COTTON APHID POPULATION DYNAMICS MODELING M.N. Parajulee Texas Agricultural Experiment Stations Lubbock, TX J.E. Slosser Texas Agricultural Experiment Stations Vernon, TX L.T. Wilson Texas Agricultural Experiment Stations Beaumont, TX

Abstract

During the past three years, significant progress has been made toward developing a cotton aphid, *Aphis gossypii* Glover population dynamics model. Two life history parameters, including fecundity and mortality, have been identified as the most influential determinants in cotton aphid population dynamics in the Texas High Plains and Rolling Plains regions. Factors affecting fecundity and mortality parameters have been identified. Fecundity and mortality schedules have been described as functions of temperature and aphid age. The density-dependent effect on fecundity has also been described and incorporated into the fecundity function. The effect of natural enemy inflicted mortality and plant quality parameters on cotton aphid dynamics is being described. A time-varying distributed-delay protocol was used to simulate variation in development times, with the time-step of 26 DD (>7.4 °C). Then, the fecundity and survivorship schedules were applied as insects moved through stages. The model structure has been completed and a web-based delivery approach of the model is under construction.

Introduction

The cotton aphid, *Aphis gossypii* Glover, is an intermittent problem in west Texas cotton; in some years the aphid is a secondary pest (Leser 1994), while in other years, years in which widespread outbreaks occur, the aphid is a severe and economically significant pest (Leser et al. 1992). Currently, there are no accurate methods of predicting the density to which aphid populations will develop in cotton fields. Ample amount of biological and ecological data on cotton aphids are now available (Ebert and Cartwright 1997, Slosser et al. 1998) for us to be able to develop a population dynamics model. Nevertheless, the population growth parameters on cotton aphids from the field are largely limited. The objective of this study was to develop a population dynamics model based on available data and continue to improve the model parameters as more data become available through laboratory and field experimentation that are specifically designed to generate data for the modeling purpose.

Materials and Methods

Model Parameterization

Fecundity Function. Aphid fecundity was modeled as a hyper-power function (Stinner et al. 1975) of temperature and aphid age that would give a sigmoid cumulative fecundity curve as follows:

 $F_i = t^* (1-\alpha)^{t'*\alpha t''}$ where F_i = cumulative fecundity on degree-day *i*,

 $\alpha = \frac{DD100 - DDi}{DD100 - DD0}; \qquad \text{t, t', t''} = \text{f(temp)}; \qquad \text{DD0 and } \text{DD100} = \text{f(temp)};$

DD0 = Degree-days (>7.4 °C) required for an aphid to reach the reproductive stage;

DD100 = Degree-days (>7.4 °C) accumulated by an aphid during its entire life;

DDi = Degree-days (>7.4 °C) accumulated by an aphid from birth to i^{th} day to which the fecundity prediction is desired.

The above equation first estimates the relative fecundity rate (a sigmoid function of aphid age and temperature), and then the function is multiplied with the maximum fecundity function at different temperatures (parameter *t*). The database for this function included aphid fecundity profiles for temperatures ranging from 10 to 35 °C (Xia et al. 1999). Degree-days (*DD0*, *DD100*, and *DDi*) were calculated using a common threshold of 7.4 °C for all temperatures. A nonlinear iterative regression was used to estimate the parameter values and their significance using JMP Statistical Software (SAS Institute 2000).

$$M_i = (1-\alpha)^{t^*\alpha} d^{t'}$$
 where M_i = percentage cumulative mortality on degree-day *i*,

$$\alpha = \frac{DD100 - DDi}{DD100 - DD0}; \qquad t, t' = f(temp); \quad DD0 \text{ and } DD100 = f(temp);$$

DD0, DD100, and DDi were as in fecundity function above.

Mortality function was derived by first calculating the stage-specific proportional mortality (for each instar and 15 adult age classes) for each of the 6 temperature regimes. We then calculated the aphid age (degree-days >7.4 °C) corresponding to each mortality value. Mortality function was then derived based on temperature and aphid age. A nonlinear iterative regression was used to estimate the parameter values and their significance using JMP Statistical Software (SAS Institute 2000).

Density Dependent Effect on Fecundity (Crowding Effect). The density dependent effect on fecundity was modeled as follows:

$$F_{j} = \frac{e^{\left(a^{*}N^{b}\right)^{DD_{j}}}}{e^{\left(a\right)^{DD_{j}}}} \text{ where } F_{j} = \text{ Total fecundity on day } j, DD_{j} = \text{Degree-days (>7.4 °C) on day } j.$$

<u>Effect of Photoperiod on Fecundity.</u> The effect of photoperiod on fecundity was modeled using a polynomial function $y = a + \frac{b}{x} + \frac{c}{x^2} + \frac{d}{x^3}$, where y = lifetime fecundity, x = photoperiod (h) ranged from 10 to 18 hours; a, b, c, d are parameters.

Effect of Plant Quality on Fecundity. The relationship between plant quality parameters (% leaf nitrogen and % leaf moisture) and aphid abundance is being established and the equation will be used to scale fecundity schedules.

<u>Effect of Arthropod Predators on Cotton Aphid Mortality.</u> Equations are being developed to describe predation effect on cotton aphid population dynamics. Functional response and predation efficacy of convergent lady beetle, *Hippodamia convergens* Guerin-Meneville, have been estimated based on both laboratory and field-cage studies. We are in the process of estimating predator power and predator efficacy (Tamaki and Long 1978) based on field-cage studies.

Model Development

A time-varying distributed-delay protocol (Manetsch 1976) was used to simulate variation in development times. That is, some individuals in any given time-step age faster than the others to skip the next time-step, while other individuals age normally to reach to the next time-step, and some age slower to remain in their original time-step. Therefore, individual aphids are moved through stages as they age. The maximum lifespan of an aphid (670 DD at 25 °C) was divided into 25 age-classes (cells), so the approximate time-step in this case was approximately 26 DD. The aging process was adjusted to account for day-to-day variation in degree-day accumulation. Then, the fecundity and survivorship schedules were applied as insects moved through stages. The density dependent effect and photoperiodic effect were applied to fecundity. Predation effect and plant nutrition effect are being incorporated. The sum of all individuals across all stages in a distributed-delay matrix gives the population size. The model structure has been completed and a web-based delivery of the model is under construction.

Results and Discussion

Model Parameterization

Fecundity Function. The hyper-power function described the cumulative fecundity very well at all temperature regimes, with 99% of the variability explained (Table 1, Fig. 1). Aphid fecundity was lowest at 10 °C and increased significantly at every 5 °C temperature increase up to 25 °C. Fecundity then declined significantly for the next two 5 °C temperature increments. Thus, the best temperature for maximal fecundity was 25 °C.

<u>Mortality Function</u>. The hyper-power function also described the cumulative mortality schedules at all temperature regimes, with 98% of the variability explained (Table 2, Fig. 2). Aphid mortality was highest at 10 °C and the mortality rate declined as temperature increased to 25 °C. Mortality rate again increased as temperature increased to 30 and 35 °C. However, the mortality at the highest temperature (35 °C) was lower than the mortality at the lowest temperature (10 °C). Thus, the best temperature for maximum survivorship was 25 °C.

<u>Density Dependent Effect on Fecundity (Crowding Effect).</u> The coefficient of parameters for density dependent effect on fecundity were as follows: a = -0.0122998, b = 0.2155161. Fecundity schedules were scaled using these parameters before the fecundity was applied to the distributed-delay matrix.

<u>Effect of Photoperiod on Fecundity.</u> A polynomial function adequately described the relationship between cumulative fecundity and photoperiod, with 97% of the variability explained. The parameter values for this function were as follows: a = 237.83, b = -8043.13, c = 126919.30, d = -629656.30.

<u>Effect of Plant Quality on Fecundity.</u> Preliminary analyses have been conducted to establish relationships between plant quality parameters (% leaf nitrogen and % leaf moisture) and aphid abundance. The equations have adequately described the relationship between plant parameters and cotton age (degree-days >12 °C from planting). In addition, equations have been developed to estimate cotton aphid population abundance based on plant quality parameters. We are in the process of incorporating this component into the distributed-delay matrix.

<u>Effect of Arthropod Predators on Cotton Aphid Mortality.</u> In a laboratory study, the rate of convergent lady beetle predation on the cotton aphid showed that the rate of consumption increased through time, with at least 25 aphids eaten during the first 4 hours of the experiment. At the highest density (400 aphids per petridish arena), lady beetles consumed 40 aphids in 1 h, 100 aphids in 4 h, 150 aphids in 8 h, 270 aphids in 24 h, and nearly all 400 aphids in 48 h. Predators showed a curvilinear response in the time they used to consume their prey in relation to total available time. These data demonstrate that convergent lady beetles have potential to suppress larger populations of cotton aphids through continuous feeding by changing their predation efficiency during feeding. The analysis of age-specific mortality without prey or water showed that lady beetle adults could survive for an extended period of time. The ability of a predator to survive without prey for an extended period of time delays or prevents the rebound of pest populations and is a significant factor in natural biological control. Once we calculate the predator power and predation efficiency of lady beetles from field-cage studies, we will be incorporating this component into the model.

Model Development and Delivery

The time-varying distributed delay matrix has been developed in Microsoft Excel and fecundity and survivorship models have been coupled with the matrix. After we incorporate the predation effect on mortality and plant nutrition effect on fecundity, the model should be ready for its release. We are currently writing a computer program for web-based delivery of the model (Fig. 3).

References

Ebert, T. A., and B. Cartwright. 1997. Biology and ecology of *Aphis gossypii* Glover (Homoptera: Aphididae). Southwest. Entomol. 22: 116-153.

Leser, J. F., C. T. Allen, and T. W. Fuchs. 1992. Cotton aphid infestations in west Texas: A growing management problem, pp. 823-827. *In* Proceedings, Beltwide Cotton Conferences, Nat. Cotton Council of Amer., Memphis, TN.

Leser, J. F. 1994. Management of cotton aphids: Texas style, pp. 137-141. *In* Proceedings, Beltwide Cotton Conferences, Nat. Cotton Council of Amer., Memphis, TN.

Manetsch, T. J. 1976. Time-varying distributed delays and their use in aggregative models of large systems. IEEE Trans. Syst. Man Cybern. SMC-6: 547-553.

SAS Institute. 2000. SAS user's guide: Statistics. SAS Institute, Cary, NC.

Slosser, J. E., W. E. Pinchak, and D. R. Rummel. 1998. Biotic and abiotic regulation of *Aphis gossypii* Glover in west Texas dryland cotton. Southwest. Entomol. 23: 31-65.

Stinner, R. E., G. D. Butler, Jr., J. S. Bachelor, and C. Tuttle. 1975. Simulation of temperature-dependent development in population dynamic models. Can. Entomol. 107: 1167-1174.

Tamaki, G., and G. E. Long. 1978. Predator complex of the green peach aphid on sugarbeets: Expansion of the predator power and efficacy model. Environ. Entomol. 7: 835-842.

Xia, J. Y., W. van der Werf, and R. Rabbinge. 1999. Influence of temperature on bionomics of cotton aphid, *Aphis gossypii*, on cotton. Entomol. Exp. Appl. 90: 25-35.

Temperature parameter in		
$F_i = t^* (1-\alpha)^{t'*\alpha t''}$	Parameter	Coefficient
t	Intercept	-467.76313410
	Temperature	130.71027705
	Temperature ²	-13.90170139
	Temperature ³	0.70806691
	Temperature ⁴	-0.01706201
	Temperature⁵	0.00015569
ť	Intercept Temperature	15.03802233
	Temperature ²	0.36601834
	Temperature ³	-0.01697117
	Temperature ⁴	0.00037625
	Temperature ⁵	-0.00000322
<i>t</i> "	Intercept	1.18994573
	Temperature	-0.00409036

Table 1. Coefficients of parameters estimated for cottonaphid fecundity function.

Table 2. Coefficients of parameters estimated forcotton aphid mortality function.

Temperature		
parameter in		
$M_i = (1 - \alpha)^{t^* \alpha^{t'}}$	Parameter	Coefficient
t	Intercept	2.879689
	Temperature	-0.580561
	Temperature ²	0.043818
	Temperature ³	-0.001235
	Temperature ⁴	0.000012
	Temperature⁵	15.360710
ť	Intercept	-2.577818
	Temperature	0.154616
	Temperature ²	-0.003831
	Temperature ³	0.000034
	Temperature ⁴	2.879689
	Temperature⁵	-0.580561



Figure 1. Cumulative fecundity as a function of temperature and aphid age. Numbers at the end of each curve indicate the temperatures at which the corresponding curves were generated. Scatter points represent observed values and solid lines represent model estimates.



Figure 2. Cumulative percentage mortality as a function of temperature and aphid age. Numbers at the end of each curve indicate the temperatures at which the corresponding curves were generated. Scatter points represent observed values and solid lines represent model estimates.



Figure 3. Selected windows of the cotton aphid population dynamics model, showing the information page, user-input pages, and the model output page.