among 12 families in each habitat. Whitcomb, Exline, and Hunter (1963) in studying the spider species composition and density in Arkansas cotton fields found 143 species among 19 families, consisting of 82 "hunters" and 61 "web-builders." Studies on the food of spiders and collection location on cotton plants in Arkansas were made by Whitcomb and Bell (1964). They reported that every insect pest in Arkansas cotton is subject to attack by several spider species. Studies on the occurrence, species complex, and economic importance of spiders in grain sorghums were conducted by Bailey and Chada (1968).

Seventeen families, 57 genera, and 61 identifiable species were found which gave information that was not available previously. Food preference tests also were conducted in the laboratory. It was concluded that spiders were of much more economic importance as insect control factors in grain sorghums than was known previously.

Spiders in non-cultivated areas

Barnes (1953) collected 139 species of spiders belonging to 24 families from non-forest maritime areas of North Carolina. Each plant community displayed a distinct spider population structure, characterized by certain species and the density each exhibited.

Spider life cycles

Published information on the life cycle and biology of spiders is somewhat limited. Kaston (1948) gave a good discussion on generalized spider biology. He reported that *Phidippus audax* (Hentz) wintered in the penultimate and younger instars, maturity being attained in late April and May. He observed this species overwintering in a group of about 30 specimens in an old log.

Dondale (1961) studied the life cycle of five species, two of which were salticids. He reported 24-28 months were required for the life cycle of *Paraphidippus marginatus* (Walck.) and 20-23 months to reach the productive stage.

Snetsinger (1965) stated that *Phidippus audax* (Hentz) and *Phidippus rimator* (Walck.) were two of the most abundant spiders in Illinois wild habitats. He discussed copulation, mating, and survival of spiderlings.

Gardner (1965) found that the young of *Phidippus coccineus* remained in the egg sac through the first molt (about 16 days) and emerged from the nest 21 days after hatching. A period of 37-46 days was required from oviposition to emergence of young from the nest.

Hite *et al*. (1966) in studying the biology of *Loxosceles reclusa* Gertsch and Mulaik reported that it took an average of 335 days for this species to emerge from egg to adult, with a minimum of 266 and a maximum of 444 days.

Spider eggs

Kaston (1948) reported the egg mass of *P. audax* to be about 9 mm in diameter and 3.5 mm or more in vertical thickness. The eggs were orange and measured from 1.2 to 1.4 mm long by 1.1 to 1.2 mm in width. Gardner (1965) observed egg laying of 7 *P. coccineus* females kept in the laboratory. A median of 44 spiderlings hatched from the first batches of eggs, 30 from the second, and 3 from the third. Hite *et al*. (1966) found that the number of egg sacs produced in the laboratory by *L. reclusa* ranged from one to five per female. The egg sacs were found from February to September, with May, June, July, and August being the months of greatest oviposition. The time from oviposition to emergence of the young was 25-39 days with a mean of 32.6 days. A maximum of 300 eggs were laid by one female, and the maximum number of young was 158.

Molting

Bonnet (1930) found an inconsistency in the number of developmental instars in spiders. Even among the offspring of a single female when reared under apparently identical conditions, the offspring at maturity differed by as many as four instars. It was also shown that there was a direct relationship between the number of instars and size. Body size varied considerably among spiders of the same species of the same age.

Bonnet also suggested that the number of molts inside the cocoon in the case of Salticidae depended to a certain extent on the size of the egg or the amount of yolk left for the spiderlings. Kaston (1948) stated that the first instar spiders cannot spin webs or eat and have no pigment, hairs, or spines. The first molt took place within the cocoon several days after hatching, and this is the first real shedding of exuviae. He says that in Salticidae a second or even a third ecdysis is undergone inside the cocoon. Gardner (1965) reported that only 30 of almost 180 young P. coccineus lived five months after hatching. Most of the deaths occurred the first night after leaving the nest, generally while the spiders were molting. Hite et al. (1966) found eight instars for L. reclusa, but the time in the instars varied from one month to nearly four months.

Mating habits

Kaston (1936) described in detail the courtship, pre-mating, and mating procedure for P. audax. Bristowe (1929) described the mating habits of several spiders, including some members of the family Salticidae. Problems associated with sex dimorphism were also discussed in some detail. Bristowe (1931) made observations on nine species of spiders. A brief description of the pre-mating dance of one salticid, Ballus dispressus (Walck.) was given. Exline and Whitcomb (1965) made microscopic examinations of the epigynum of previously mated females of an oxyopid, Peucetia viridans. While mating the paracymbium of the male was broken off and was left embedded in the epigynum of the female. From this information it was concluded that during copulation the right palpus of the male is used for the right side of the epigynum of the female, and the left palpus for the left side of the epigynum.

Hite *et al.* (1966) reported that the preliminary courtship of *L. reclusa* consisted of the male slowly touching and stroking the anterior pair of legs of the female as they moved closer together, head to head, both vibrating their palpi. The male then thrust his cephalothorax ventrad to that of the female, extending his palpi forward and inserting the apical divisions of both bulbs, apparently simultaneously.

Hunting behavior of Salticidae

Gardner (1964) found that the hunting behavior of the jumping spiders consists of five responses that occur in regular order: orientation, pursuit, crouching, attachment, and jumping. During orientation, the spider turns until the main anterior eyes are in line with the prey. Pursuit occurs only after the orientation process is complete. The spiders then go into a crouched position, with the front legs raised to expose the mouthparts. Just before jumping the spider attaches a thread of silk to the substrate which prevents falls if the spider fails to make contact with another substrate during the capturing process. If the jumping resulted in capture of the prey, the spiders remained at the location until they were ready to discard the undigestable remains of the prey.

Feeding habits of spiders

Early observations by Lovell (1915) indicated that spiders might be of economic importance. He found that members of the family Thomisidae would attack large insects such as butterflies, dragonflies, wasps, bumblebees, honeybees, and large Diptera. Fletcher and Thomas (1943) observed numerous instances in cotton fields where spiders caught and devoured cotton bollworm larvae, and they concluded that the spiders were beneficial. Clark and Glick (1961) tagged pink bollworm moths with a radioactive carbohydrate solution. Spiders feeding on the tagged moths became radioactive. Through their technique they recorded nine families of radioactive spiders, among which was P. audax. Whitcomb and Tadic (1963) in investigating the natural enemies of the fall webworm, Hyphantria cunea (Drury), found that a number of spiders prey upon both the larvae and adults. These included P. audax, P. carolinensis Peckham and Peckham, Metaphidippus protervus (Walck.), and Metaphidippus galathea (Walck.), all members of the family Salticidae. The prey of P. audax is sometimes larger than the spider itself, according to Fitch (1963). He observed them eating dragonflies, butterflies, caterpillars, and grasshoppers, and even other spiders. Gardner (1965) observed that when given a choice of size of prey, most chose the larger size, but some preferred smaller prey. Hite et al. (1966) found the feeding site preference on flies by L. reclusa was: (1) head, (2) abdomen, and (3) thorax. Forty-one species of spiders belonging to 11 families were taken from 400 fall webworm nests by Warren et al. (1967). The most commonly found species was Aysha gracilis (Hentz) which accounted for 41.4% of the total collection, but P. audax was also commonly taken and observed feeding on the larvae. Bailey and Chada (1968) in conducting feeding tests with 19 spider species involving all stages of the corn earworm, coccinellid larvae and adults, chrysopid larvae and adults, and the sorghum midge, found that P. audax, Metaphidippus galathea (Walck.) and Habronattus coronatus (Hentz) were the only spiders that fed on all of the prey offered. They all belong to the family Salticidae.

Aerial dispersal of spiders

Some of the earliest observations on ballooning by spiders were made by McCook (1877), who stated that it occurred on days of low wind velocities. When he was classifying the spider collection in the Academy of Natural Science of Philadelphia, McCook (1878) observed a possible correlation between geographical distribution of Sarotes venatorius Linn (Thomisidae) and trade winds. He traced movement from Santa Cruz, Virgin Islands, to Cuba and Florida; across Central America, Yucatan and Mexico; across the Pacific Ocean by way of the Sandwich Islands, Japan and Loo-Choo Islands; and across the continents of Asia and Africa to Liberia.

Emerton (1908) collected 200 spider species on calm November days in Massachusetts from the air and on fences, 10 species of which were adult and 11 immature. Emerton (1918) was able to collect 68 species of ballooning adult and immature spiders in November between 9:30 and 10:30 AM when there was little or no wind. It was suggested by Blackwell (1927) that overpopulation causes spider ballooning and that bright, still weather is necessary. According to Bristowe (1929), wind and man are the two principal means by which spiders are dispersed, and distribution is influenced by temperature, humidity, exposure to light, exposure to environment, physical and chemical properties of soil and plants, food supply, and competition.

Airplane collections of spiders over Louisiana by P. A. Glick were reported by Crosby and Bishop (1936) at elevations ranging from 20 to 5,000 feet. Glick (1939) collected 14 spider families in airplane mounted nets. Most collections were below 5,000 feet, but some Linyphiidae, Thomisidae, Salticidae, and Araneidae were taken above 5,000 feet. One spider was taken at the 15,000-foot elevation. Later, Glick (1960) collected 10 identifiable spider species by airplane in the lower Mississippi River Valley at elevations of 100 to 4,000 feet.

Freeman (1946) reported spider distribution up to 300 feet in the air to be fairly uniform. Spiders collected were mainly adult and immature forms of the family Linyphiidae. Temperatures above 64 F., relative humidity below 60%, and wind below 12 mph were best for collecting large numbers.

Duffy (1956) in studying the aerial dispersal of a known spider population reported that the relative abundance among species varied according to the season. Ballooning by Linyphiidae occurred in the colder months when adults were numerous. Many herb inhabiting species did not generally disperse by air, but some were caught. Aerial catches from different grassland type habitats and woodlands differed in species composition. Species having peak activity periods on the ground in autumn, early winter, or spring, all disperse in the spring. Others were influenced by population density, and some dispersed at all times.

METHODS AND MATERIALS

Source of the Phidippus audax colony

The *P. audax* spider colony was obtained during May to August, 1966, by collecting wild adults and immature forms from Oklahoma State University Entomology Research buildings and vegetation in the vicinity.

Laboratory room

All spider rearing was done in a small laboratory room in which light was provided by four 40-watt daylight-type fluorescent tubes, operated by a time clock set to come on at 6:00 AM and go off at 6:00 PM. The temperature was maintained at 78 ± 5 F., and the uncontrolled relative humidity ranged from 30 to 50%.

Rearing, mating, and egg laying chambers

Round one-half pint paper ice cream containers, having the lid replaced by clear plastic petri dish covers, were used as rearing, mating, and egg laying chambers. The petri dish covers prevented escape of the spiders but at the same time allowed observation of their activities. The open end of a 1-dram glass vial was inserted into the side of each chamber, which provided a place for the small spiders to construct molting webs and a place for adult females to oviposit. If the plastic lid was sealed by webbing, the vial opening provided an alternate way for introduction of food and water into the chamber. These chambers are shown in Fig. 1.

Fig. 1. Spider rearing, mating, and egg laying chambers

Soon after oviposition the eggs were removed and placed in 2½-gallon fish aquariums covered with fine mesh muslin to prevent escape of the hatching spiderlings. Each aquarium supported about 400 spiderlings through the third instar. Since spiders beyond the third instar are cannibalistic, further rearing was done by placing each spider in an individual one-half pint ice cream container, where it was reared to the adult stage. A male was then introduced, and mating took place in this same rearing chamber; however, the vial opening was closed to prevent the female from retreating into it.

Food used for rearing spiders

Greenbugs, fruit fly adults, house fly adults, and Lepidoptera adults were used as food in the rearing process. The greenbugs, used to feed second and third instar spiderlings, were maintained in the greenhouse on Rogers barley. The fourth and fifth instar spiders were fed adult fruit flies which were reared on bananas in one-half pint fruit jars.

House fly larvae were reared in 1-gallon glass jars on the standard CSMA fly medium. After pupation and emergence, the flies were fed on milk in a screen cage where oviposition also took place. These adult flies were fed to the spiders.

In the case of the fruit flies and the house flies, the adults were taken out of the containers to be used as spider food by turning the jars horizontal and introducing carbon dioxide gas. After they were anesthetized the flies were placed in a 4-dram vial from which they could be transferred easily to the spider feeding chamber as needed. House flies were fed to the spiders from the sixth instar through the adult stage.

Lepidoptera adults (mostly moths) were also used as spider food from the sixth instar through the adult stage. These moths were collected from a light trap during the time of the year in which the moths were active.

Feeding test

Feeding tests were conducted in the spider rearing chambers. They involved all immature stages and the adults of P. audax and Oxyopes salticus. Insects used in the feeding test were all larval instars and adults of the fall armyworm, sorghum midge adults, cornleaf aphid adults, lady beetle larvae and adults, and lacewing larvae and adults. Fall armyworms were obtained from cultures in the laboratory, and the other insects were collected either from light traps or from field crops.

The feeding tests were replicated five times with each test lasting seven days. Readings were made every 24 hours to determine how many insects each spider had eaten in this amount of time.

Life cycle studies

Daily observations were made to collect data on oviposition, hatching, molting, mating, and feeding habits of P. audax.

Measurements of the carpace width of 25 specimens of each instar and adult P. audax were made by use of an ocular micrometer, as did Dondale (1961) and Hite et al. (1966) as an indication of the instars involved.

Aerial dispersal of spiders

A Johnson-Taylor suction trap, mounted on top of a 40-foot high building on the Oklahoma State University campus, was used to study aerial dispersal of spiders. The spiders were collected in a 1-pint plastic jar containing 70% alcohol. The contents of the jar were removed and recorded daily from September, 1966, through August, 1967. Weather data for this study were obtained from the agronomy weather station on the Oklahoma State University campus.

RESULTS AND DISCUSSION

In studies conducted by Bailey and Chada (1968), it was noted that one of the spiders that could be found on all parts of the sorghum plant and on the ground was Phidippus audax. This species was also one of the most numerous hunting spiders found in sorghum. It was observed in the field and in the laboratory that this species would feed on most all insect pests of this crop. From a review of the literature it was found that very little was known about the biology and life cycle of this species; therefore, the following study was made in an effort to better understand the role P. audax plays in controlling sorghum pests.

Life Cycle of Phidippus audax

Egg sac construction and oviposition

Construction of the egg sac was observed several times. The female would first construct a thinly woven sheet of web suspended off the substrate by many threads of silk. Then she moved to the center of the sheet where she began to make the densely woven base of the egg sac by slowly swinging her spinnerets back and forth. She moved slightly from time to time so that the base covered an almost circular area from 7 to 12 mm in diameter. After the base was completed the female began to deposit eggs, the oviposition period lasting from 1½ to 3 hours, with 2 to 3 periods of rest. Soon after oviposition was completed she began to cover the eggs with a dense layer of silk, using the same method as in making the base. The completed egg sac is white, flat on the lower side, and convex on the upper side. It ranges from 7 to 12 mm in diameter and 3 to 5 mm thick. The eggs are light yellow to orange in color and range from 1.1 to 1.2 mm in diameter. A P. audax egg mass with the dorsal portion of the web removed to expose the eggs is shown in Fig. 2.

After oviposition is complete and the eggs are covered, the female makes a dome-like shelter over the egg sac, with an opening at both ends. This web is similar to the molting web made by the immature spider forms. Inside this dome is where the female will spend most of the time until the spiderlings are ready to leave the egg sac.

Incubation and hatching

To follow the development of the eggs, 25 egg sacs were examined daily using a dissecting microscope. In order to examine the eggs, the dorsal silk covering of the egg sac was carefully raised and then placed back into position after the examination.

The color of the eggs did not change at all from the time of oviposition through the postembryo. The first visible change in the eggs was noted about the ninth day after oviposition when the chorions began to wrinkle and the eggs became slightly elongate and bulged at one end. This developmental stage of an egg is shown in Fig. 3.

Within a few hours after the chorion began to wrinkle, slight movements could be detected inside the egg. It was evident that the embryo was applying pressure, and each time pressure was applied the egg would bulge until finally the chorion would burst. The cephalothorax, mouthparts, pedipalps, and legs were first to emerge from the chorion. The chorion then peeled backward and downward over the abdomen, but remained attached in the region of the spinnerets. A postembryo with the legs,

Fig. 2. A Phidippus audax egg mass with the dorsal portion of the egg sac removed to expose the eggs

Fig. 3. A Phidippus audax egg nine days after oviposition

pedipalps, mouthparts, and the cephalothorax still enclosed in a transparent membrane, with the chorion still attached to the abdomen, is shown in Fig. 4.

The postembryo remains in the membrane covering for an average of 1.1 days. About two hours prior to the shedding of the membrane, the dorsal part of the cephalothorax expands and contracts until the membrane breaks along the lateral edges. Then the spiderling works its legs, mouthparts, and pedipalps free from the membrane. The membrane and the chorion are attached to each other as they separate from the first instar spiderling. This is shown in Fig. 5.

Fig. 6 shows the first instar spiderling soon after hatching. The abdomen and posterior portion of the cephalothorax are light yellow in color. The legs, mouthparts, pedipalps, and anterior portion of the cephalothorax are light in color and somewhat transparent. According to Kaston (1948), first instar spiderlings cannot spin web or eat and are devoid of pigment, hairs, and spines. However, we observed fine hairs on the abdomen, legs, and pedipalps in this species. These spiders could move around slowly if left in contact with the web in the egg sac.

Fig. 7 shows the first instar spiderling 7 hours after emergence from the postembryo. The color of all body parts has darkened considerably, and the body hairs are distinctly visible.

Molting behavior

The shedding of the exoskeleton of the various instars of *P. audax* was observed several times. Detailed movements of the spider during the molting process were hard to observe because of the molting web each spider constructed prior to the end of a stadium.

Fig. 4. A Phidippus audax postembryo with the legs, pedipalps, mouthparts, and cephalothorax enclosed in a transparent membrane and the chorion still attached

Fig. 5. The membrane and chorion still attached to each other after they were shed from the first instar spiderling

Fig. 6. First instar Phidippus audax spiderling immediately after hatching

Fig. 7. Showing the change in color of a first instar *Phidippus audax* spiderling seven hours after emergence from the postembryo

The first instar spiderlings shed the exoskeleton inside the egg sac before emerging. The second through the eighth instar spiders build individual molting webs, which they enter about one day before molting. After the spider enters the web, it will not feed again until two or more hours after molting is complete. The molting web is about 2 times as long and 1½ times as wide as the spider instar that constructed it, and it has an opening at both ends. The web is used as a substrate for attachment of the exoskeleton during the molting process and also provides the spider with protection.

A break appeared laterally on each side of the cephalothorax just above the base of the legs and extended anteriorly just above the base of the chelicera and posteriorly along the lateral margins of the pedicel at the start of molting. As the spider began to emerge, the exoskeleton in the region of the carpace lifted but remained attached to the anterior portion of the abdomen. The spider then began to work free from the exoskeleton by way of the opening in the old cephalothorax. First to emerge was the cephalothorax, then came the chelicera, pedipalps, legs, and abdomen. The entire molting process takes from 1 to 1½ hours.

After ecdysis was complete the newly emerged spider would stay inside the molting web for about 2 or more hours before emerging to feed. The old molting web was then deserted, leaving the cast exoskeleton inside. A new molting web was built usually within 1 day. Table I gives the carpace width of the various instars which will give some indication of the size of each stage.

TABLE I

CARPACE WIDTH OF PHIDIPPUS AUDAX SPIDERS IN VARIOUS INSTARS[a]

Instar	Width in millimeters	
	Range	Average
1	0.90-0.98	0.95
2	1.09-1.27	1.18
3	1.26-1.46	1.30
4	1.38-1.57	1.38
5	1.50-1.71	1.66
6	1.68-1.86	1.78
7	1.79-2.11	1.97
8	2.00-2.41	2.15
Adult male	2.33-2.65	2.40
Adult female	2.60-3.41	2.96

[a]Based on measurements of 25 spiders at each instar

Premating and mating behavior

Numerous observations were made of the premating and mating behavior of P. audax. Soon after the last molt both sexes were ready to mate. The male first constructed a sheet-like web upon which he deposited sperm which was then adsorbed into the terminal bulb of the pedipalp. The male then sought a female, and when one was found, the premating activity began. The male waved his front pair of legs in front of the female as described by Kaston (1936). The female raised her front legs as if she was in a defensive attitude. Usually after four or five approaches by the male the female lowered her front legs, apparently indicating a receptive mood. When this happened the male approached from the front and crawled onto the back of the female. Now the two sexes were facing in opposite directions. The male then turned the abdomen of the female to one side by using his front pair of legs. If the abdomen was turned to the left, the left palp was used to transfer sperm to the epigynum of the female. If the abdomen was turned to the right, the right palp was used in the sperm transfer process. The male may switch back and forth from the right to the left side 9 or 10 times during the mating process. These spiders have been observed in apparent copulation from two minutes to as long as four hours, with an average of 45 minutes. Attempts were made to get the female to mate for a second time but without success. The males, however, would mate several times; one male mated with six different females, with each female producing spiderlings. The longevity in days for the various developmental stages of P. audax from egg through the adult state is given in Table II.

TABLE II

LONGEVITY IN DAYS OF THE VARIOUS DEVELOPMENTAL STAGES OF *PHIDIPPUS AUDAX* FROM EGG THROUGH THE ADULT STAGE[a]

Developmental Stage	Range	Average
Incubation	8-12	10.3
Postembryo	1-3	1.1
1st instar	7-8	6.2
Emergence from egg sac	12-17	14.4
2nd instar	32-41	35.9
3rd instar	16-48	24.0
4th instar	9-40	18.3
5th instar	8-42	22.8
6th instar	20-66	43.8
7th instar[b]	32-73	49.3
8th instar[b]	46-85	58.0
Egg to adults having 7 instars	209-259	235.8
Egg to adults having 8 instars	220-342	285.1
Duration of adult males	95-172	134.4
Duration of adult females	156-373	208.7
Egg to death of adult males	304-481	405.2
Egg to death of adult females	365-582	487.9

[a] Based on data from 40 individuals in each stage

[b] 15% reached adult stage in 7 instars; 85% reached adult stage in 8 instars

Mass Rearing

Seasonal production of egg sacs

Production of egg sacs varied according to the season. No eggs were laid in February, March, and April, and the production of eggs was very low in November, December, and January. August was the month in which most of the eggs were laid, but several were produced in June, July, and September. It was postulated by Hite et al. (1966), "That since spiders produce none or very few eggs in the colder months of the year, that this may be correlated with the available food supply for the spiders." Under laboratory conditions this should have no effect because spiders are fed the same in the cold as in the warm months. Therefore, it is believed that if spiders emerged as adults in the laboratory in January then they would produce eggs in February, March, and April. The native spiders in this study were all collected as adult females in the spring or early summer. The laboratory females emerged as adults in spring and early summer. Therefore, most of them laid all the eggs they were capable of laying before the cold months arrived. A comparison of egg sac production throughout the year by native and laboratory *P. audax* females is shown in Table III.

Oviposition and oviposition period

Ten laboratory females laid 4 egg sacs and 13 produced 5 sacs during the oviposition period. The largest number of egg sacs laid by a female was 10, and the smallest number was 1. The time from mating to oviposition ranged from 12 to 35 days with an average of 18.5. The oviposition period ranged from 1 to 211 days with an average of 82. Data on oviposition for 44 laboratory females are given in Table IV.

TABLE III

COMPARISON OF EGG SAC PRODUCTION THROUGHOUT THE YEAR BY NATIVE AND LABORATORY *PHIDIPPUS AUDAX* FEMALES

Month	Number of egg sacs	
	25 Native females	44 Laboratory females
January	1	2
February	0	0
March	0	0
April	0	0
May	7	2
June	17	20
July	16	27
August	28	61
September	9	36
October	1	19
November	1	2
December	2	0

TABLE IV

DATA ON OVIPOSITION AND OVIPOSITION PERIOD FOR 44 LABORATORY *PHIDIPPUS AUDAX* FEMALE SPIDERS

No. of females	No. of egg sacs per female	Average number of days		
		Mating to oviposition	Mating to completion of oviposition	Oviposition Period
2	1	35.0	35.0	1.0
7	2	21.7	48.7	27.0
6	3	14.2	57.2	43.0
10	4	16.5	85.2	68.7
13	5	17.0	109.4	92.4
4	6	14.5	113.7	99.2
1	7	12.0	127.0	115.0
0	-	-	-	-
0	-	-	-	-
1	10	18.0	229.0	211.0

Comparison of native and laboratory progeny production

In a comparison of egg sac, egg, and spiderling production by native and laboratory *P. audax* females, it was found that the laboratory specimens had a higher average in all categories. This included egg sacs per female, eggs per sac, eggs per female, spiderlings per sac, and spiderlings per female. Total progeny of the 25 native and 44 laboratory females was 249 egg sacs, 30,623 eggs, and 22,227 spiderlings. It is believed the reason why the laboratory spiders produced more progeny than the native spiders is because the native spiders had to adjust to the laboratory conditions. The native adults did not eat as much as the laboratory specimens, and the immature stages did not have an abundance of food as did the laboratory specimens. A comparison of egg sac, egg, and spiderling production by native and laboratory *P. audax* females is given in Table V.

Mortality

In mass rearing studies, data on the per cent survival from the first instar to the adult is needed. Mortality of the various developmental instars of laboratory-reared *P. audax* is given in Table VI. The highest percentage mortality occurs in the early instars, with the first instar having the most deaths. Almost all the deaths occurred while the spiders were molting, which is believed to be caused by low relative humidity. In this study 79% of the spiders reached the adult stage.

Storing eggs and spiderlings at low temperature

In examining the problem of mass rearing spiders, it was realized that large numbers of approximately the same developmental stage would be needed for use in a testing or release program. Studies were

TABLE V

COMPARISON OF EGG SAC, EGG, AND SPIDERLING PRODUCTION BY NATIVE AND LABORATORY *PHIDIPPUS AUDAX* FEMALES

	Number of eggs and spiderlings			
	25 Native females[a]		44 Laboratory females[b]	
	Range	Average	Range	Average
Egg sacs per female	1-5	3.2	0-10	3.8
Eggs per sac	21-249	111.7	17-244	128.4
Eggs per female	21-761	357.3	0-1015	493.1
Spiderlings per sac	0-231	78.0	0-235	94.6
Spiderlings per female	0-672	249.6	0.728	363.3

[a] 80 egg sacs; 8,933 eggs; 6,240 spiderlings (1966 and 1967)

[b] 169 egg sacs; 21,690 eggs; 15,987 spiderlings (1967)

TABLE VI

MORTALITY FOR THE VARIOUS IMMATURE INSTARS OF LABORATORY *PHIDIPPUS AUDAX*[a]

	Instars							
	1	2	3	4	5	6	7	8
Percentage Mortality	7	4	4	3	2	1	0	0

[a] Based on a sample of 100 spiders

conducted to test the effects of temperature and relative humidity on the maturation process of the eggs and first instar spiderlings. It was found that best survival of eggs and spiderlings was obtained at a temperature of 52 F. and relative humidity of 60%. Table VII shows the effects of cool temperature on hatching and survival of P. audax eggs and spiderlings.

If eggs were placed in the chamber within two days after they were laid and left for 10 days, none hatched. If eggs were allowed to stay under laboratory conditions from 4 to 8 days after oviposition, then placed in the chamber for 10 days, some hatching resulted; however, the percentage was very low. If eggs were placed in the chamber the same day they would have hatched under laboratory conditions, or if the postembryo or early first instar spiderlings were placed in the chamber and left for 30 days, the percentage alive after molting to the second instar was high.

Feeding test with Phidippus audax and Oxyopes salticus

In feeding studies with 19 commonly occurring spider species found in grain sorghum, it was found by Bailey and Chada (1968) that P. audax and O. salticus would feed on most stages of the destructive insects of sorghum. These two species were also found on all parts of the sorghum plant, but primarily in the head. Because of this information, feeding tests were conducted to determine the average number of certain of the destructive and beneficial insects of sorghum that these two spider species would eat in a 24-hour period. These results are presented in Table VIII.

Fall armyworms were used in the feeding test rather than corn earworms, because the larvae were not cannibalistic, and more accurate

TABLE VII

EFFECTS OF STORING AT 52 F. AND 60% RELATIVE HUMIDITY ON HATCHING AND SURVIVAL OF *PHIDIPPUS AUDAX* SPIDER EGGS AND SPIDERLINGS

Date of oviposition	Date placed in chamber	Date taken out of chamber	Percentage hatch	Percentage alive in second instar[a]
9/11/67	9/11/67	9/21/67	0.00	0.00
9/11/67	9/13/67	9/23/67	0.00	0.00
9/11/67	9/15/67	9/25/67	2.67	2.67
9/11/67	9/17/67	9/27/67	11.12	10.00
9/11/67	9/19/67	9/29/67	14.62	14.62
9/11/67	9/21/67	10/1/67	78.34	75.43
9/12/67	9/22/67[b]	10/6/67	82.16	81.40
9/12/67	9/22/67	10/11/67	72.58	72.58
9/12/67	9/22/67	10/16/67	84.12	82.06
9/14/67	9/26/67[c]	10/20/67	--	96.43
9/14/67	9/26/67	10/26/67	--	95.71
9/14/67	9/27/67[d]	10/27/67	--	92.89

[a]Spiderling reaching second instar continues to live and feed

[b]Eggs were close to hatching date

[c]Postembryo stage

[d]First instar spiderlings

TABLE VIII

NUMBER OF FOOD INSECTS CONSUMED BY VARIOUS STAGES OF PHIDIPPUS AUDAX AND OXYPES SALTICUS OVER A 24-HOUR PERIOD

Spiders	Fall Armyworm Instars							S.M.[a]	C.A.[b]	L.B.[c]		L.W.[d]	
	1	2	3	4	5	6	Adult	Adult	Adult	Lar.	Adult	Lar.	Adult
Phidippus audax													
Instars - 1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2	7.3	4.2	0.0	0.0	0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0
3	12.3	6.9	1.2	0.0	0.0	0.0	0.0	2.2	4.3	0.0	0.0	0.0	0.0
4	12.5	8.0	2.1	0.5	0.4	0.0	0.0	3.8	4.8	0.0	0.0	0.0	0.0
5	8.3	9.7	2.7	1.1	1.0	0.4	0.0	6.6	1.8	0.0	0.0	0.0	0.9
6	0.6	10.6	3.0	1.5	1.5	0.5	0.4	2.7	0.0	0.0	0.0	0.2	1.3
7	0.0	12.0	3.5	2.0	1.6	0.9	0.5	0.0	0.0	0.0	0.0	0.3	1.4
8	0.0	12.4	3.9	2.8	2.0	1.0	0.6	0.0	0.0	0.0	0.0	0.3	1.4
Adult male	0.0	1.1	1.0	0.6	0.5	0.3	0.5	0.0	0.0	0.0	0.0	0.2	0.4
Adult female	0.0	12.7	4.4	3.3	2.3	1.4	2.0	0.0	0.0	0.2	.05	0.5	1.5
Oxyopes salticus													
Adult male	7.2	2.6	0.4	.07	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.2
Adult female	30.0	8.7	0.9	0.1	.05	0.0	0.0	0.0	6.3	.05	.05	0.2	0.3

[a] S.M.= Sorghum midge
[b] C.A.= Corn leaf aphid
[c] L.B. = Lady beetle
[d] L.W. = Lacewing

readings could be made. In these tests there was a direct relationship between spider size and the insect fed upon. In most cases, the larger spiders preferred to feed on the larger insects and would pay little or no attention to the smaller ones. The small spiders fed on small insects and would not attack larger ones.

Phidippus audax feeding test

The first instar spiderling remains in the egg sac and does not feed as shown in Table VIII. The second through fourth instars of this species fed only on fall armyworm larvae, sorghum midge adults, and corn leaf aphid adults. The third and fourth instars fed on more of the first instar fall armyworms than any of the other spider stages. The sixth instar spider was the only one that would feed on all stages of fall armyworms. The fifth through the adult instars of this species would feed on the larval and adult stages of lacewings, but only the adult females would feed on the larval and adult lady beetles, however, none of the beneficial insects were preferred. In all cases the adult females fed on more insects than did the males.

Oxyopes salticus feeding test

The adults of both sexes of O. salticus were used in this test. Both fed readily on the first two instars of the fall armyworms, and the corn leaf aphid adults (Table VIII). The females fed on both larvae and adults of the lady beetles and lacewings, but the males fed only on the mature lacewings. Neither sex preferred the beneficial insects.

Food preference observations

During the rearing process various insects were introduced into the spider feeding chambers, and observations were made on what type insects the various spider instars preferred. The smaller instars of P. audax preferred the small, soft-bodied insects over the larger ones or the beneficial insects. The seventh through the adult instars preferred the larger, flying, soft-bodied insects, such as the adult fall armyworms or house flies. These spiders were attracted to fast movement or noise such as that produced by the moths and house flies while they were in flight. O. salticus preferred the soft-bodied, slow-moving insects such as the first three instars of the fall armyworms.

In all feeding tests, beneficial insects were not eaten if the spiders had a choice of food insects. Only after about two days of starvation with no choice would they feed on the beneficial insects alone offered as food. From observations in this connection, reasons why spiders did not feed on larvae and adults of lady beetles and lacewings were: (1) the immature insects took a defensive attitude toward the spiders, (2) the heavily scleratized exoskeleton and elytra in the case of adult lady beetles is too hard for the spiders' mouthparts to penetrate easily, and (3) the odor of the adults of both insects seemed to act as a repellent.

Aerial dispersal

It has been known for many years that spiders disperse through the air by first climbing to the tops of plants or other objects, then spinning a silk thread strong enough to support the weight of the spider. They are then borne by air currents. As far as is known, this was the first time a study of aerial dispersal of spiders was conducted in Oklahoma. There were eight identifiable spider families collected. Many of the collected specimens were immature forms and identifications could not be made at the present time. It is believed that when determination of these immature forms is made there will be three or four additional families represented. The spider families with the numbers of each and the month collected are given in Table IX.

Over half of the total number of spiders collected belong to the family Oxyopidae, of which almost all are one species, Oxyopes salticus. This was one of the more numerous spiders found in grain sorghum in the Stillwater, Oklahoma, area by Bailey and Chada (1968). Since most of the larger species of spiders that disperse through the air do so when they are very immature, the large number caught in the trap at various periods indicates when hatching takes place.

Freeman (1946) reported that the largest numbers of spiders were collected when the temperature was above 64 F., relative humidity below 60%, and wind below 12 mph. Similar observations by the author were made at Stillwater, Oklahoma, as follows: about half the total number of spiders were collected during September when the average daily wind speed never exceeded 5.7 mph and the mean daily temperature ranged between 61 and 78 F. Relative humidity was not recorded, but on days when there was precipitation the spider catches were relatively low. From September 19 to 23 when spider catches were higher than at any other time of the year, the mean daily temperature ranged between 62 and 68 F., average wind speed was between 1 and 2.9 mph, and there was no precipitation. On days of heavy cloud cover or on rainy days there were few aerial dispersing spiders. On those days in which relatively large numbers of spiders were collected the average wind speed was very low. Large numbers of spiders were also collected during June, July, August, October, and November. The spider collections correlated with weather data were about the same for these months as they were for September.

TABLE IX

NUMBERS OF AERIAL DISPERSING SPIDERS COLLECTED THROUGHOUT
A ONE-YEAR PERIOD - STILLWATER, OKLAHOMA

Family	1966				1967								Total
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
Oxyopidae	752	255	77	28	1	2	5	15	14	39	12	40	1240
Thomisidae	160	84	28	6	8	5	16	23	22	7	17	36	412
Argiopidae[a]	71	0	0	0	0	0	0	0	0	59	21	119	270
Salticidae	18	27	18	3	3	0	11	4	9	8	45	36	182
Erigonidae[a]	119	0	0	0	0	0	0	0	0	0	0	0	119
Theridiidae	0	0	0	0	0	0	0	0	0	0	1	1	2
Linyphiidae	1	0	0	0	0	0	0	0	0	0	0	0	1
Lycosidae	0	0	0	0	0	0	0	0	0	0	1	0	1
Totals	1121	366	123	37	12	7	32	42	45	113	97	232	2227

[a]Further determinations may show that some of these spiders belong to Tetragnathidae, Linyphiidae, and Theridiidae.

During every month of the year some spiders were collected. On days of the colder months in which spiders were collected, the temperature was usually above freezing and the wind speed was very low. Detailed data on aerial dispersal of spiders as affected by temperature, wind velocity, and precipitation at Stillwater, Oklahoma, during September 5, 1966, to September 4, 1967, are presented in Fig. 8 through 19.

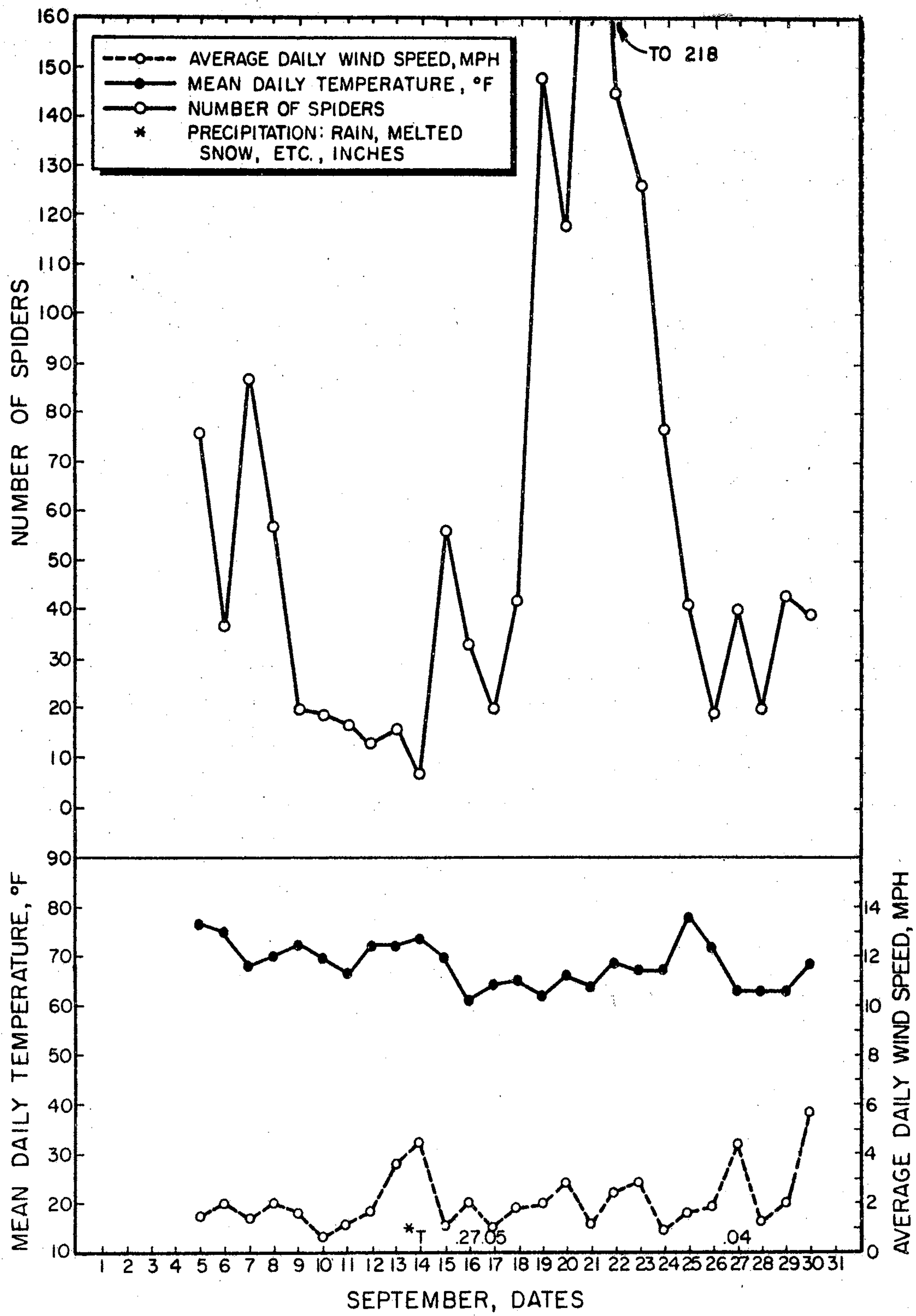

Fig. 8. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, September 1966.

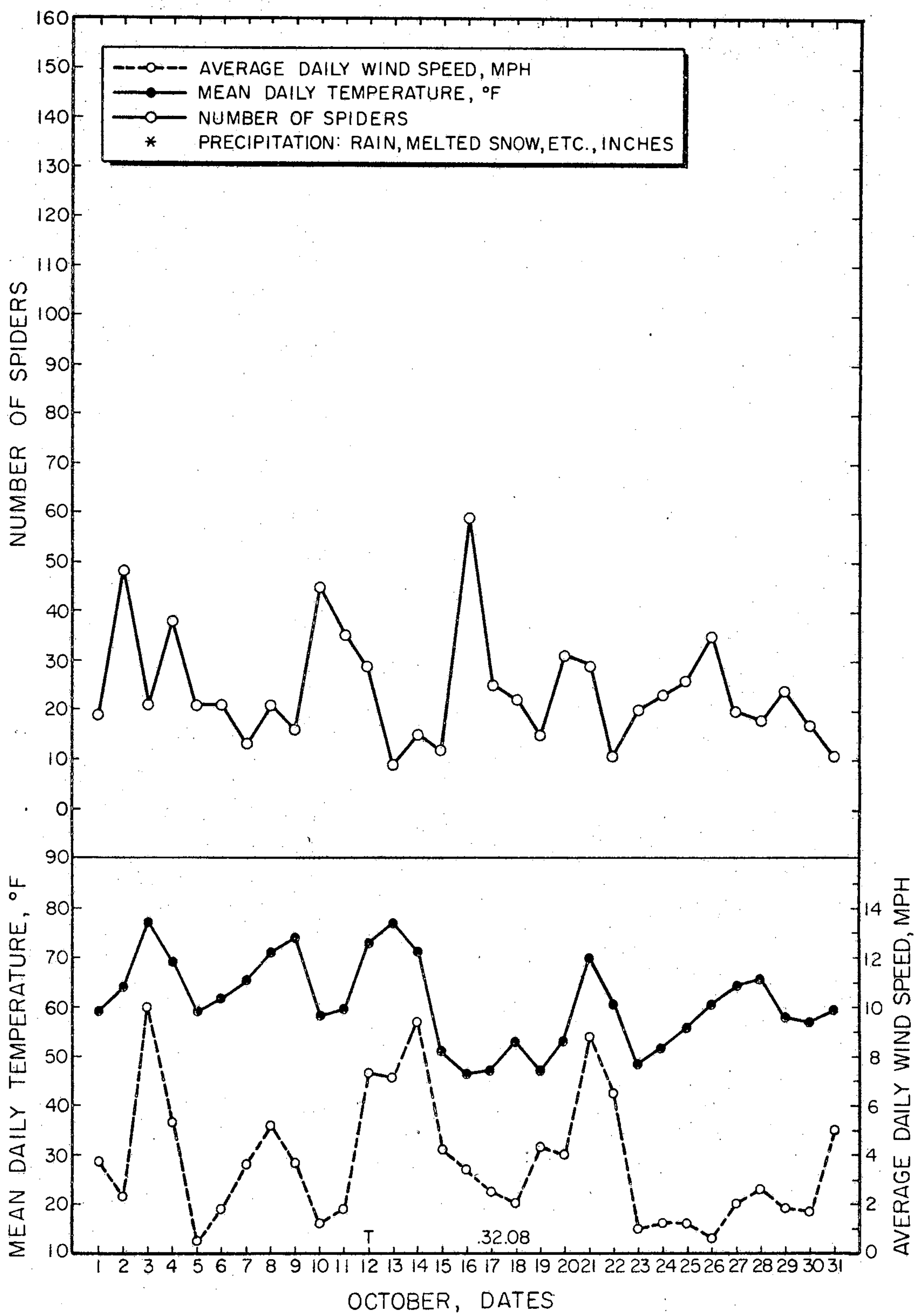

Fig. 9. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, October 1966.

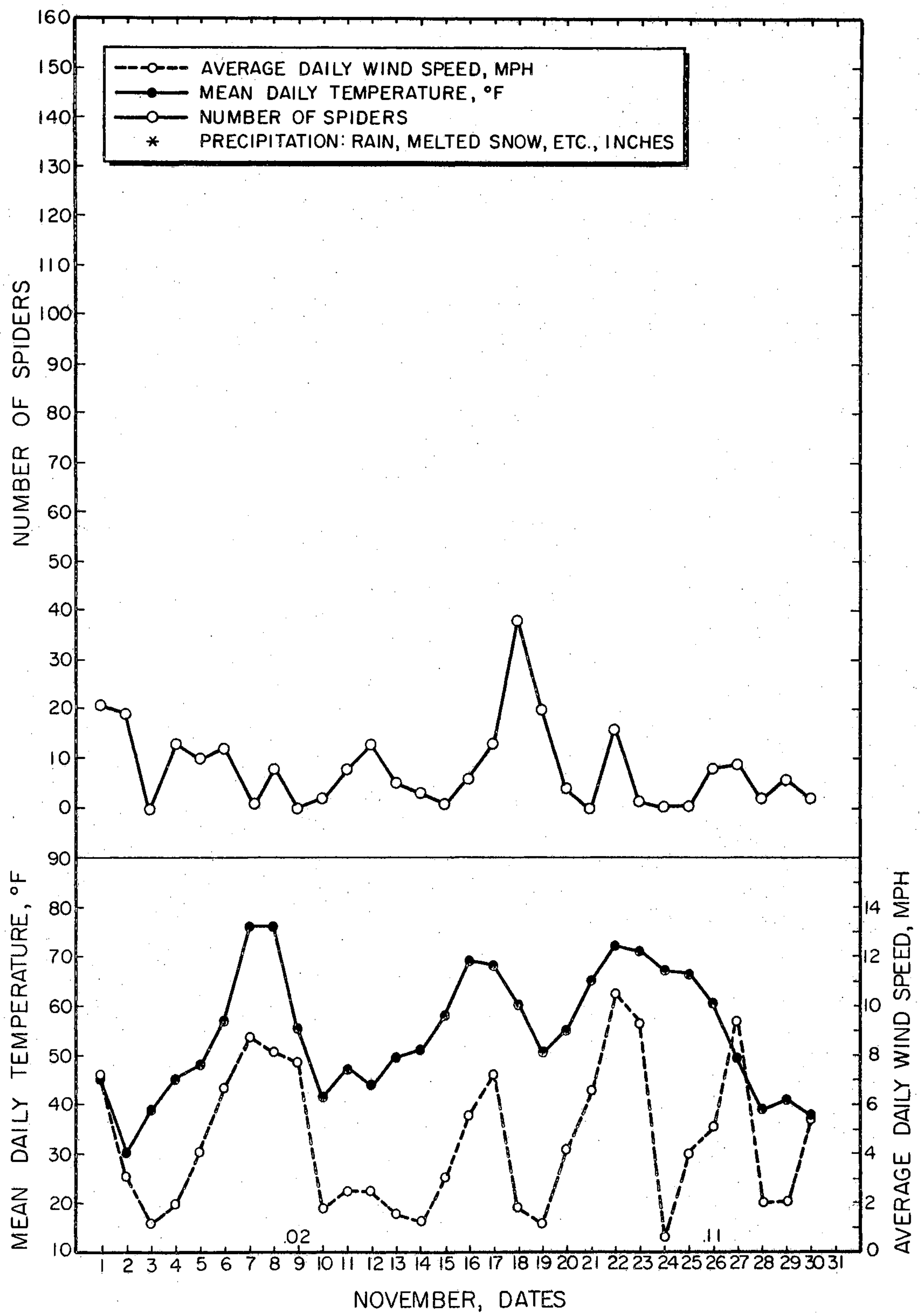

Fig. 10. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, November 1966.

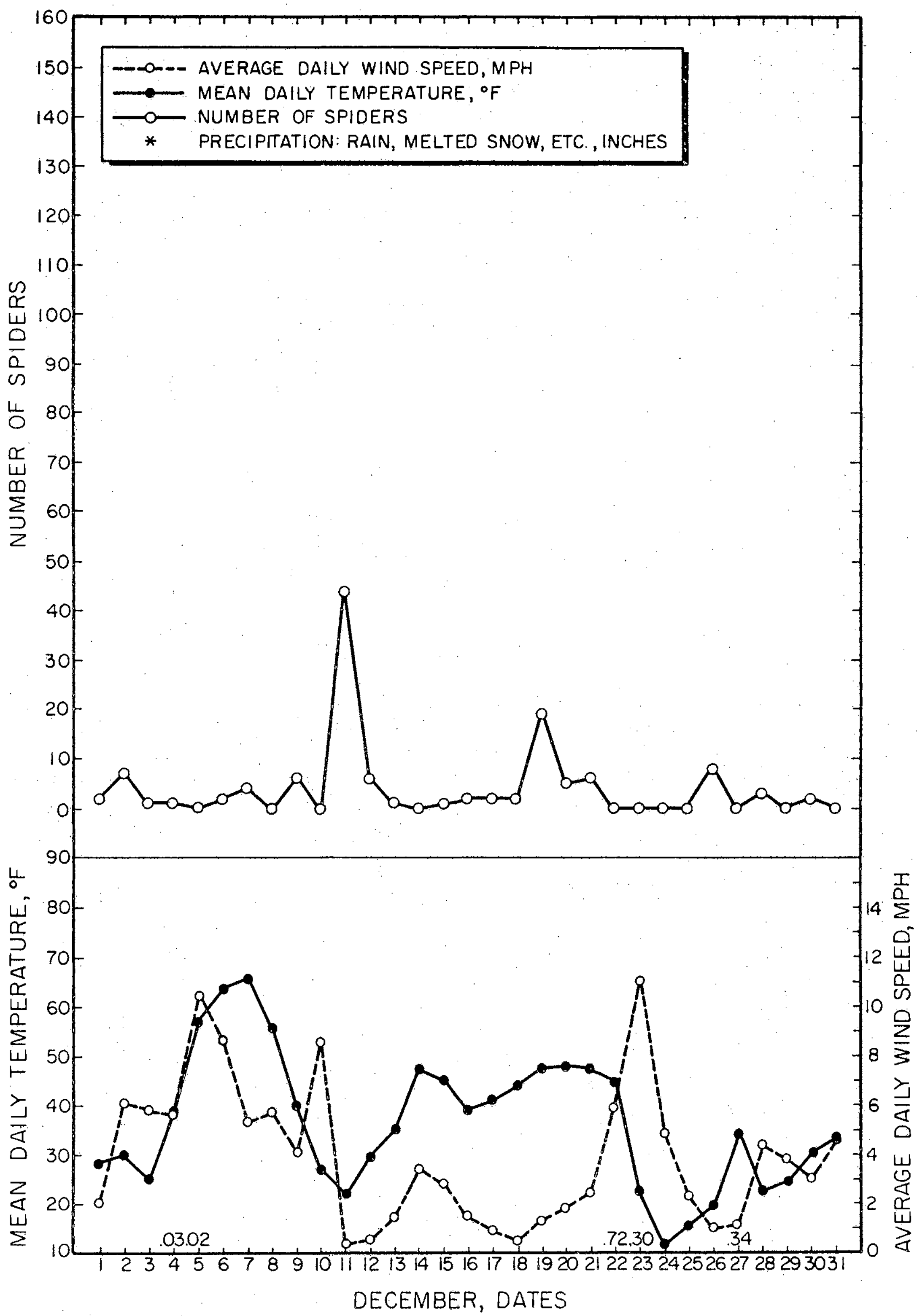

Fig. 11. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, December 1966.

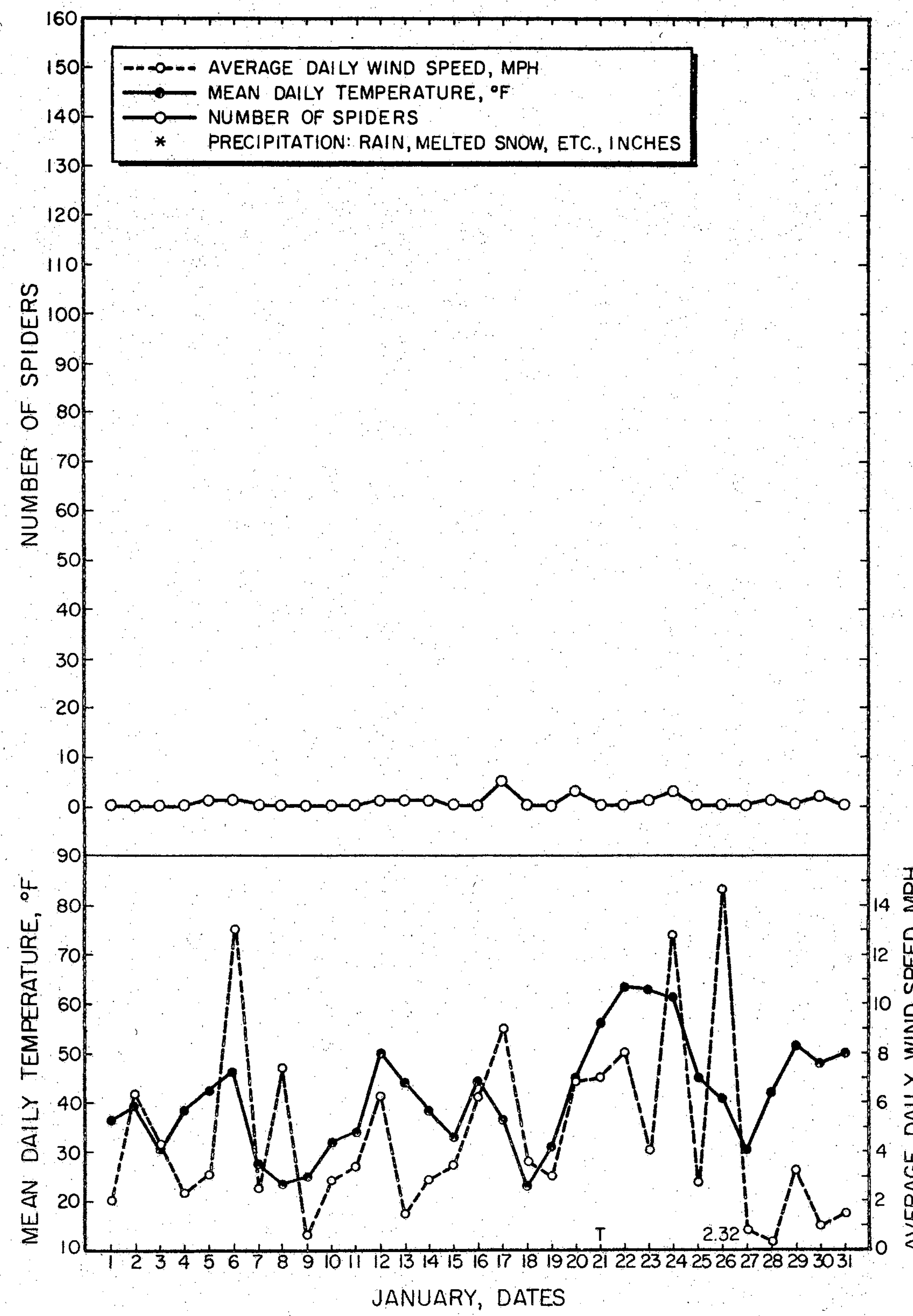

Fig. 12. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, January 1967.

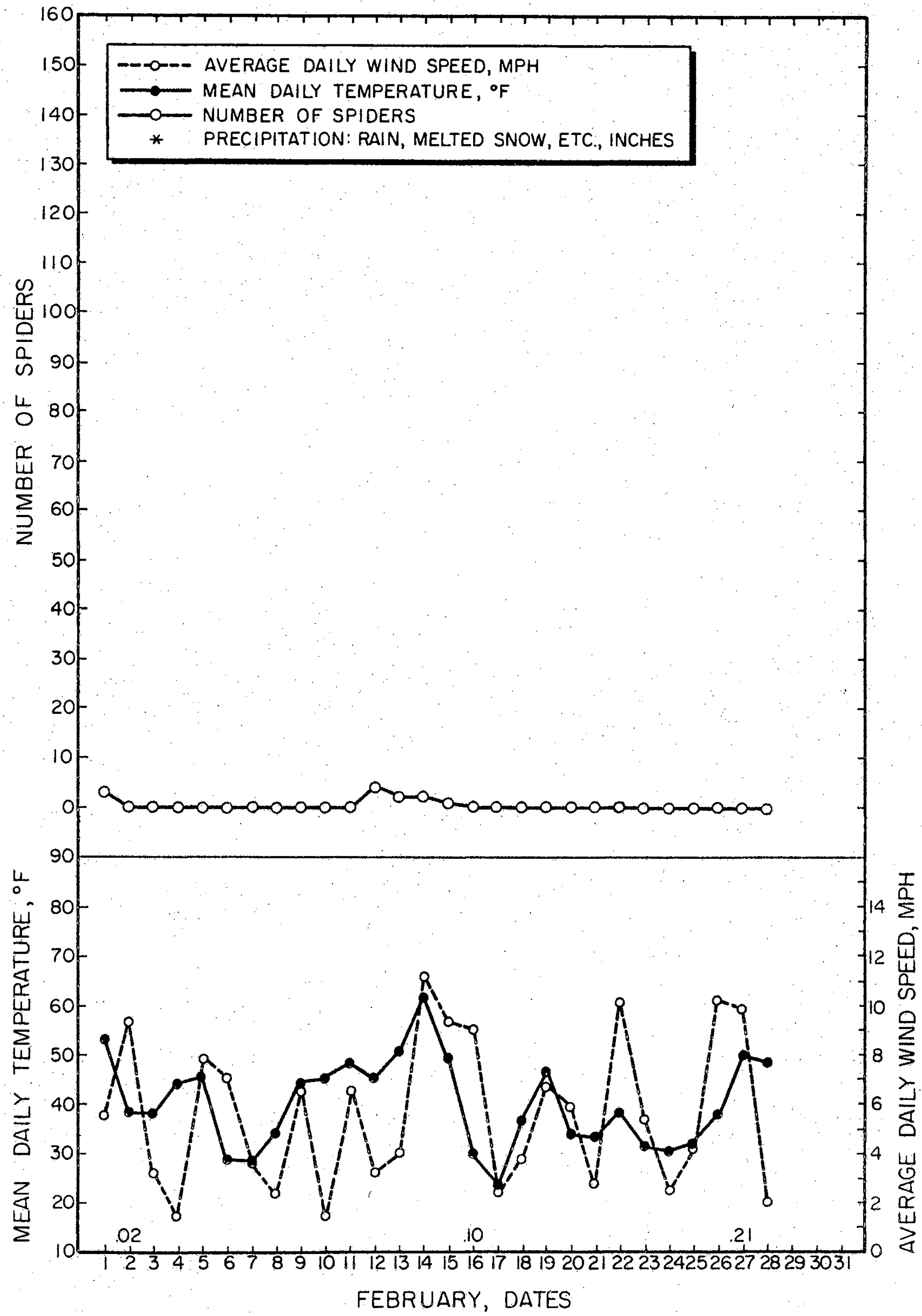

Fig. 13. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, February 1967.

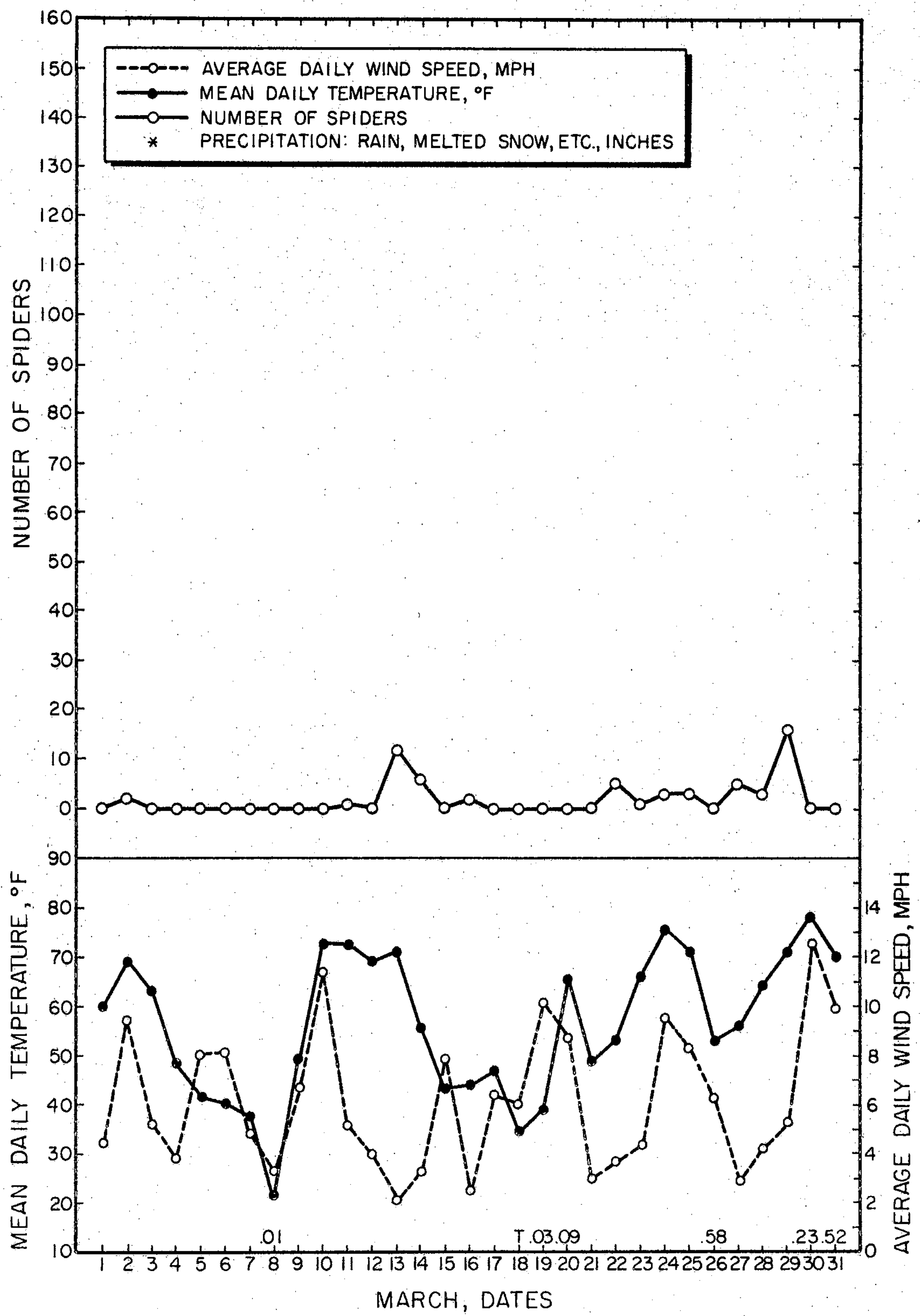

Fig. 14. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, March 1967.

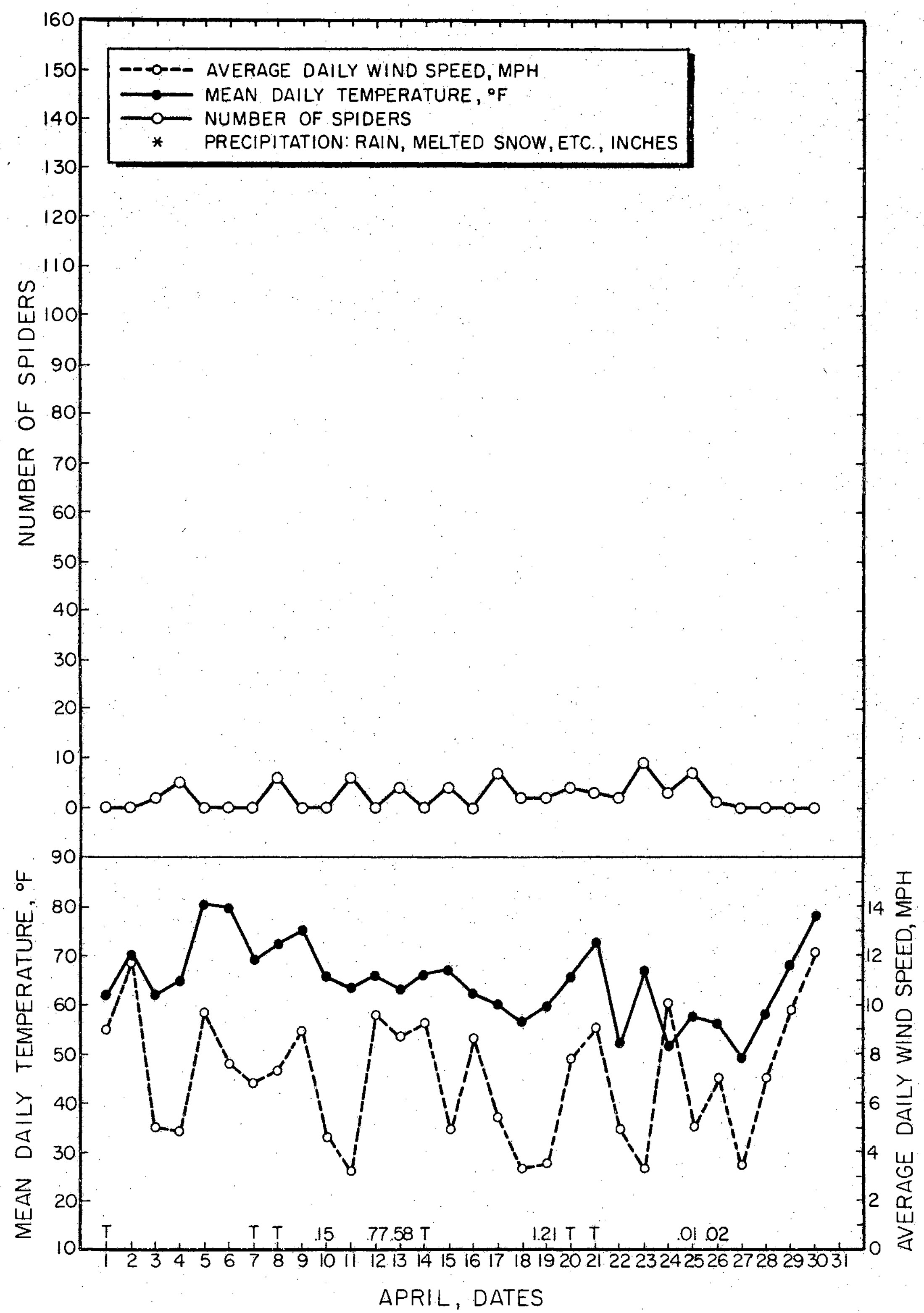

Fig. 15. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, April 1967.

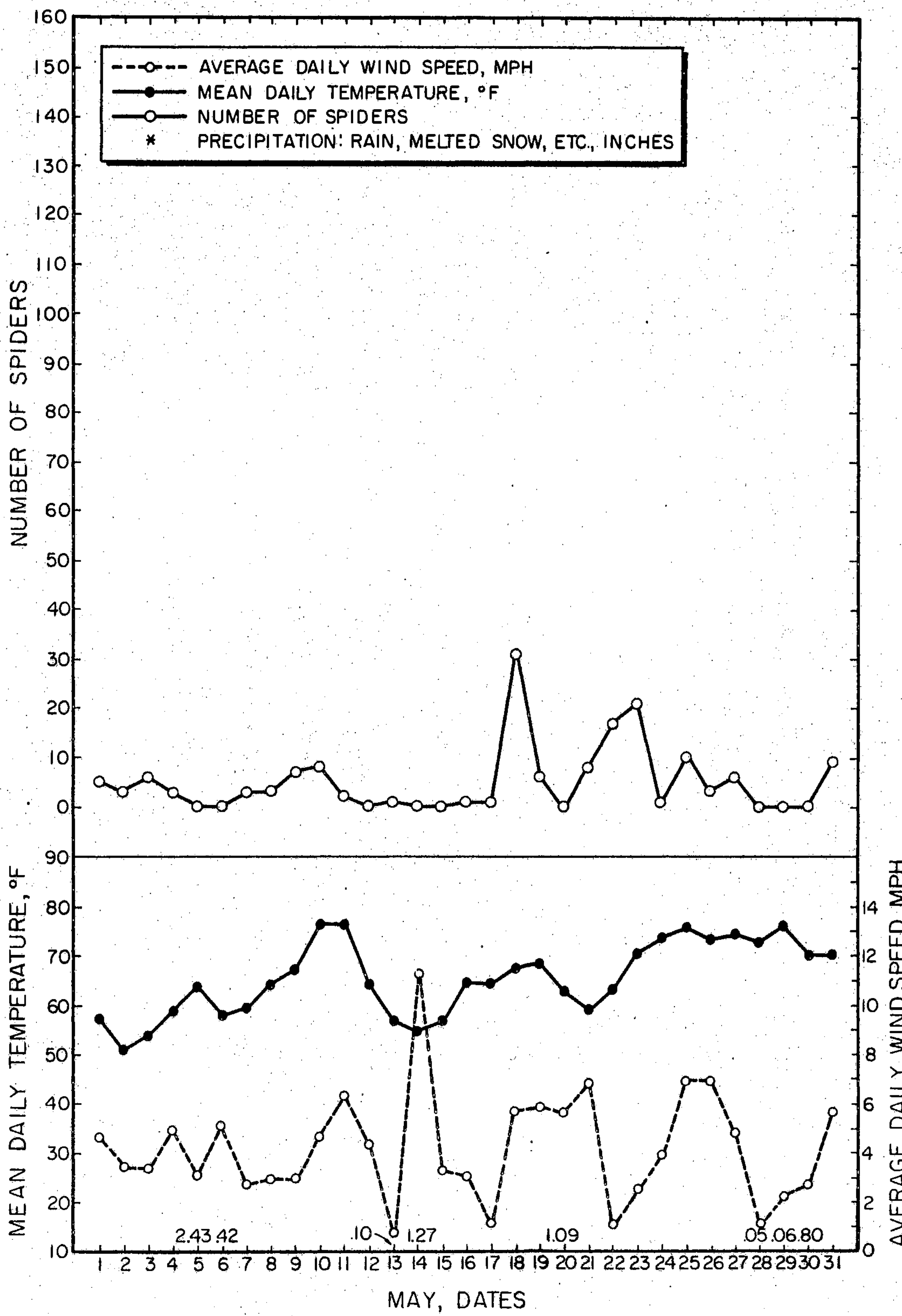

Fig. 16. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, May 1967.

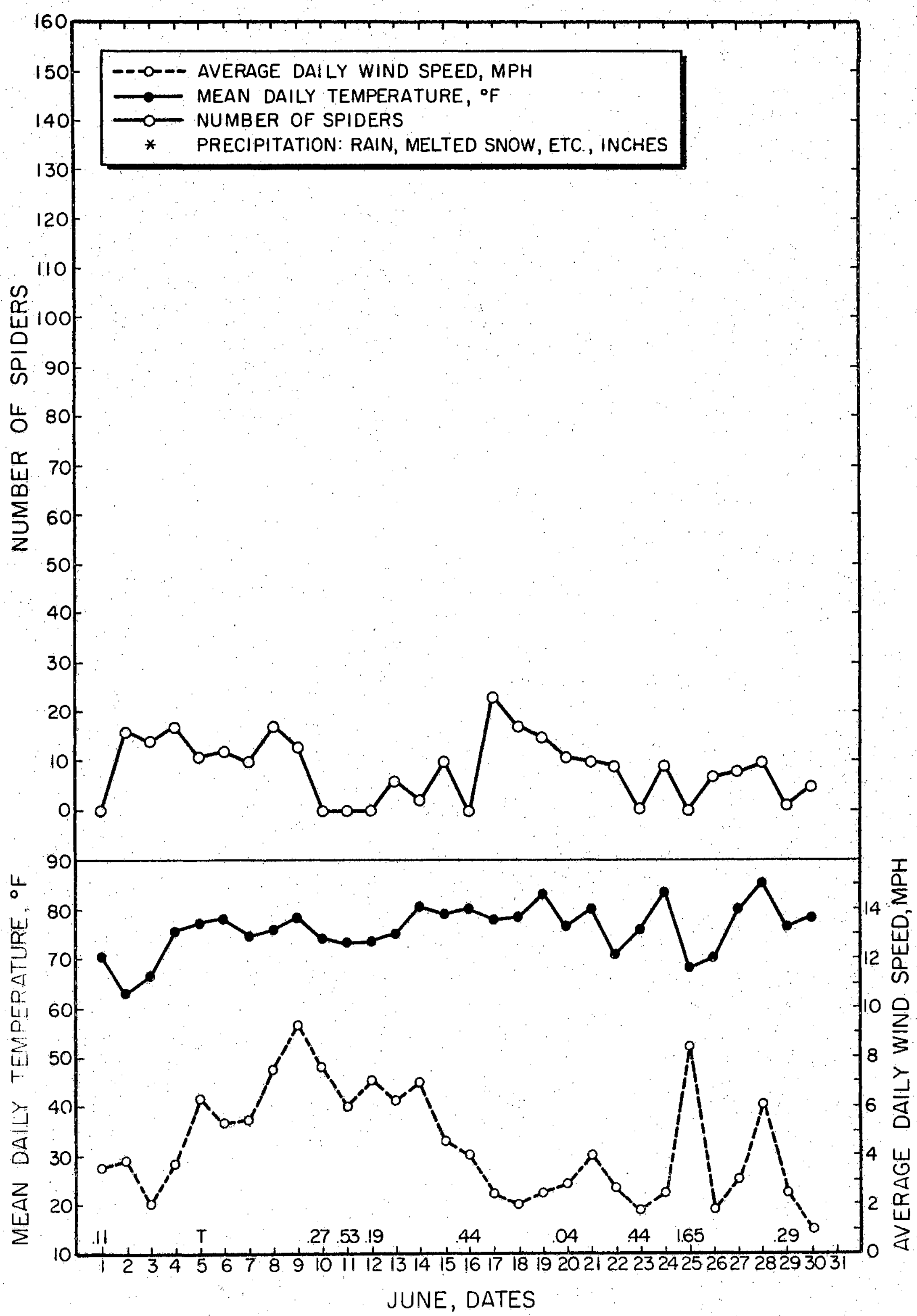

Fig. 17. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, June 1967.

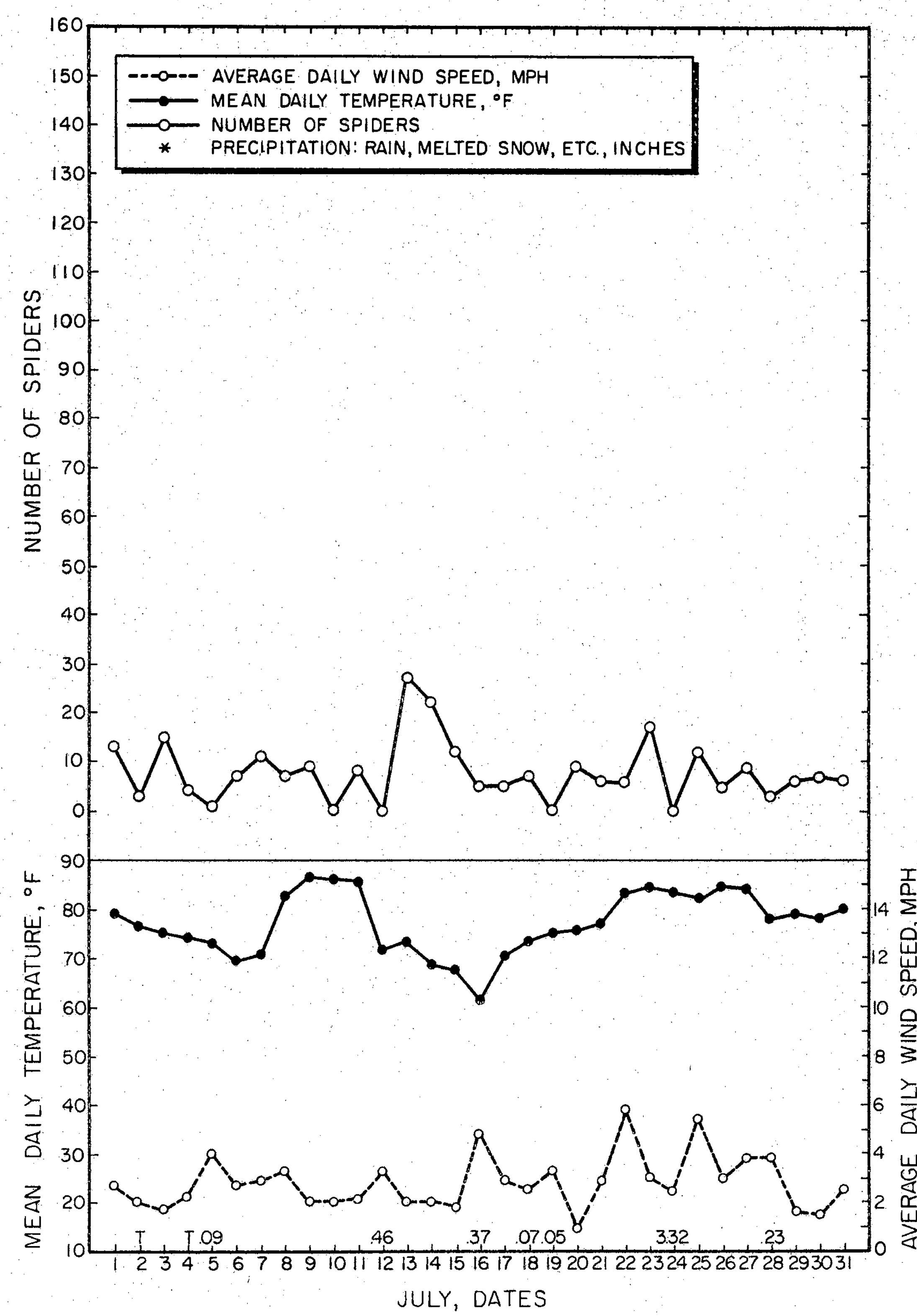

Fig. 18. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, July 1967.

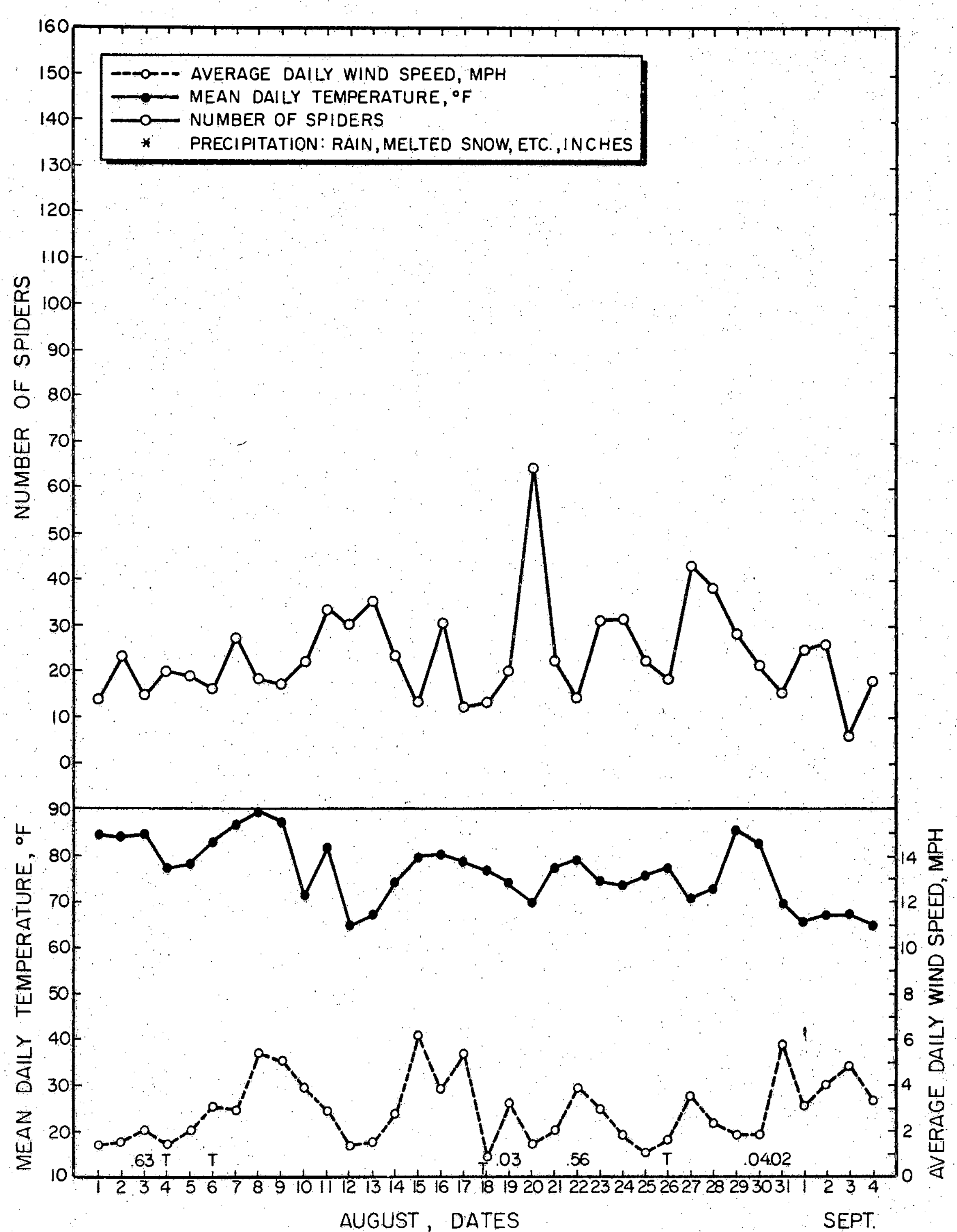

Fig. 19. Aerial dispersal of spiders in relation to ecological factors. Stillwater, Oklahoma, August 1967.

SUMMARY AND CONCLUSIONS

The life history of the spider, Phidippus audax (Hentz), was studied from oviposition through the developmental stages of hatching, molting, mating, and death of the adult spiders. The females construct a web case for each mass of eggs oviposited. An average of 8 hours is required for construction and oviposition of each mass. The incubation period of the eggs averaged 10.3 days. The first instar spider remains inside the egg mass through the first molt and does not feed. All other immature instars build a web chamber which they enter to molt. Measurements of the carpace width of each instar showed an increase in size with each molt. Based on studies with 100 laboratory-reared specimens, 15% reached the adult stage after 7 instars and 85% after 8 instars. The average time from oviposition to the adult stage was 285 days. The premating activity follows a definite pattern of movements by both males and females. The females mate only once while the males mate several times. Copulation time ranged from 2 minutes to 4 hours, with an average of 45 minutes.

The production of eggs was seasonal, with most eggs being laid in June, July, August, and September. The number of egg sacs laid per laboratory female ranged from 1 to 10 with an average of 3.8, the average number of eggs per sac was 128.4, and the oviposition period ranged from 1 to 211 with an average of 82 days. In all cases the egg sac, egg, and spiderling production was higher in laboratory than in native females. The average time required in the laboratory specimens from egg through the death of the adults was 405.2 days for the males and 487.9 for the females. In tests on mortality of laboratory P. audax, 79% of 100 spiders reached the adult stage, with most of the deaths occurring in the early instars while in the process of molting.

P. audax eggs (just before hatching) and young spiderlings could be stored at a temperature of 52 F. and a relative humidity of 60% without further development of the eggs or spiderlings.

In feeding tests with P. audax and O. salticus 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 only on the small, soft-bodied insects used in the test, while the larger spiders preferred the larger insects.

In spider aerial dispersal studies eight identifiable and possibly three or four more unidentified families were collected. About half of the total number of spiders taken belonged to the family Oxyopidae, and most of these to the species Oxyopes salticus. Most of the larger species of spiders that disperse through the air do so when they are immature. About half the total number of spiders were collected during September.

Most dispersal of the immature spider forms occurred at temperatures between 60 and 70 F., when average wind velocity was below 6 mph, and during periods when there was no precipitation. Some spiders were collected during every month of the year at Stillwater, Oklahoma.

Because of the economic importance of spiders in controlling insects attacking grain sorghums and insects in other crops, data regarding their biology are necessary in developing techniques for their mass rearing and possible liberation as biological control agents. The above information on Phidippus audax (Hentz) is of value in this regard. The techniques developed here should be of value in studying the biology and feeding habits of other economically important spiders. It is hoped that the information obtained in this study and in previous studies by the author will stimulate further research on spiders in regard to their importance in insect control.

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Doctor of Philosophy

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