Comparative life table of *Aphis craccivora* (Hem.: Aphididae) on host plant, *Robinia pseudoacacia* under natural and laboratory conditions

R. Jalalipour, A. Sahragard*, Kh. Madahi and A. Karimi-Malati

Department of Plant Protection, Faculty of Agricultural Sciences, University of Guilan, Rasht, Iran.

*Corresponding author, E-mail: sahragard@guilan.ac.ir, ahad.sahragard@gmail.com

Abstract

The cowpea aphid, *Aphis craccivora* Koch, is an important pest of *Robinia pseudoacacia* Frisia. The life table parameters of *A. craccivora* were determined under natural (16- 33ºC and 32-89% RH) and laboratory (25 ± 1ºC, 70 ± 5% RH and a photoperiod of 16:8 h (L: D) conditions. The data were analyzed using the age-stage, two-sex life table theory. Each experiment was replicated 45 times for each condition. There were significant differences between the survivorship, fecundity and longevity of the *A. craccivora* in laboratory and natural conditions. Under natural conditions, *A. craccivora* had a significantly shorter nymphal developmental time, adult longevity and life span than those reared under laboratory condition. However, the intrinsic rate of increase (*r*), net reproductive rate (*R*₀), the finite rate of increase ( ) and gross reproductive rate (*GRR*) in laboratory were higher than those obtained in the field except for higher mean generation time (*T*) resulted from field experiment. The results provide better understanding of the population dynamics of *A. craccivora* under field condition to effectively control the pest through integrated pest management (IPM) programs.

Keywords: *Aphis craccivora,* generation time, intrinsic rate of increase, life table parameters, natural condition

چکیده

جدول زندگی مقایسه‌ای (Aphididae : :Hem) *Aphis craccivora* روی میزبان گیاهی *Robinia pseudoacacia* در شرایط مزرعه و آزمایشگاه

رضا جلالی پور، احد صحراگرد، خدیجه مداحی و آزاده کریمی‌ملاطی

شته اقاقیا، Aphis craccivora Koch آفت مهم اقاقیا، *Robinia pseudoacacia* Frisia است. ویژگی‌های جدول زندگی *A. craccivora* در شرایط طبیعی (دمای ۱۶–۳۳ درجه سلسیوس و رطوبت نسبی ۳۲–۸۹ درصد) و آزمایشگاهی (دمای ۲۵±۱ درجه سلسیوس، ۷۰±۵ درصد و دوره نوری ۱۶ ساعت روشنایی و ۸ ساعت تاریکی) تعیین شدند. داده‌ها با استفاده از نظریه سن– مرحله جدول زندگی دوجنسی تجزیه و تحلیل شدند. آزمایش‌ها در هر کدام از شرایط ۴۵ بار تکرار شدند. تفاوت معنی‌داری بین بقا، باروری و طول عمر *A. craccivora* در شرایط آزمایشگاهی و طبیعی وجود داشت. در شرایط طبیعی، *A. craccivora* به طور معنی‌داری طول دوره پورگی، طول عمر حشرات کامل و چرخه زندگی کوتاه‌تری نسبت به شرایط آزمایشگاهی داشت. به هرحال، نرخ ذاتی افزایش (r)، نرخ خالص تولید مثل (R0)، نرخ متناهی آفزایش جمعیت (λ) و نرخ ناخالص تولید مثل (GRR) در شرایط آزمایشگاهی بالاتر از مقادیر به دست آمده در شرایط طبیعی بودند. در هر حال، مدت زمان نسل در شرایط طبیعی طولانی‌تر از شرایط آزمایشگاهی بود. به طورکلی، نتایج این مطالعه نشان داد که شرایط متفاوت (مزرعه و آزمایشگاه) تاثیر معنی‌داری روی دوره‌های رشد و ویژگی‌های جدول زندگی *A. craccivora* داشتند و گریز از نتیجه‌گیری آشکار مبنی بر این که باید از تعمیم نامناسب نتایج آزمایشگاه برای کاربرد در شرایط طبیعی جلوگیری کنیم، سخت است. نتایج به دست آمده در اینجا می‌تواند در درک پویایی جمعیت *A. craccivora* در شرایط مزرعه و توسعه برنامه مدیریت تلفیقی موثر نیز به ما کمک کند.

واژگان کلیدی: *Aphis craccivora،* مدت زمان نسل، نرخ ذاتی افزایش، ویژگی های جدول زندگی، شرایط طبیعی

Introduction

Black locust, *Robinia pseudoacacia* Frisia*,* is a nitrogen-fixing leguminous tree that is widely planted in the temperate regions of North America, Europe and Asia for its resistance to many environmental stresses such as drought, low and high temperature, air pollutants and low fertility (Surles *et al*., 1989; Dini-Papanastasi & Panetsos,

2000). Therefore, *R. pseudoacacia* is an economically and ecologically important tree species in the world.

One of the most important pests of black locust is *Aphis craacivora* Koch (Hemiptera: Aphididae). The cowpea aphid, *A. craccivora*, is considered as a major pest of important economic crops like alfalfa, beans and

cowpea in Asia, Africa and Latin America (Singh & Jackai, 1985; Pettersson *et al*., 1998). It can transmit plant pathogenic viruses (Coceano & Peressini, 1989; Chen *et al*., 1999). The early season injuries caused by this pest on *R. pseudoacacia* induce severe malformation of the newly established leaves (Rakhshani *et al*., 2005).

Understanding the factors affecting the aphid's development and implementing this information into forecast models, may increase the efficacy and success of control methods (Kührt *et al*., 2006). Understanding the ecology of a pest and estimating the growth parameters and reproduction potential of insect population is an important issue for successful theoretical and applied population ecology and pest management programs (Soroushmehr *et al.,* 2008). The life table provides an integrated and comprehensive description in details of development times, survival rates of each growth stage, fecundity and life expectancy of a population, and is often used by scientists as a method of projecting the growth of populations and predicting their sizes (Chi, 1990; Carey, 1993; Medeiros *et al*., 2000; Southwood & Henderson, 2000).

Population growth rate is a basic ecological characteristic that usually described as the intrinsic rate of increase (r), an estimate of population growth potential introduced by Birch (1948). Southwood (1966) demonstrated that the intrinsic rate of increase is the most practical life table parameter to compare the population growth potential of different species under specific climatic and nutritional conditions (Roy *et al.,* 2003). The intrinsic rate of increase has been widely used as a bioclimatic index (Hulting *et al*., 1990).

Numerous studies have been intended to evaluate the effect of crop density on the population dynamics of *A. craccivora* (Farrell, 1976), relationship between *A. craccivora* and host plant odors and pheromones (Pettersson *et al*., 1998), its parasitoids (Johnson, 1959; Rakhshani *et al*., 2005), different species of ants (Katayama & Suzuki, 2002; 2003), and clover stunt virus (Gutierrez *et al*., 1971; 1974) and presence of different endosymbiont on *A. craccivora* (Brady & White, 2013). The only study on life table and population parameters of *A. craccivora* was done on five cowpea varieties in laboratory condition by Obopile & Ositile (2010).

R. pseudoacacia is an important ornamental tree in Iran. The main purpose of this study was to determine

the impact of two different rearing conditions (natural and laboratory conditions) on the life table parameters of *A. craccivora* on black locust to construct precise predictions of the dynamics of its populations in the field.

Materials and methods
Insect culture

Leaves bearing apterous adults and different instars of *A. craccivora* were collected from *R. pseudoacacia* bushes on the campus of Faculty of Agricultural Sciences at the University of Guilan (Northern Iran) in 2013 and placed in a growth chamber at 25±1ºC, 65±5% relative humidity (RH) and photoperiod of 16:8h (L:D).

Life table study

The colony of *A. craccivora* was maintained for two generations on *R. pseudoacacia*. Some adults of *A. craccivora* were released on *R. pseudoacacia* leaves for 24 h. This procedure allowed standardizing the age of newly born nymphs. Then, newly born nymphs of *A. craccivora* were placed separately on a *R. pseudoacacia* leaf in plastic Petri dishes (10 cm in diameter) with a hole in the center of the lid covered with fine nylon mesh for aeration. A layer of wet cotton padding, 0.5 cm-thick, lined the Petri dish, and the leaf was on the bottom of the Petri dish according to Madahi & Sahragard (2012) and Hosseini-Tabesh *et al*. (2015). Once leaves appeared to be discolored, they were replaced with fresh ones (usually daily). The aphid nymphs were placed in their natural position on the undersurface of the leaves in laboratory condition (25±1ºC, 65±5% RH) (Liu & Meng, 1999). Nymphal development was recorded daily. After adult appearance, longevity and the number of produced nymphs by females were recorded daily.

A similar methodology was used to study the life table of *A. craccivora* in leaf cages in the field. Each Petri-dish had a hole in the center of the lid, and was covered with muslin for aeration. A hole was made through both the lid and the body of the Petri dish. The leaf cage was placed over the leaf with the stem of the plant passing through the side hole of the cage. The aphids' development was checked every 24 h, from the first instars to the death of the adults (Fig. 1). A magnifier 55x was used to monitor the insects. Daily temperature

and humidity were measured with Digital hygro-thermometer. The temperature ranged from 16–32°C, and the relative humidity was 27–95%. Each experiment was replicated 45 times for each condition.

Data analysis

Data were analyzed using age-stage, two-sex life table theory (Chi & Liu, 1985) and the method described by Chi (1988). To facilitate the tedious procedure, data analysis and population parameters were calculated using the TWOSEX-MSChart program designed in visual BASIC for the Windows operation system (Chi, 2015). The TWOSEX-MSChart is available at http://140.120.197.173/Ecology/prod02.htm (Chung sing University) and http://nhsbig.inhs.uiuc.edu/wes/chi.html (Illinois Natural History Survey).

The age-stage specific survival rate (S_{xj}) (where x= age and j= stage), the age-stage specific fecundity (f_{xj}), the age-specific survival rate (l_x), the age-specific fecundity (m_x), and the population parameters (r, the intrinsic rate of increase; , the finite rate of increase; R_0, the net reproductive rate, and T, the mean generation time) were calculated accordingly.

The means and standard errors of the life table parameters were estimated with the bootstrap (m=10.000) method (Erfon & Tibshirani, 1993). Differences between treatments were then compared by using the paired bootstrap test (Efron and Tibshirani, 1993, Polat-Akköprü *et al*. 2015).

Fig. 1. Leaf cage used to study life table of *Aphis craacivora* under field condition.

Results

The developmental times for each stage are listed in Table 1. The first, second and fourth instar nymphs of *A. craccivora* showed significantly slower development under natural condition (Table 1). However, no significant differences were found in third instar nymph of *A. craccivora* reared in both natural and laboratory conditions. The adult longevity and total life span of *A. craccivora* was significantly shorter under natural condition.

The parameters l_x, m_x, and age-specific maternity ($l_x m_x$) are plotted in fig. 2. The survival rate (l_x) in the laboratory condition was higher. The trend of age-specific fecundity (m_x) showed that reproduction began at the age of 7 days in both laboratory and field. The highest fecundity occurred at the ages of 13 and 12 days in laboratory and natural conditions, respectively. Based on the age-stage, two-sex life table, the age-stage-specific life expectancy (e_{xj}) gives the expected life span of an individual of age x and stage j can live after age x (fig. 3). The trends of life expectancy in both conditions were almost equal but life expectancy of *A. craccivora* in laboratory was higher. The age-stage specific survival rates (s_{xj}) showed the probability of a newborn surviving

to age *x* and stage *j*. The age-stage specific survival rates of *A. craccivora* under field and laboratory conditions are shown in fig. 4. The survival rate of *A. craccivora* in laboratory condition was higher. The reproductive value (v_{xj}) is the contribution of individuals of age *x* and stage *j* to the future population (fig. 5). The results revealed that female with ages of 8 and 7 days made the highest contribution to the population when reared in laboratory and natural conditions, respectively.

Table 2 presents significant differences of population parameters of *A. craccivora* between laboratory and natural conditions. The intrinsic rate of increase (*r*), the finite rate of increase ( ), net reproductive rate (R_0) and gross reproductive rate (*GRR*) were significantly higher under laboratory condition. Mean generation time (*T*) was significantly lower under laboratory condition.
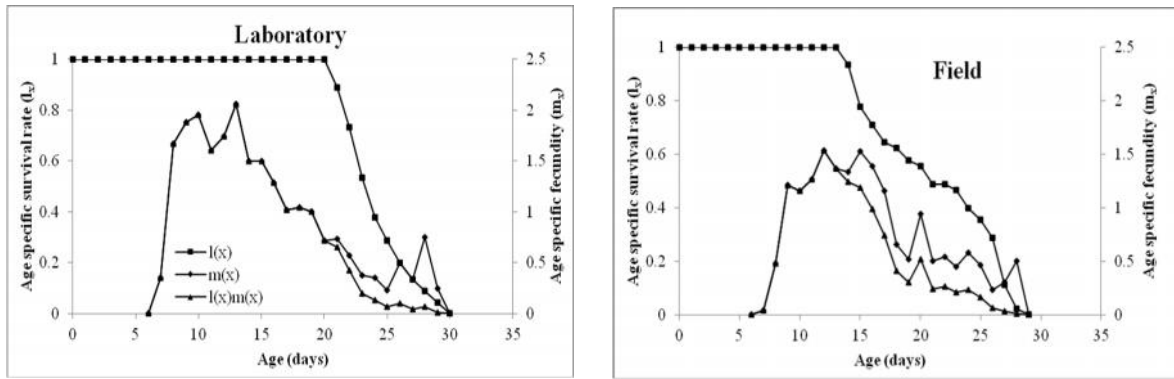

Fig. 2. Age-specific survival rate (l_x), age-specific fecundity (m_x) and age-specific maternity (l_xm_x) of *Aphis craccivora* under laboratory and field conditions.
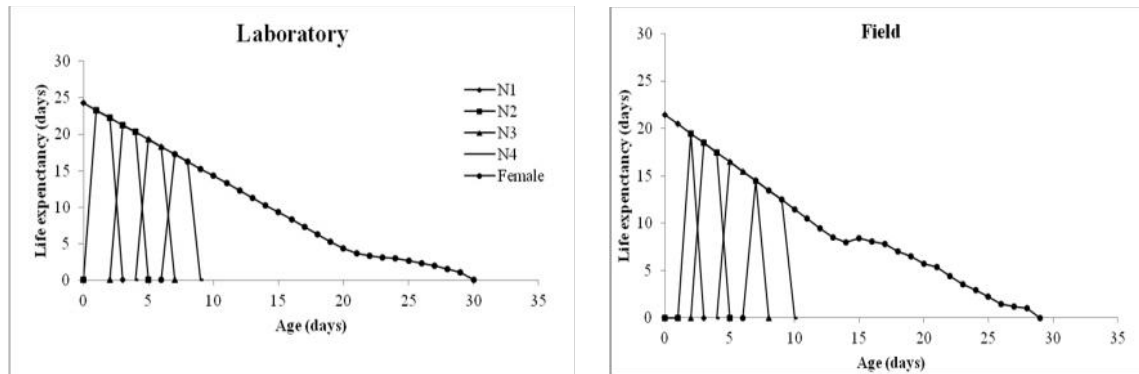

Fig. 3. Age-stage specific life expectancy of *Aphis craccivora* under laboratory and field conditions.

Table 1. Mean developmental times in days (mean ± SE), longevity and fecundity of *Aphis craccivora* in laboratory at 25 ± 1ºC, 70% ± 5% RH, photoperiod 16:8h (L: D) and in natural condition (range of temperature 16ºC -33ºC and 32-89% of RH).

Stages	Laboratory	Field
First instar nymph	2.02 ± 0.04b	2.18 ± 0.06a
Second instar nymph	1.89 ± 0.07b	2.36 ± 0.08a
Third instar nymph	1.98 ± 0.07a	2.09 ± 0.05a
Fourth instar nymph	1.98 ± 0.04b	2.13 ± 0.05a
Immature	7.87 ± 0.088b	8.76 ± 0.106a
Adult longevity	16.42 ± 0.374a	12.69 ± 0.807b
Life span	24.29 ± 0.376a	21.44 ± 0.784b

Mean in the same row followed by the same letter are not significantly different (Paired bootstrap test, P<0.05).

Table 2. Life table parameters (Means ± SE) of *Aphis craccivora* in laboratory at 25 ± 1ºC, 70±5 % RH, photoperiod 16:8h (L: D) and in natural condition (temperature ranged 16ºC - 33 C and 32-89% RH.

Population parameters	Laboratory	Field
Intrinsic rate of increase (r) (day^{-1})	0.2339 ± 0.0037a	0.1906 ± 0.0055b
Finite rate of increase ( ) (day^{-1})	1.2635 ± 0.00462a	1.2100 ± 0.0066b
Net reproductive rate (R_0) (offspring)	21.033 ± 0.71303a	13.689 ± 0.9573b
Mean generation time (T) (day)	13.023 ± 0.148b	13.73 ± 0.228a
Gross reproductive rate (GRR) (offspring)	23.439 ± 0.855a	18.164 ± 0.893b

Means in the same row followed by the same letter are not significantly different (Paired bootstrap test, P<0.05).
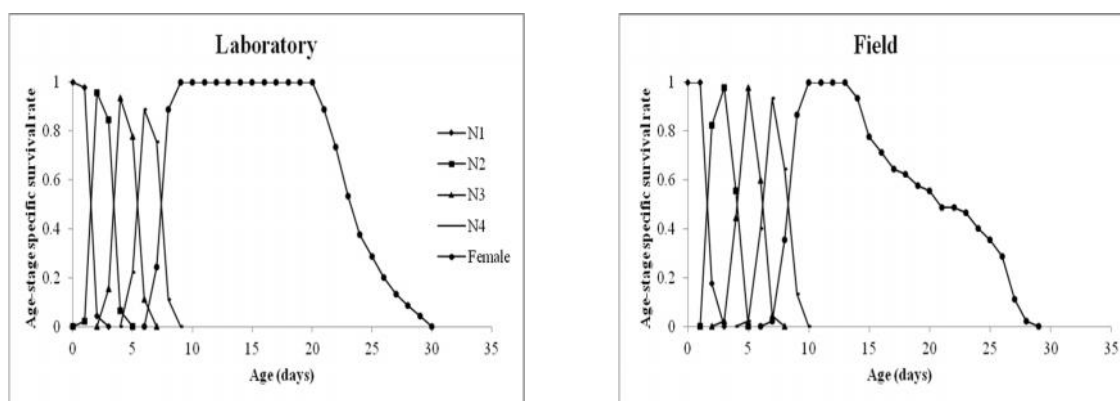

Fig. 4. Age-stage specific survival rate of *Aphis craccivora* under laboratory and field conditions.
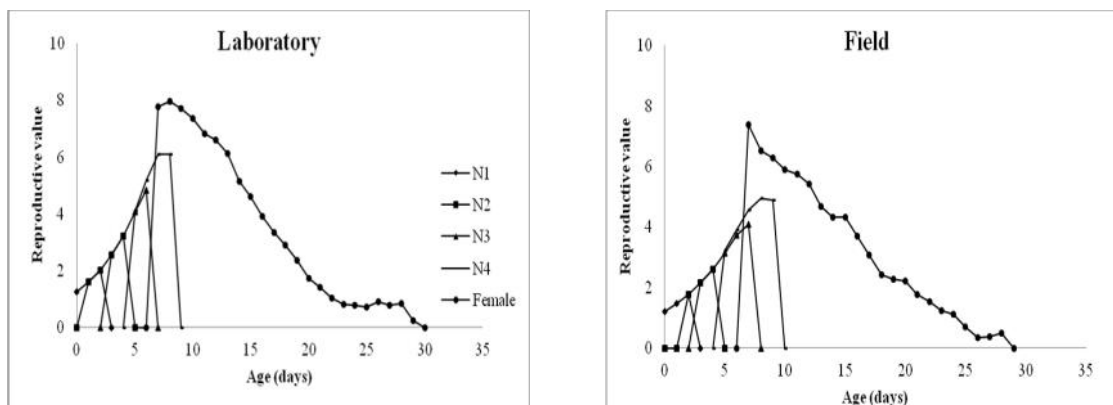
Fig. 5. Age-stage-specific reproductive value of *Aphis craccivora* under laboratory and field conditions.

Discussion

Our study showed that immature development times of *A. craccivora* under field conditions were higher, except for the third instar nymphs with no significant difference. The prolonged immature developmental times in the field may reflect the unsuitability of the environmental conditions. Our result were consistent with those of Zanuncio *et al*. (2006) who stated that longevity of the predatory pentatomid, *Brontocoris tabidus* (Signoret), was longer under field conditions. Afshari *et al*. (2007) mentioned that the fluctuating climatic and natural conditions of cotton fields could increase immature development time and decrease adult development times and reproduction of *A. gossypii*. Similar results were found for nymphal developmental stage of *Bactericera cockerelli* (Sulc) on tomato (Yang *et al*., 2013) and *Aphis gossypii* Glover on *Hibiscus syriacus* L. (Hosseini-Tabesh *et al*., 2015) except for the fifth and first instar nymphs, respectively.

The adult longevity and life span of *A. gossypii* in field conditions were found to be shorter due to the fluctuating temperature and humidity of field conditions. Yang *et al*. (2013) reported that female longevity of *B. cockerelli* reared on tomato were shorter under field conditions (16.2±0.9 days) comparing to laboratory conditions (60.5±8.4 days). According to Hosseini-Tabesh *et al*. (2015), shorter adult longevity of *A. gossypii* occurred in field, which is consistent with our finding. These results corroborate studies on reverse relationship between temperature and adult longevity of *Hyalopterus pruni* (Geoffroy) (Latham & Mills, 2011),

mean developmental times of *Bemisia argentifolii* (Bellows & Perring) (Yang & Chi, 2006), *Brachycaudus schwartzi* (Börner) (Satar & Yokomi, 2002) and *Aphis spiraecola* Patch (Wang & Tsai, 2000). Zamani *et al*. (2006) also reported that temperature had negative impact on the developmental time of *A. gossypii* reared on *Cucumis sativus* L. under laboratory conditions.

In the past, the response of aphids to environmental conditions has been used to develop phenological models to forecast aphid outbreaks (Collier *et al*., 1994; Ro *et al*., 1998). Dixon (1987) showed that the length of time required for an aphid from birth to adult is variable and dependent on two intrinsic factors, birth weight, whether the morph is winged or unwinged, and two extrinsic factors, food quality and weather conditions (especially temperature). Environmental conditions, such as temperature and relative humidity determine the physiological state of insects that are the key variables regulating their survival, fecundity, and population growth. Different temperature and relative humidity were important factors in significant differences (25 ± 1ºC, 70±5% RH and 16–32°C, and 27–95% RH, respectively). Similar studies found that aphid population dynamics was affected by the abiotic factors such as environmental factors (Ruggle & Gutierrez, 1995; Diaz & Fereres, 2005; Arbab *et al*., 2006; Hosseini-Tabesh *et al*., 2015).

In this study, the life table parameters of *A. gossypii* showed significant differences between field and laboratory conditions. Since intrinsic rate of increase (*r*) is the reflection of several factors such as fecundity, survival and generation time and physiological qualities

of an animal in relation to its capacity to increase, it would be an appropriate index to evaluate the performance of an insect in different situations (Kocourek *et al*., 1994; Southwood & Henderson, 2000). The *r* value is more useful to compare the population growth potential of different species than R_0 (Price, 1997). The Intrinsic rate of increase (*r*) was 0.2339 and 0.1906 d^{-1} under laboratory and natural conditions, respectively. According to Obopile & Ositile (2010), the *r* value of *A. craccivora* on five cowpea *Vigna unguiculala* (L.) varieties under laboratory condition ranged from 0.32+0.01 to 0.36+0.01 d^{-1}, that was higher than our results (0.1906 ±0.0055 and 0.2339 ±0.0037 d^{-1} in natural and laboratory conditions, respectively). These differences may be due to discrepancy in host plants and environmental conditions such as temperature and relative humidity. The *r* of *B. cockerelli* fed on potato was also significantly higher in the laboratory (0.1966 d^{-1}) than in field conditions (0.1015 d^{-1}) (Yang *et al*., 2010). Hosseini-Tabesh *et al*. (2015) reported higher intrinsic rate of increase of *A. gossypii* in laboratory condition. The higher *r* value in laboratory condition indicated that *A. craccivora* had a greater reproductive potential and more suitability. The R_0 was also significantly higher under laboratory conditions. Similar results was found for melon flies (Huang & Chi, 2013) and *A. gossypii* (Hosseini-Tabesh *et al*., 2015), as the net reproductive rate was calculated higher under laboratory conditions. The mean generation time (*T*) for *A. craccivora* in laboratory condition was significantly higher, suggesting that laboratory condition is more suitable for *A. craccivora*.

It is concluded that life table of insect pests in field conditions could be a useful tool for making accurate management decisions and selecting proper measures to control insect pests of economically important crops. The differences reported here between the laboratory and field studies, together with the life table analysis, provide valuable information leading to establish a successful control program.

Acknowledgments

References

Afshari, A., Soleyman-Nejadian, E., Bayat-Assadi, H. & Shishehboor, P. (2007) Demographic parameters of the cotton aphid, *Aphis gossypii* (Homoptera: Aphididae), population in cotton field of Gorgan. *Journal of Entomological Society of Iran* 26 (2), 23–44.

 Arbab, A., Kontodimas, D. & Sahragard, A. (2006) Estimating development of *Aphis pomi* (Degeer) (Homoptera: Aphididae) using nonlinear models. *Environmental Entomology* 35(5), 1208-1215.

Birch L. C. (1948) The intrinsic rate of natural increase of an insect population. *Journal of Animal Ecology* 17, 15– 26.

Brady, C. & White, J. A. (2013) Cowpea aphid (Aphis craccivora) associated with different host plants has different facultative endosymbionts, *Ecological Entomology* 38, 433-437.

Carey J. R. (1993) *Applied demography for biologists with special emphasis on insects*. Oxford University Press, New York.

Chen, K. R., Xu, Z. Y., Zhang, Z. Y., Fang, X. P. & Yan, L. Y. (1999) Biological characters and sequence analysis of coat protein gene of Chinese strains of peanut stripe virus (PStV). *Chinese Journal of Oil Crop Science* 21(2), 55–59.

Chi, H. (1988) Life-table analysis incorporating both sexes and variable development rate among individuals. *Environmental Entomology* 17, 26–34.

Chi, H. & Liu H. (1985) Two new methods for the study of insect population ecology. *Bulletin of the Institute of Zoology, Academia Sinica* 24, 225–240.

Chi, H. (1990) Timing of control based on the stage structure of pest population: a simulation approach. *Journal of Economic Entomology* 83, 1143-1150.

Chi, H. (2015) TWOSEX-MSChart: a computer program for the age-stage, two-sex life table analysis. http://140.120.197.173/Ecology/.

Coceano P. G. & Peressini, S. (1989) Colonisation of maize by aphid vectors of barley yellow dwarf virus. *Annals of Applied Biology* 114 (3), 443–447.

Collier, R. H., Davies, M., Roberts, M., Leatherland, S. R. & Smyth, J. B. (1994) Monitoring and forecasting the times of attack of the lettuce root aphid, *Pemphigus bursarius* L. *Bulletin IOBC/WPRS* 17, 31-40.

Diaz, B. M. & Fereres, A. (2005) Life table and population parameters of *Nasonovia ribisnigri* (Homoptera: Aphididae) at different constant temperatures. *Environmental Entomology* 34, 527–534.

Dini-Papanastasi, O. & Panetsos, C. P. (2000) Relation between growth and morphological traits and genetic parameters of *Robinia pseudoacacia* var. monophylla D.C. in northern Greece. *Silvae Genetica* 49, 37–44.

Dixon, A. F. G. (1987) Parthenogenetic reproduction and rate of increase in aphids. pp. 269-287. in Minks, A. K. & Harrewijn, P. (Eds), *Aphids their biology, natural enemies and control.* Vol. A. Elsevier, Amsterdam, The Netherlands.

Efron, B. & Tibshirani, R. J. (1993) *An introduction to the bootstrap*. Chapman and Hall, New York, USA.

Farrell, J. A. K. (1976) Effects of groundnut crop density on the population dynamics of *Aphis craccivora* Koch (Hemiptera, Aphididae) in Malawi. *Bulletin of Entomological Research* 66, 317-329.

Gutierrez, A. P., Morgan, D. J. & Havenstein, D. E. (1971) The ecology of *Aphis craccivora* Koch and subterranean Clover Stunt Virus. I. The phenology of Aphid populations and the epidemiology of virus in pastures in south-east Australia. *Journal of Applied Ecology* 8, 699-721.

Gutierrez, A. P., Havenstein, D. E., Nix, H. A. & Moore, P. A. (1974) The Ecology of *Aphis craccivora* Koch and subterranean clover stunt virus in South-East Australia. II. A model of cowpea aphid populations in temperate pastures, *Journal of Applied Ecology* 11, 1-20.

Hill, D. S. (1983) *Agricultural insect pests of the tropics and their control*. Cambridge University Press, Cambridge.

Hosseini-Tabesh, B., Sahragard, A. & Karimi-Malati, A. (2015) A laboratory and field condition comparison of life table parameters of *Aphis gossypii* Glover (Hemiptera: Aphididae). *Journal of Plant Protection Research* 55, 1-7.

Huang, Y. B. & Chi, H. (2013) Life tables of *Bactrocera cucurbitae* (Diptera: Tephritidae): with an invalidation of the jackknife technique. *Journal of Applied Entomology* 137 (5), 327–339.

Hulting, F. L., ORR, D. B. & Brycki J. J. (1990) A computer program for calculation and statistical comparison of intrinsic rates of increase and associated life table parameters. *Florida Entomologist* 73(4), 601–612.

Johnson, B. (1959) Effect of parasitization by *Aphidius platensis* Brethes on the developmental physiology of its host, *Aphis craccivora* Koch. *Entomologia Experimentalis et Applicata* 2, 82-99.

Katayama, N. and Suzuki, N. (2002) Cost and benefit of ant attendance for *Aphis craccivora* (Hemiptera: Aphididae) with reference to aphid colony size. *Canadian Entomologist* 134, 241–249.

Katayama, N. & Suzuki, N. (2003) Bodyguard effects for aphids of *Aphis craccivora* Koch (Homoptera: Aphididae) as related to the activity of two ant species, *Tetramorium caespitum* Linnaeus (Hymenoptera: Formicidae) and *Lasius niger* L. (Hymenoptera: Formicidae). *Applied Entomology and Zoology* 38, 427-433.

Kocourek, F, Havelka, J., Berankova, J. & Jarosik, V. (1994) Effect of temperature on developmental rate and intrinsic rate of increase of *Aphis gossypii* reared on greenhouse cucumbers. *Entomologia Experimentalis et Applicata* 71, 59–64.

Kührt, U., Samietz, J., Höhn H. & Dorn S. (2006) Modelling the phenology of codling moth: influence of habitat and thermoregulation. *Agriculture ecosystems and environment* 117(1), 29–38.

Latham, D. R. & Mills, N. J. (2011) Effects of temperature on the life history parameters and population growth rates of *Hyalopterus pruni* (Hemiptera: Aphididae). *Journal of Economic Entomology* 104(6), 1864–1869.

Liu, S. S. & Meng, X. D. (1999) The change pattern of development rates under constant and variable temperature in *Myzus persicae* and *Lipaphis erysimi*. *Acta Ecologica Sinica* 9, 182-190.

Madahi, Kh. & Sahragard, A. (2012) Comparative life table of *Aphis pomi* (Hemiptera: Aphididae) on two host plants *Malus pumila* L. and *Chaenomeles japonica* under laboratory conditions. *Journal Crop Protection* 1(4), 321-330.

Medeiros, R. S., Ramalho, F. S., Lemos, W. P. & Zanuncio, J. C. (2000) Age-dependent fecundity and fertility life tables for *Podisus nigrispinus* (Heteroptera: Pentatomidae). *Journal of Applied Entomology* 124, 319–324.

Obopile, M. & Ositile, B. (2010) Life table and population parameters of cowpea aphid, *Aphis craccivora* Koch (Homoptera: Aphididae) on five cowpea *Vigna unguiculata* (L. Walp.) varieties. *Journal of Pest Science* 38, 9-14.

Pettersson, J., Karunaratne, S., Ahmed, E. & Kumar, V. (1998) The cowpea aphid, *Aphis craccivora*, host plant odours and pheromones. *Entomologia Experimentalis et Applicata* 88, 177–184.

Polat-Akköprü, E., Atlıhan, R., Okut, H. & Chi, H. (2015) Demographic assessment of plant cultivar resistance to insect pests: a case study of the dusky-veined walnut aphid (Hemiptera: Callaphididae) on five walnut cultivars. *Journal of Economical Entomology* 108: 378–387.

Price, P. W. (1997) *Insect Ecology*. 3rd ed. Wiley, New York.

Rakhshani, E., Talebi, A. A., Kavallieratos, N. G., Rezwani, A., Manzari S. & Tomanovic Z. (2005) Parasitoid complex (Hymenoptera, Braconidae, Aphidiinae) of *Aphis craccivora* Koch (Hemiptera: Aphidoidea) in Iran. *Journal of Pest Science* 78, 193-198.

Ro, T. H., Long, G. E. & Toba H. H. (1998) Predicting phenology of green peach aphid (Homoptera: Aphididae) using degree-days. *Environmental Entomology* 27, 337-343.

Roy, M., Brodeur, J. & Cloutier, C. (2003) Effect of temperature on intrinsic rates of natural increase (r_m) of a coccinellid and its spider mite prey. *Biocontrol* 48, 57–72.

Ruggle, P. & Gutierrez, A. P. (1995) Use of life tables to assess host plant resistance in alfalfa to *Therioaphis trifolii maculata* (Homoptera: Aphididae): hypothesis for maintenance of resistance. *Environmental Entomology* 24, 313–325.

SAS Institute (2003) SAS user's manual, version 9.1. SAS Institute, Cary, NC.

Satar, S. & Yokomi, R. (2002) Effect of temperature and host on development of *Brachycaudus schwartzi* (Homoptera: Aphididae). *Annals of the Entomological Society of America* 95(5), 597–602.

Singh, S. R. & Jackai, L. (1985) Insect pests of cowpeas in Africa: their life cycle, economic importance, and potential for control. Pp. 217-231. in Singh, S. R. and Rachie, K. O. (Eds) *Cowpea research, production and utilization.* Wiley, Chichester.

Soroushmehr, Z., Sahragard, A. & Salehi, L. (2008) Comparative life table statistics for the ladybeetle *Scymnus syriacus* reared on the green citrus aphid, *Aphis spiraecola*, fed on two host plants. *Journal of Entomological Science* 11, 281-288.

Southwood, T. R. E. (1966) *Ecological methods with particular reference to the study of insect populations.* Methuen, London.

Southwood, T. R. E. & Henderson, P. A. (2000) *Ecological methods*. 3rd ed. Blackwell, Oxford, United Kingdom.

Surles, S. E., Hamrick, J. L. & Bongarten, B. C. (1989) Allozyme variation in black locust (Robinia pseudoacacia). *Canadian Journal of Forest Research* 19, 471–479.

Wang, J. & Tsai, J. (2000) Effect of temperature on the biology of *Aphis spiraecola* (Homoptera: Aphididae). *Annals of the Entomological Society of America* 93(4), 874–883.

Yang T.C. & Chi H. (2006) Life tables and development of *Bemisia argentifolii* (Homoptera: Aleyrodidae) at different temperatures. *Journal of Economic Entomology* 99(3), 691–698.

Yang, X. B., Zhang Y. M., Henne, D. C. & Liu, T. X. (2013) Life tables of *Bactericera cockerelli* (Hemiptera: Triozidae) on tomato under laboratory and field conditions in Southern Texas. *Florida Entomologist* 96(3), 904–913.

Zamani, A. A., Talebi, A. A., Fathipour, Y. & Baniameri, V. (2006) Effect of temperature on biology and population growth parameters of *Aphis gossypii* Glover (Hom.: Aphididae) on greenhouse cucumber. *Journal of Applied Ecology* 130(8), 453–460.

Zanuncio, J. C., Lemos, W. P., Lacerda, M. C., Zanuncio, T.V., Serrãã, O. J. E. & Bauce, E. (2006) Age-dependent fecundity and fertility life tables of the predator *Brontocoris tabidus* (Heteroptera: Pentatomidae) under field conditions. *Journal of Economic Entomology* 99(2), 401–407.