OVERWINTERING BIOLOGY OF THE COTTON APHID, *APHIS GOSSYPII* GLOVER, IN CALIFORNIA'S SAN JOAQUIN VALLEY

J. J. Cisneros, L. D. Godfrey and K. E. Keillor
Department of Entomology, University of California
Davis, CA
P. B. Goodell and C. M. García
UC Statewide IPM Project
Parlier, CA

Abstract

Field and laboratory studies were conducted in 1998-2000 on the biology and life history traits of the overwintering cotton aphid morphs. Cotton aphids in California overwinter as both, viviparous individuals and eggs. Low numbers of aphid immature and adults were found on annual winter weeds such as whitestem filaree, prickly lettuce, shepherd's purse, chickweed, and London rocket, and some individuals were also observed on the new growth of citrus trees throughout the winter. Conversely, large numbers of cotton aphid eggs were found on pomegranate orchards during the winter period. The pomegranate orchards surveyed during this study harbored substantial number of fundatrices (first generation of asexual aphids that develop from eggs) early in the spring (February), which in a few weeks built up to large aphid populations with numerous alates (April). These alates may play an important role in colonizing other spring-summer crops, making the pomegranate host a potentially important source of aphids in the San Joaquin Valley. The preliminary laboratory experiments showed that the sexual females (oviparae) required to mate to lay eggs, and that multiple mating in the females increased oviposition 2-3 times when compared to females that mated once. The average number of eggs produced by a multiple-mated ovipara was 4.5 eggs. Eggs required cold temperatures to break dormancy (< 6°C). The preliminary degree-day study showed that the aphid eggs can develop at temperatures above 5.55°C and require about 240 degree-days to hatch. In addition, the fundatrices can also develop at temperatures above 5.55°C and required 115 degree-days to reach the adult stage. The implications of these results in developing and designing alternative aphid management plans are discussed.

Introduction

The cotton aphid, *Aphis gossypii* Glover, is an important pest in many crops around the World, with more than 300 plants reported as hosts. In California, it is found infesting citrus, melons, cotton, among other crops. Only in cotton, the economic impact of this pest to the California industry in 1997 totaled $34 million in crop loss and $38 million in control costs (Williams 1998). Considerable research has been conducted on this pest in California cotton in the 1990's mainly focusing on economic thresholds (Rosenheim et al. 1995, 1997, Godfrey et al. 1997, Godfrey and Wood 1998) and developing management tools. Even though these studies are very important in establishing a robust IPM program, we are not aware of any study that has focused on the aphid seasonal dynamics, especially the biology of this insect during the winter.

Before the present study, little was known about where the cotton aphid overwinters in California and in what stage (i.e., viviparae, eggs, or both). In the 1940's, it was believed that only winged and apterous parthenogenetic females (viviparae) occurred throughout the year in California (Essig 1938). However, Swift observed sexual forms on squash under greenhouse conditions (Swift, 1958). Unfortunately, he was unsuccessful in finding sexual individuals in the field. Thus, that study has been the only report on sexual forms in California until today. Conversely, alate males and sexual females (oviparae) have been reported in other states. O'Brien and colleagues (1990) reported finding males and oviparae on cotton in Mississippi during late November. An inspection of specimens deposited in the National Collection of Insects housed at Beltville, Maryland showed that sexual forms also occur in Massachusetts, Kansas, Washington DC and New Mexico (O'Brien et al. 1990).

Aphid species have very complex life cycles in which they alternate sexual with asexual reproduction, especially in locations with harsh winters. Thus, sexual forms (alate males and oviparae) are produced during the fall, they mate, and the oviparae lay eggs. These eggs are the aphid overwintering stage. The eggs hatch during the spring, producing a first generation of aphids known as fundatrix. These fundatrices reproduce asexually as well as their descendants throughout the spring and summer until fall, when the sexual forms are produced again, completing the cycle. The cotton aphid belongs to the Aphididae family. Members of this family are known for alternating host plants throughout the year. Thus, the asexual reproduction, or parthenogenesis, occurs mainly in what is known as "secondary host" or summer host, meanwhile the mating and the oviposition occurs in the "primary host" or winter host (Dixon 1998). Kring in Connecticut (1958) described the host-alternating behavior of the cotton aphid as facultative, with aphids being able to complete the total egg-to-egg cycle on a single host (*Catalpa bignoides* Walt. or *Hibiscus syriacus* L.). A similar pattern was observed in Japan with aphids breeding all year around on *H. syriacus* L and with sexual forms produced during the fall (Inaizumi 1980) . In this last study, overwintering viviparous aphids were also observed reproducing on *Veronica persica, Capsella bursa-pastris*, and *Lamium amplexicaule*, and migrating during the spring to other host plants. O'Brien and colleagues (1993) also reported overwintering viviparous aphids in Mississippi and Louisiana living on *Oenothera speciosa* Nutt., *L. amplexicaule* L., and *Rumex* spp.

The objective of the present study is to determine the life history of cotton aphids in California, including host plants/weeds utilized, population buildup in crops other than cotton, overwintering strategy, presence of a sexual stage, and other aspects of the life cycle.

Materials and Methods

Field and laboratory experiments were conducted in 1998-1999 and 1999-2000, respectively, to study the biology of the cotton aphid during the winter season. Field experiments included the survey of multiple host plants in the San Joaquin Valley of California meanwhile the laboratory studies involved manipulative experiments with the sexual forms, the egg stage, and the fundatrices.

Cotton Aphid Survey on Winter Weeds and Key Crops

The survey was conducted in 1998-99 (fall/winter/spring) in four different locations: Tulare, Fresno, Merced, and Kern Counties. Within each sample location, cotton aphids (eggs, immatures, and adults) were counted and collected during three 5-minute search periods from several potential host species. Samples were taken biweekly from areas with history of aphid out-breaks; especially areas where infestations have began early in the cotton production season. The host plants searched were pomegranates, citrus, and several broadleaf weeds (whitestem filaree, prickly lettuce, shepherd's purse, chickweed, and London rocket).

Laboratory Experiment 1: Sexual Forms

Sexual aphids (alate males and oviparae) were collected from a pomegranate orchard located in Tulare Co. on 20 November 1999. During the collection, mating events in the field were commonly observed and oviposition was already occurring. Under laboratory conditions, sexual females were observed mating multiple times. It is possible that this phenomenon also occurs under field conditions. The objective of this experiment was to determine the advantage of multiple mating versus

Reprinted from the *Proceedings of the Beltwide Cotton Conference*
Volume 2:1059-1063 (2001)
National Cotton Council, Memphis TN

mating once. For that, field-collected immature sexual females were reared on pomegranate twigs under laboratory conditions. Once the oviparae reached the adult stage (22 November) they were assigned to one of three treatments: no males (i.e., the female stayed virgin), one male (i.e., female was allowed to mate once and then the male was removed), and four males (i.e., female was allowed to mate multiple times). The oviparae were kept alive on pomegranate twigs throughout their life span enclosed in small cages. The aphids from the three treatments were kept under room temperature conditions throughout the duration of the experiment. Eggs laid by these females were counted at the end of the experiment.

Laboratory Experiment 2: Egg Stage

Oviparae collected from the field for the previous experiment were also used for this experiment. Pomegranate twigs were collected at Davis, Yolo County, from trees that were not infested with aphids, and this material was used as a substrate for oviposition. Females were transferred to these twigs on 21 November and allowed to lay eggs on them for a period of 12 hours. After this period, females were removed. A total of 80 twigs with eggs were obtained and divided into two groups. The first group of eggs was accommodated into one single chamber/temperature regime (6°C) for two months before assigning them to the different chambers/temperature treatments. The objective of this pre-treatment was to expose the eggs to cold temperatures to break the dormancy. After the cold pre-treatment, the twigs were randomly assigned to one of 10 chambers programmed with different constant temperature regimes. These temperature treatments were 6, 8.5, 12, 13, 18.5, 21, 24, 25, 26, and 28°C. To standardize the photoperiod in all chambers, eggs were kept in the dark throughout the duration of the experiment. The second group of eggs was assigned to the same temperature treatments than the previous group but without the cold pre-treatment. Eggs in both groups were monitored daily to determine their hatching time.

Laboratory Experiment 3: Fundatrix

Twigs harboring eggs were collected from a pomegranate orchard located in Tulare Co. on 3 January 2000. Pomegranate trees were dormant (i.e., no leaves), and aphid eggs, the only stage of the cotton aphid present, were already exposed to cold temperatures for several weeks (important to break the dormancy). These twigs were placed in a chamber at 13°C. Eggs were monitored daily, and once nymphs eclosed they were transferred to new twigs (one nymph per twig). These new twigs were obtained one week before the eggs started to hatch from pomegranate trees located at Davis, Yolo Co. and placed in a chamber set up at 28°C to promote the growth of the dormant buds until they were used for the experiment. The nymphs eclosed from eggs were randomly assigned to one of eight chambers that were programmed to produce different temperature regimes. These temperature treatments were: 8.5, 12, 13, 15, 18.5, 21, 25, and 28°C. There were a total of 58 replicates (6-8 replicates for each temperature regime). The development of the nymphs was monitored daily and the dates when they reached adulthood and produced their first offspring were recorded for each aphid.

Results

Cotton Aphid Survey on Winter Weeds and Key Crops

Results from the survey showed that both, viviparous aphids and eggs can be found during the winter season in California. Low populations of asexual cotton aphids were found on winter annual weeds throughout the winter-spring months, Tulare Co. site (Fig.1). In Kern Co., viviparous aphids were also found on citrus during the fall and beginning of the winter but their densities were very low (Fig. 2) and confined to the growing parts of the trees. In all four sites, pomegranates had the highest densities of aphids during the winter/spring months, reaching their peak in spring (Fig. 3). A closer look at the Tulare Co. site showed that only eggs were found during the January and February months, and the fundatrices (first viviparous aphids emerging from these eggs) were first observed at the end of February. These fundatrices reproduced parthenogenetically and at least a couple of generations occurred before reaching the largest aphid populations in late April (~500 individuals counted in a 5-minute search). Alate production started in mid April (Fig. 4). These alates are considered the colonizers of several crops grown in the valley during the spring-summer season. Ongoing studies have shown that sexual forms and egg production can occur in pomegranates as early as mid November and oviposition can continue for several weeks.

Laboratory Experiment 1: Sexual Forms

Some aspects in the biology of the sexual forms of the cotton aphid were investigated in this study. During the experiment, we reared some individuals collected from a pomegranate orchard that turned into alate males. Thus, at least some of the males are produced in situ instead of coming from other host plants, as suggested by the literature reviewed for aphids in the Aphididae family. Results from the laboratory experiment demonstrated that virgin females do not lay eggs, despite the presence of eggs in their bodies (dissected females showed 2-3 "developed" eggs). Thus, mating is required not only for fertilization of the eggs but also for the induction of oviposition. In addition, oviparae that mated multiple times laid 2-3 times the number of eggs than females that mated singly: 4.5 and 1.8 eggs/female, respectively (Fig. 5).

Laboratory Experiment 2: Egg Stage

Results of this experiment showed that the aphid eggs require cold temperatures to break the dormancy. Thus, none of the eggs from the group of twigs that was allocated directly into the different chambers/temperature treatments hatched. The other group of eggs that was pre-treated with cold temperatures (6°C) hatched but in very low numbers. It is possible that cotton aphid eggs require colder temperatures to break their dormancy. The hatching time ranged from 70 days in the 8.5°C chamber to 16 days in the 18.5°C chamber. All eggs in chambers adjusted to temperatures above 18.5°C dried out, probably as a result of low humidity. The present data are based on the few eggs that hatched (a total of 11 eggs), therefore, these results should be considered preliminary. The analysis showed that the aphid eggs developed at temperatures above 5.55°C and required about 240 degree-days to hatch (Fig. 6). We are currently repeating this experiment (winter 2000-2001) with a larger number of eggs (>500 eggs) and pre-treating the eggs with colder temperatures (i.e., 4.5°C) to facilitate breaking the dormancy.

Laboratory Experiment 3: Fundatrix

The methodology employed in this experiment (rearing fundatrix aphids on pomegranate twigs) showed that cotton aphids could be kept alive until they reach adulthood by feeding on open buds. Most fundatrices, once placed on a particular bud, stayed there throughout their development. There was a negative correlation between the number of days that it took the aphid to reach adulthood and the temperature in which the aphid developed. Even at low temperatures, such as 8°C, the aphids were able to develop to adult and produce offspring. However, aphids showed a higher mortality at this temperature (8°C) compared to the other temperatures (Table 1). The range of days for the developmental time from the lowest (8°C) to the highest temperature (28°C) was 37 to 5.3 days, respectively. There was also a negative correlation between the numbers of days needed by the adults to produce their first offspring and the temperature in which they were reared. Thus, aphids that developed at the highest temperature (28°C) produced their first progeny less than 24 hours after reaching the adult stage; meanwhile aphids that were reared at the lowest temperature (8°C) spent an average of 7.5 days before they started to produce their first progeny (Table 1). A degree-day analysis showed that the fundatrices could develop at temperatures above 5.55°C and that they required 115 degree-days to reach adulthood (Fig. 7).

Summary

The seasonal dynamics of the cotton aphids were studied, concentrating on the overwintering period. Cotton aphids overwinter primarily as eggs on pomegranates and as viviparous individuals on winter weeds and citrus. The substantial number of aphids found on pomegranates (eggs during the winter, and viviparous during the spring), makes this host plant potentially an important source of aphids for the spring-summer crops. Further studies should focus on the role that this overwintering host plays in the maintenance of this species in California. Laboratory experiments have shown that sexual females required mating to lay eggs, and multiple mating doubled their egg production. Eggs developed at temperatures above 5.55°C and required ~240 degree-days to hatch. Fundatrices (first generation of aphids coming from these eggs) also developed at temperatures above 5.55°C and required 115 degree-days to reach the adult stage. The development of the knowledge of cotton aphid biology during the winter (off-season period of cotton) is important in designing alternative management plans. Timely targeting oviparae or fundatrices with augmentative releases of natural enemies (i.e., entomopathogens, parasitoids, etc) and/or using chemical sprays (i.e., dormant oils) for egg control are potential tools that can be used to lessen the buildup of aphids on pomegranates in spring, and therefore, reducing the aphid source for other crops such as cotton.

Acknowledgments

We thank Christine Alexander and Richard Lewis for their invaluable field and laboratory assistance. This research was supported by the Cotton Incorporated California State Support Program and the University of California Statewide IPM Program.

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Table 1. Effect of the temperature treatments on the developmental time (i.e., from nymph to adult) and generation time (i.e., when the aphid produces its first offspring) of the fundatrices.

Temperature treatment (°C)	Number of replicates	Percentage of survivors	Develop-mental time (days)[a]	Generation time (days)[a]
8.5	8	50	37.0 ± 0.7	44.5 ± 0.6
12	8	87.5	16.7 ± 0.6	18.5 ± 0.7
13	6	83.3	16.4 ± 0.7	18.4 ± 0.4
15	8	75	13.3 ± 0.6	14.6 ± 0.5
18.5	6	83.3	9.2 ± 0.6	10.2 ± 0.7
21	6	83.3	6.4 ± 0.7	7.0 ± 0.6
25	8	87.5	5.9 ± 0.5	6.3 ± 0.5
28	8	87.5	5.3 ± 0.6	5.3 ± 0.6

[a] Means ± SE.

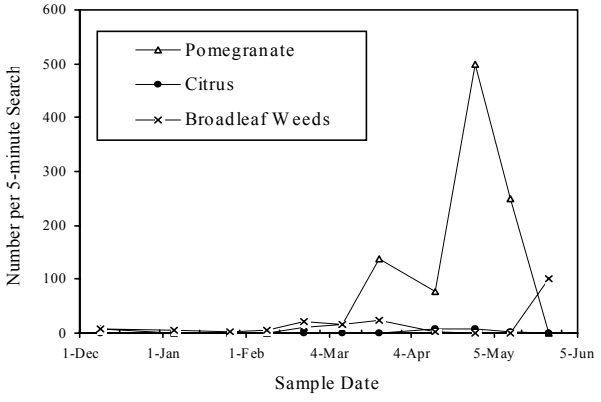

Figure 1. Cotton aphid population densities (immatures and adults) found in different host plants during the winter-spring season; Tulare. Co., 1998-99.

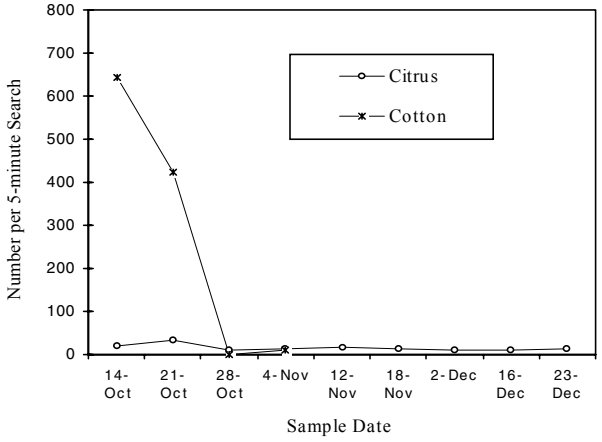

Figure 2. Cotton aphid population densities (immature and adults) on cotton and citrus during the fall/winter period; Kern Co., 1998.

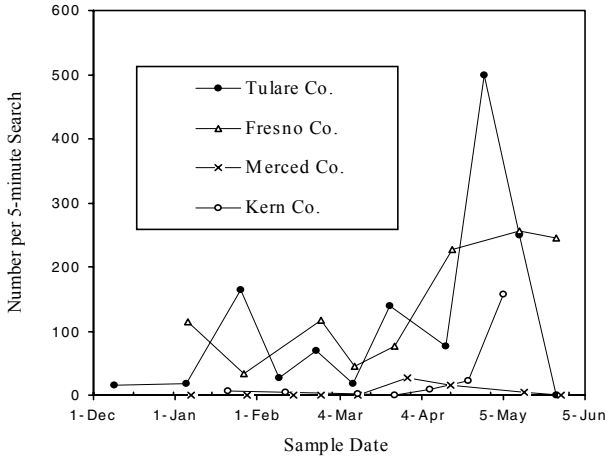

Figure 3. Cotton aphid population densities (all stages) found on pomegranates during the winter-spring season; San Joaquin Valley sites, 1998-99.

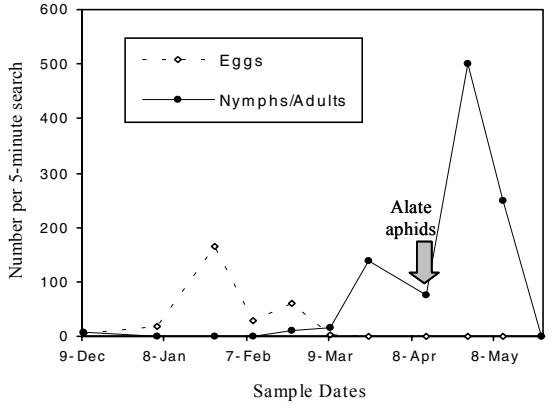

Figure 4. Cotton aphid population density from a pomegranate orchard during the winter-spring season; Tulare Co., 1998-99.

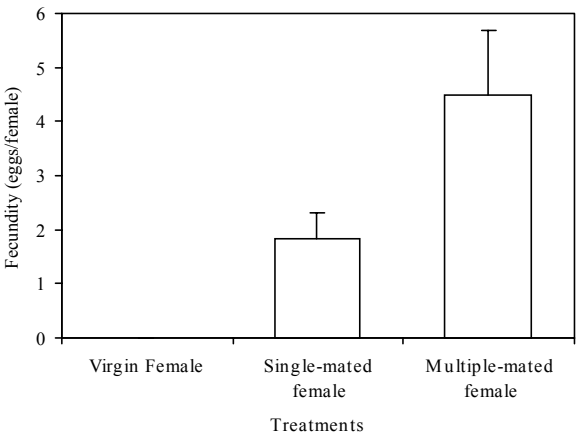

Figure 5. Effect of mating in the fitness (i.e., fecundity) of the cotton aphid *Aphis gossypii* Glover.

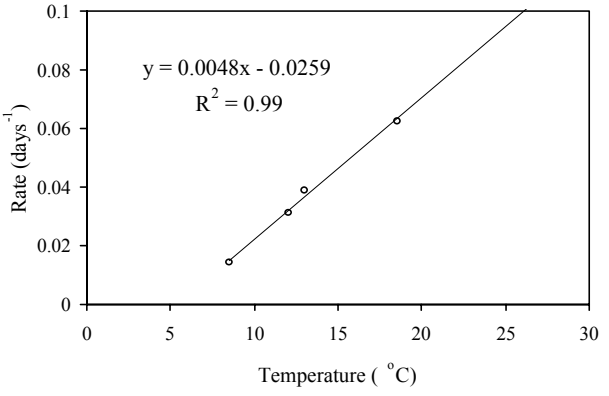

Figure 6. Effect of temperature on the egg developmental time.

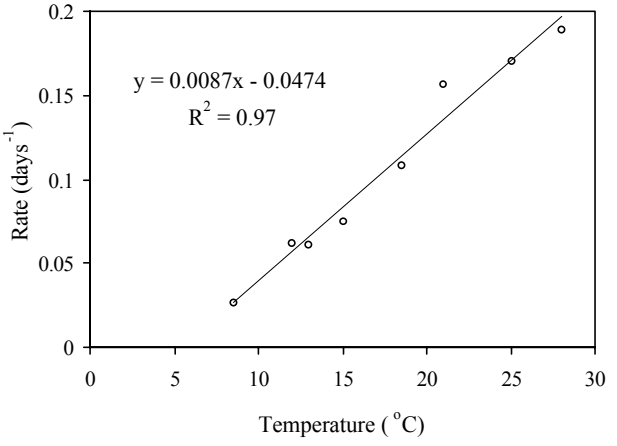

Figure 7. Effect of temperature on the developmental time (i.e., from nymph to adult) on the fundatrices.