LIFE HISTORY AND LIFE TABLE OF *PHYTOSEIULUS PERSIMILIS* ATHIAS-HENRIOT [1]

BY

J. E. LAING.

Division of Biological Control
University of California, Berkeley.

Introduction.

The Chilean stock of the predatory mite *Phytoseiulus persimilis* Athias-Henriot was recently introduced into California for the biological control of the two-spotted mite *Tetranychus urticae* Koch.

Considerable controversy exists over the effectiveness of phytoseiid mites in regulating the densities of the many economically important phytophagous mites. CHANT (1963) stressed the need for precise experimentation in studies on population dynamics in both the field and laboratory. He suggests that these studies can lead to a more intelligent manipulation of pest populations. Results of preliminary field releases (OATMAN, 1965 ; OATMAN and McMURTRY, 1966) indicate that *P. persimilis* may have a significant role in the control of *T. urticae* in field strawberries. This paper presents the biology and life table of *P. persimilis* under controlled laboratory conditions to provide a basis for further studies on the relative control potentials of *P. persimilis* and *Metaseiulus occidentalis* (Nesbitt) preying on *T. urticae* in interacting population systems (LAING and HUFFAKER, in press).

Phytoseiulus riegeli Dosse was synonymized with *Phytoseiulus persimilis* Athias-Henriot by CHANT (1959) and KENNETT and CALTAGIRONE (1968), the latter supported by cross-breeding experiments. KENNETT and CALTAGIRONE have also synonymized *Amblyseius tardi* Lombardini with *P. persimilis*. Thus, *Phytoseiulus persimilis is* used throughout this paper.

1. This work was conducted as part of a program of research on phytoseiid predation on tetranychid mites, under support of a National Institute of Health Grant to Dr. C. B. HUFFAKER, and it formed a part of a dissertation in partial fulfillment of the Ph. D. degree under his direction.

Materials and Methods.

The stock of *P. persimilis* used in this research was introduced into the United States from Chile via Canada and Germany (KENNETT and CALTAGIRONE, 1968).

Twenty-five freshly oviposited eggs of the two-spotted mite were placed on strawberry leaflets in several modified Munger cells (MUNGER, 1942 ; HUFFAKER, 1948) to serve as food for the predators. Adult female *P. persimilis* taken at random from stock cultures were allowed to lay one egg in each of these cells. The cells were then kept in a plant growth chamber programmed to give 15.5 hours of light in each 24 hours. The temperature was controlled on a 24-hour cycle by a cam cut to give a temperature varying from 58.5° F at 3 : 00 a.m. to 83.0° F at 1 : 00 p.m. The average of the hourly temperatures was 68.5° F. The relative humidity fluctuated from 65 percent during the light period to 95 percent during the dark period.

The individual cells were observed at two-hour intervals until the predators had completed their development. A fresh supply of two-spotted mite eggs was added to each cell daily and the number eaten was recorded for each stage. Cells containing adult females were observed daily for egg laying, prey consumption and mortality. Adult females were also placed in Munger cells with strawberry pollen, individuals of all stages of *Metaseiulus occidentalis* and other stages of *P. persimilis* to determine possible alternate food sources and cannibalism.

Results.

Egg Stage. — The oval eggs of *P. persimilis* when first deposited are translucent and on aging they change from light orange to dark orange in color. Prior to hatching, the chorion of the egg becomes shiny, probably due to air being trapped between the larva and the chorion.

The average duration of incubation for both males and females was 3.1 ± 0.2 days (table 1).

Larval Stage. — Larvae did not attempt to feed and remained inactive near the old egg shell (table 2). Both males and females remained in the larval stage for an average of 1.0 ± 0.1 days (table 1).

The larva does not have a true quiescent stage before molting. It is capable of rapid movement if touched, even within a few minutes of molting ; however, it remains inactive unless disturbed.

Protonymphal Stage. — Immediately upon molting, the protonymph began searching the leaf surface. Very often the protonymph was observed to initiate feeding within five minutes after shedding the larval skin.

TABLE 1. Duration of the immature stages of *P. persimilis*.

Sex	Number observed	Number of days			Standard deviation
		Maximum	Minimum	Average	
		EGG			
Male	3	3.3	2.9	3.1	0.2
Female	22	3.5	2.8	3.1	0.2
		LARVA			
Male	3	1.0	0.9	1.0	0.1
Female	22	1.2	0.8	1.0	0.1
		PROTONYMPH			
Male	3	1.9	1.5	1.7	0.2
Female	22	2.0	1.3	1.6	0.2
		DEUTONYMPH			
Male	3	1.8	1.7	1.7	0.1
Female	22	2.0	1.4	1.7	0.1
		ALL STAGES COMBINED			
Male	3	7.7	7.4	7.5	0.1
Female	22	8.0	7.0	7.4	0.3

The male protonymphs remained in this stage an average of 1.7 ± 0.2 days. The protonymphal period of the females was similar to that of the males — 1.6 ± 0.2 days (table 1). The protonymphs remained active to within minutes of molting to the deutonymphal stage. During their active period, the nymphs ate an average of 4.4 ± 0.6 two-spotted mite eggs, with a minimum of four and a maximum of six. The males and females did not differ significantly in the number of eggs consumed in the protonymphal stage (table 2).

TABLE 2. Number of *T. urticae* eggs eaten during the development of the immature stages of *P. persimilis*.

Stage	Number observed	Number of eggs			Standard deviation
		Maximum	Minimum	Average	
Larva	25	0.0	0.0	0.0	—
Protonymph	25	6.0	4.0	4.4	0.6
Deutonymph	25	9.0	3.0	6.0	1.4
Total	25	13.0	7.0	10.5	1.4

Deutonymphal Stage. — The eight-legged, final nymphal stage remained active throughout the period. Both males and females remained an average of 1.7 ± 0.1 days in this stage (table 1).

The deutonymphs ate an average of 6.0 ± 1.4 eggs of the two-spotted mite (table 2). As in the protonymphal stage, both sexes ate the same number of eggs. For *P. persimilis* males or females to reach maturity under these conditions, an average of 10.5 ± 1.4 two-spotted mite eggs were consumed.

Adult Stage. — Mating was never observed to take place immediately after the deutonymph molted to an adult. Usually six to twelve hours elapsed between the time of molting and the time of mating. Both males and females began to feed almost immediately after they had molted. After feeding, the female became very active and spent much of her time running around the cell enclosure. Only when a male was encountered and mating had taken place did the female settle down. The duration of mating was erratic, taking from five minutes to several hours. Many females mated more than once, but multiple matings were not necessary for continued egg production and oviposition, as has been reported for some phytoseiids (see KENNETT and CALTAGIRONE, in press).

Thirty-eight mated adult females lived an average of 29.6 days, with a range of 12 to 50 days. The duration of the ovipositional period ranged from six to 39 days, with an average of 22.3 days (table 3).

TABLE 3. Duration of various periods for adult females of *P. persimilis.*

Period	Number observed	Number of days			Standard deviation
		Maximum	Minimum	Average	
Preoviposit.	22	4.2	2.2	3.0	0.6
Oviposition	38	39.0	6.0	22.3	—
Adult	38	50.0	12.0	29.6	—

The preovipositional time averaged 3.0 ± 0.6 days for 22 individuals. The maximum number of eggs laid by any female in a day was six. Thirty-eight females laid an average of 53.5 eggs during their lifetimes. The maximum number of eggs laid by one female was 101, the minimum, 14. These thirty-eight females laid an average of 2.4 eggs per day (table 4). Unmated females did not oviposit.

The number of two-spotted mite eggs consumed by a female per day was dependent on whether she was in her preovipositional period, was ovipositing, or had ceased to oviposit. During the preovipositional period, 30 adult females each ate an average of 7.3 ± 1.2 eggs per day. This rate of consumption increased during the egg laying period to 14.3 ± 1.9 eggs per day. Ten females which lived an average of 7.1 days after completion of oviposition, ate an average of only 3.9 ±

TABLE 4. Number of eggs laid by *P. persimilis*.

	No. of females	Number of eggs			Standard deviation
		Maximum	Minimum	Average	
Total no. per female	38	101	14	53.5	—
No. per female per day	38	3.2	1.6	2.4	0.3

1.5 eggs per female per day (table 5). The maximum number of eggs eaten by any female in one day was 23, and these were consumed during the ovipositional period.

Sex Ratio. — For 245 progeny of 20 females, the sex ratio was 4.1 females : 1.0 male.

TABLE 5. Feeding of adult female *P. persimilis* on eggs of *T. urticae*.

Period	Number observed	Avg. no of days observed	Eggs eaten per female per day			Standard deviation
			Maximum	Minimum	Average	
Preoviposition	22	3.0	9.0	5.3	7.3	1.2
Oviposition	16	24.9	16.5	12.4	14.3	1.9
Postoviposition	10	7.1	5.4	2.6	3.9	1.5

Alternate Food Sources. — When isolated with strawberry pollen, *P. persimilis* did not survive or develop to a greater extent than individuals kept without food.

Cannibalism occurred in *P. persimilis* : the adults and occasionally a deutonymph of *P. persimilis* would feed sparingly on eggs and newly emerged larvae of its own species when no other food was available.

P. persimilis was never observed to feed on any of the stages of *Metaseiulus occidentalis* (Nesbitt) when the two predatory species were maintained together without any other food. Adult *P. persimilis* attempted to eat eggs of *M. occidentalis* but seemed to be incapable of piercing the chorions.

Life Table.

A life table (table 6) was constructed for *P. persimilis* according to the method of BIRCH (1948) as given in HOWE (1953) and WATSON (1964).

TABLE 6. Life table of *Phytoseiulus persimilis* at a mean temperature of 68.5° F.

Age (days)	Proportion alive at age x	Number of female progeny per female	
x	l_x	m_x	$l_x m_x$
0-9	1.00	0.00	0.00
10	1.00	1.28	1.28
11	1.00	1.56	1.56
12	1.00	2.19	2.19
13	1.00	2.34	2.34
14	1.00	1.83	1.83
15	1.00	1.83	1.83
16	1.00	1.86	1.86
17	1.00	1.74	1.74
18	1.00	1.83	1.83
19	1.00	1.60	1.60
20	1.00	1.74	1.74
21	0.96	1.78	1.71
22	0.92	2.04	1.88
23	0.92	1.96	1.80
24	0.88	2.14	1.88
25	0.88	2.25	1.98
26	0.83	2.20	1.83
27	0.79	2.06	1.63
28	0.79	1.86	1.47
29	0.79	1.90	1.50
30	0.79	1.43	1.13
31	0.79	1.60	1.26
32	0.67	1.25	0.84
33	0.67	1.30	0.87
34	0.63	1.22	0.77
35	0.54	1.23	0.66
36	0.46	1.09	0.50
37	0.42	1.44	0.60
38	0.29	0.91	0.26
39	0.29	1.03	0.30
40	0.21	1.28	0.27
41	0.21	1.60	0.34
42	0.21	1.60	0.34
43	0.21	1.44	0.30
44	0.21	0.96	0.20
45	0.17	0.80	0.14
46	0.17	0.44	0.07
47	0.13	0.26	0.03
48	0.08	0.00	0.00
			$\Sigma = 44.36 = R_0$

BIRCH (1948) defined the intrinsic rate of increase as the actual rate of increase of a population under specified constant environmental conditions in which space and food are unlimited when there are no mortality factors other than physiological ones. From the date in the life table, the intrinsic rate of increase was calculated using the formula :

$$\Sigma e^{-r_m x} \, l_x m_x = 1 \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where " e " is the base of natural logarithms,

" x " is the age of the individuals in days,

" l_x " is the number of individuals alive at age " x " as a proportion of one,

" m_x " is the number of female offspring produced per female in the age interval " x ". (The values for " x ", " l ", and " m " were taken from the life history data).

The values of the negative exponent of " $e^{-r_m x}$ " ascertained from this experiment often lay outside the range given in the tables found in most mathematical handbooks. For this reason, both sides of equation (1) above were multiplied by a factor of 2^5 to give :

$$\Sigma e^5 \, (e^{-r_m} \, l_x m_x) = e^5 \quad \text{or}$$

$$\Sigma e^{5-r_m} \, l^x m_x = 148.41$$

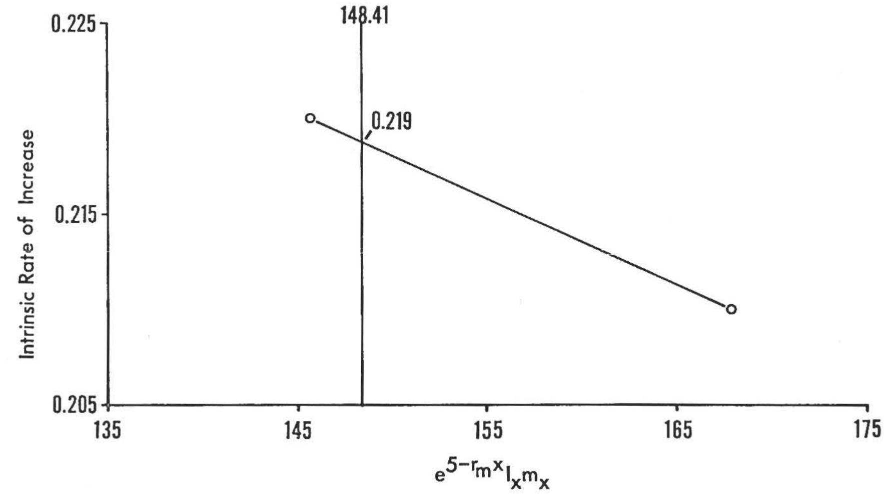

FIG. 1 : Determination of the intrinsic rate of increase for *P. persimilis*.

Provisional values of r^m, accurate to two decimal places, were substituted in the formula until the two values of the equation ($e^{5-r_m x} l_x m_x$) were found which lay immediately above and below 148.41 (table 7). The two values of $e^{5-r_m x} l_x m_x$ were then plotted on the horizontal axis against their respective provisional r_m's on the vertical axis (fig. 1). The two points were then joined to give a line which intersected a vertical line from the desired value of $e^{5-r_m x} l_x m_x$ (148.41). The point of intersection gives the accurate r_m to three decimal places.

TABLE 7. Provisional r_m's for *Phytoseiulus persimilis*.

$r_m = 0.21$				$r_m = 0.22$			
$r_m x$	$5 - r_m x$	$e^{5-r_m x}$	$e^{5-r_m x} l_x m_x$	$r_m x$	$5 - r_m x$	$e^{5-r_m x}$	$e^{5-r_m x} l_x m_x$
2.10	2.90	18.17	23.26	2.20	2.80	16.44	21.04
2.31	2.69	14.73	22.98	2.42	2.58	13.20	20.59
2.52	2.48	11.94	26.15	2.64	2.36	10.59	23.19
2.73	2.27	9.68	22.65	2.86	2.14	8.50	19.89
2.94	2.06	7.85	14.37	3.08	1.92	6.82	12.48
3.15	1.85	6.36	11.64	3.30	1.70	5.47	10.01
3.36	1.64	5.16	9.60	3.52	1.48	4.39	8.17
3.57	1.43	4.18	7.27	3.74	1.26	3.53	6.14
3.78	1.22	3.39	6.20	3.96	1.04	2.83	5.18
3.99	1.01	2.75	4.40	4.18	0.82	2.27	3.63
4.20	0.80	2.23	3.88	4.40	0.60	1.82	3.17
4.41	0.59	1.80	3.08	4.62	0.38	1.46	2.50
4.62	0.38	1.46	2.74	4.84	0.16	1.17	2.20
4.83	0.17	1.19	2.14	5.06	— 0.06	0.94	1.69
5.04	— 0.04	0.96	1.80	5.28	— 0.28	0.76	1.43
5.25	— 0.25	0.78	1.54	5.50	— 0.50	0.61	1.21
5.46	— 0.46	0.63	1.15	5.72	— 0.72	0.49	0.90
5.67	— 0,67	0.51	0.83	5.94	— 0.94	0.39	0.64
5.88	— 0.88	0.41	0.60	6.16	— 1.16	0.31	0.46
6.09	— 1.09	0.34	0.51	6.38	— 1.38	0.25	0.38
6.30	— 1.30	0.27	0.31	6.60	— 1.60	0.20	0.23
6.51	— 1.51	0.22	0.28	6.82	— 1.82	0.16	0.20
6.72	— 1.72	0.18	0.15	7.04	— 2.04	0.13	0.11
6.93	— 1.93	0.15	0.13	7.26	— 2.26	0.10	0.09
7.14	— 2.14	0.12	0.09	7.48	— 2.48	0.08	0.06
7.35	— 2.35	0.10	0.07	7.70	— 2.70	0.07	0.05
7.56	— 2.56	0.08	0.04	7.92	— 2.92	0.05	0.03
7.77	— 2.77	0.06	0.04	8.14	— 3.14	0.04	0.02
7.98	— 2.98	0.05	0.01	8.36	— 3.36	0.03	0.01
8.19	— 3.19	0.04	0.01	8.58	— 3.58	0.03	0.01
8.40	— 3.40	0.03	0.01	8.80	— 3.80	0.02	0.01
8.61	— 3.61	0.03	0.01	9.02	— 4.02	0.02	0.01
8.82	— 3.82	0.02	0.01	9.24	— 4.24	0.01	0.00
9.03	— 4.03	0.02	0.01	9.46	— 4.46	0.01	0.00
9.24	— 4.24	0.01	0.00	9.68	— 4.68	0.01	0.00
9.45	— 4.45	0.01	0.00	9.90	— 4.90	0.01	0.00
9.66	— 4.66	0.01	0.00	10.12	— 5.12	0.00	0.00
9.87	— 4.87	0.01	0.00	10.34	— 5.34	0.00	0.00
			$\Sigma = 167.96$				$\Sigma = 145.73$

$r_m = 0.219$
$R_0 = 44.36$
$T = 17.32$

The net reproduction rate (R_0) was calculated as the sum of the respective $l_x m_x$ columns (table 6), with " l_x " and " m_x " and " as already defined. The mean generation time (T) was then calculated from the formula :

$$T = \frac{\log_e Ro}{r_m}$$

The mean generation time (T) for *P. persimilis* was 17.32 days. The population of predators multiplied by a factor (R_0) of 44.36 in this period of time under the stated conditions. The intrinsic rate of increase (r_m) was determined from figure 1 to be 0.219 individuals per female per day.

Discussion.

RAGUSA (1965) found the developmental time for females of *Amblyseius tardi* Lombardini (= *P. persimilis*) from oviposition of the egg through the preovipositional period to vary from five to 12 days at a temperature oscillating between 77 and 82° F. The corresponding period for *P. persimilis* in this study varied from 9.2 to 12.2 days under a temperature range of 58.5 to 83° F, with a mean of 68.5° F. DOSSE (1958) reported a total developmental time from egg to maturity of 11.9 days for *P. riegeli* (= *P. persimilis*) at a temperature range of 50 to 77° F. This is considerably longer than the developmental time of 7.5 days observed at the higher range of 58.5 to 83° F in this experiment. DOSSE also reported the developmental time for this predator to be 4.6 days at a constant temperature of 77° F and 12.2 days at a constant temperature of 59° F. Thus, the developmental time of about 7.5 days observed at the temperature range of 58.5 to 83° F in this experiment is in reasonable agreement.

RAGUSA (1965) also observed that adult females lived 22 to 25 days and laid about 100 eggs, for an average of about four eggs per female per day at 77 to 82° F. DOSSE (1958) reported that females raised at temperatures of 50 to 77° F deposited 60 eggs in about 37 days, for an average of 1.6 eggs per female per day. In the present experiment the adult females lived an average of 29.6 days and laid a total of 53.5 eggs per female in 22.5 days, for an average of 2.4 eggs per female per day.

During the ovipositional period, the females ate an average of 14.3 eggs of *T. urticae* per day, for a total of about 322 eggs. During the preovipositional and postovipositional periods a total of 49 eggs were eaten per female, for a total adult female consumption of about 370 eggs. RAGUSA (1965) found that the adult females ate 150 to 200 individuals of *T. urticae*. A direct comparison of these figures is not possible as the adults fed only on eggs in the present experiment while all stages of *T. urticae* served as food in RAGUSA's experiment. Also, the relative humidities of the two experiments differed and as MORI and CHANT (1966) point out, prey consumption by *P. persimilis* is greater at low than at high humidities.

During their development, the larvae of *P. persimilis* did not feed. RAGUSA also reported that the larvae of *Amblyseius tardi* (= *P. persimilis*) did not feed.

PRASAD (1967) found that *Phytoseiulus macropolis* (Banks) did not feed in the larval stage.

In the present experiment, the protonymphs ate an average of 4.4 eggs of *T. urticae* to complete their development. RAGUSA found that *Amblyseius tardi* ate about five eggs during the period of the protonymphal stage. In this experiment, the sex ratio was 4.1 females to 1.0 male. KENNETT and CALTAGIRONE (1968) found that the sex ratio of *P. persimilis* was 3.75 females to 1.0 male for their Sicilian stock, but they also found that the sex ratio may be altered markedly in ways not yet understood.

Summary.

The life cycle of *P. persimilis* was determined under a diurnal temperature cycle of 58 to 83° F to be as follows :

The adult female, after a preovipositional period of 3.0 days, laid an average of 2.4 eggs per day for 22.3 days. During the preovipositional and ovipositional periods the females consumed 7.3 and 14.3 eggs of *T. urticae*, respectively. After ceasing to oviposit the females lived an average of 7.1 days during which each consumed 3.9 eggs per day.

The incubation time was 3.1 days. Both male and female larval stages lasted 1.0 day. The larvae did not feed. The male and female protonymphal stages lasted 1.7 and 1.6 days, respectively. During this time both males and females ate an average of 4.4 eggs of *T. urticae*. Male and female deutonymphal stages lasted 1.7 days, during which time the deutonymphs ate 6.0 eggs. Total developmental time for males was 7.5 days and for females, 7.4 days. Each sex ate an average of 10.5 eggs during development.

From the life history data, a life table was constructed. The intrinsic rate of increase was 0.219 individuals per female per day. The population multiplied 44.4 times in a generation time of 17.32 days. These statistics form one of the important components in an appraisal of the ability of this predator in the control of tetranychid prey.

ABSTRACT.

The life history of *P. persimilis* was determined at a cyclical temperature range of 58.5 to 83° F. From the life history data a life table was constructed for *P. persimilis*. The intrinsic rate of increase was found to be 0.219 individuals per female per day and the population multiplied 44.4 times in a generation time of 17.32 days under the given conditions.

RÉSUMÉ.

Le cycle de développement de *P. persimilis* a été défini pour un cycle de température compris entre 58,5° F et 83° F.. A partir du cycle de développement, une table biologique a été construite pour *P. persimilis*. La moyenne intrinsèque d'accroissement est de 0,219 individus par femelle et par jour, et la population est multipliée 44,4 fois dans le cours d'une génération de 17,32 jours sous les conditions données.

LITERATURE CITED

BIRCH (L. C.), 1948. — The intrinsic rate of natural increase on an insect population. — J. Anim. Ecol., **17** : 15-26.

CHANT (D. A.), 1959. — Phytoseiid mites (Acarina : Phytoseiidae). Part I. Bionomics of seven species in southeastern England. Part II. A taxonomic review of the family Phytoseiidae, with descriptions of 38 new species. — Can. Ent., Suppl. 12, **91** : 166 pp.

CHANT (D. A.), 1963. — Some mortality factors and the dynamics of orchard mites. — Mem. Ent. Soc. Can., **32** : 33-40.

DOSSE (G.), 1958. — Über einige neue Raubmilbenarten (Acar. Phytoseiidae). — Pflanzenschutz-Berichte, **21** : 44-61.

HOWE (R. W.), 1953. — The rapid determination of the intrinsic rate of increase of an insect population. — Ann. Appl. Biol, **40** : 134-151.

HUFFAKER (C. B.), 1948. — An improved cage for work with small insects. — J. Econ. Ent. **41** : 648-649.

KENNETT (C. E.) and CALTAGIRONE (L. E.), 1968. — Biosystematics of *Phytoseiulus persimilis* Athias-Henriot (Acarina : Phytoseiidae). — Acarologia **10** (4) : 563-577.

LAING (J. E.) and HUFFAKER (C. B.). In press.

MORI (H.) and CHANT (D. A.), 1966. — The influence of prey density, relative humidity and starvation on the predaceous behaviour of *Phytoseiulus persimilis* Athias-Henriot (Acarina : Phytoseiidae). — Can. J. Zool., **44** : 483-491.

MUNGER (F.), 1942. — A method of rearing thrips in the laboratory. — J. Econ. Ent., **35** : 373-375.

OATMAN (E. R.), 1965. — Predaceous mite controls two-spotted mite on strawberry. — Calif. Agric., **19** : 6-7.

OATMAN (E. R.) and MCMURTRY (J. A.), 1966. — Biological control of the two-spotted spider mite on strawberry in southern California. — J. Econ. Ent., **59** : 433-439.

PRASAD (V.), 1967. — Biology of the predatory mite *Phytoseiulus macropolis* in Hawaii (Acarina : Phytoseiidae). — Ann. Ent. Soc. Amer., **60** : 905-908.

RAGUSA (S.), 1965. — Osservazioni preliminari sulla biologia dell'*Amblyseius tardi* Lomb. (Acarina-Phytoseiidae), predator del *Tetranychus urticae* Koch. — Boll. Inst. Entom. Agraria Osserv. Fitopat. Palermo, **6** : 3-10.

WATSON (T. F.), 1964. — Influence of host plant condition on population increase of *Tetranychus telarius* (Linnaeus) (Acarina : Tetranychidae). — Hilgardia, **35** : 273-322.