An index model on predatory effect of female adults of *Coccinella septempunctata* L. on *Macrosiphum euphorbiae* Thomas

P. N. Deligeorgidis, C. G. Ipsilandis, G. Kaltsoudas and G. Sidiropoulos
Department of Crop Production, Technological Education Institute of Western Macedonia/Branch of Florina, Terma Kontopoulou, Florina, Greece

Abstract: The predatory effect of female adults of *Coccinella septempunctata* L. (Coleoptera: Coccinellidae) on aphid *Macrosiphum euphorbiae* (Thomas) was examined under laboratory conditions, in controlled environmental chambers. This study took place on single rose leaves in transparent small plastic cages at varying proportions of predator/number of aphids. *Coccinella septempunctata* proved to be an effective predator for the biological control of *M. euphorbiae* under controlled conditions in closed environments. It is proposed to use starved adult females of *C. septempunctata* in biological control programmes in greenhouses, as a specialized predator of *M. euphorbiae* in proportions near 1 : 35 predator/aphids. The percentage of aphids that may escape was correlated to the hunger satiation of the predator and the total number of aphids, and the theoretical models describing the predator's behaviour under controlled conditions were defined.

1 Introduction

In modern cultivations, plant resistance to pests is getting lower and plants' battery of defense is destroyed by modern way of cultivation (Stechmann, 1986). Pest management programmes involve (a) habitat modification, (b) use of resistance in plants (proper varieties) and (c) enhancement of naturally occurring biological control (Bottrell, 1979). The population dynamics of insects in agroecosystems involves interactions of phytophagous species and their natural enemies and are considered of great importance for biological control programmes (Evans and England, 1996). The complexity of this relationship is based mainly on the predator effectiveness and thus the success of a biological control programme. Predator effectiveness is a presumption for use of a specific species in biological control programmes and in such cases, laboratory estimations can be used for estimating effectiveness in controlled environments (Deligeorgidis, 2002).

Individual predator species in the families Anthocoridae, Coccinellidae, Chrysopidae, Hemerobiidae, are capable to maintain green plant pest numbers below damaging levels (Onillon, 1990). Coccinellids have been widely used in biological control in the past and the methods for using these predators have remained almost unchanged. Augmentative releases of several coccinellids species are well documented and usually effective (Van Lenteren and Woets, 1988). *Coccinella septempunctata* L. is considered one of the most important species of coccinellids (Gordon, 1985), which have experimentally appraised established throughout Europe in glasshouse crops such as tomato, sweet peppers and cucumbers. *Coccinella septempunctata* is also one of the most numerous coccinellid beetles in Greece. It is predaceous usually on aphids (which can cause great damages to many plant species) and additionally on thrips, whiteflies, mites and lepidoptera (Gordon, 1985). Especially the adults of *C. septempunctata* prefer aphids to feed and are reported as common aphid predators and thus they can be used in biological control programmes (Harpaz, 1955; Franz, 1961 as referred by Sundby, 1966). In general, adult stages of *C. septempunctata* are more predaceous than larvae stages (Sethi and Atwal, 1964; Agrawala and Saha, 1986; Singh et al., 1994; Kumari and Singh, 1999). Among aphid species, *Macrosiphum euphorbiae* (Thomas) is preferred rather than *Myzus persicae* (Sulzer) by the predator *C. septempunctata* (Shands and Simpson, 1972).

Predation rate of *C. septempunctata* on cereal aphids was higher when aphid density was higher and was depended on temperature conditions (Triltsch and Roßberg, 1997). These researchers proposed a model that can simulate the predation rate, depending on temperature, pest density and availability in the experimental field. Foglar et al. (1990), studied the functional response and preference of *Macrolophus caliginosus* (Wagner) for two of its prey: *Myzus persicae* (Sulzer) and *Tetranychus urticae* (Koch). They developed a model which describes the predation rate on two prey simultaneously, based on estimations of handling time and

attack rate, within a 24-h period and under laboratory (controlled) conditions. All these models are based on the type II functional response model proposed by HOLLING (1959). The functional response model (usually of type II), in general, can describe the predator's behaviour under a stable prey density and in a certain period of time. This model cannot tell us under which conditions the predation rate must considered effective by estimating individual consumption of prey in relation to predator/total prey density ratio.

In this study, a laboratory estimation of the predatory effect under controlled conditions, of 2-day-old female adults *C. septempunctata* on an aphid species (*M. euphorbiae* Thomas) was conducted. The aim was to propose a simple index based on a mathematical model that can estimate easily the rate of effective predation under controlled conditions.

2 Materials and Methods

The predatory effect of *C. septempunctata* L. (Coleoptera: Coccinelidae) was studied in 2002 on aphids of the species *M. euphorbiae* Thomas (Hemiptera: Aphididae) using a series of experiments in small cages. The basic experimental unit was a single rose leaf (approximately 45 cm^2) in a $15 \times 10 \times 4$ cm clear plastic cage. The cages had one hole of 6×5 cm covered with dense material made of muslin (0.06 mm opening) for airing and a wet piece of cotton for moisturizing air. Each rose leaf in the cage was held away from the upper internal part of the cage with sticky tape. Two-day-old females of *C. septempunctata* (collected from original rearing kept in the laboratory for 9 months at 25 ± 1°C) were used for all experiments and were starved for 24 h before use by placing them on rose leaves in individual cages. Also, *M. euphorbiae* were collected from laboratory colonies reared on tomato leaves (for 9 months at 25 ± 1°C). After introduction of the aphids and the predator, cages were held in controlled environment chambers at a temperature of 22 ± 1°C, $65 \pm 2\%$ relative humidity (RH), with a 16 h light : 8 h dark photoperiod and intensity of light 9000 Lux, after which survivor of aphids was counted. One single female *C. septempunctata* corresponded to 10, 15, 20, 25 or 30 aphids per cage (five different pest densities). Each treatment was replicated eight times. Five more cages (treatments) were used as control (check). In these cages there were 10, 15, 20, 25 or 30 aphids per cage but in absence of the predator (no beetles) and aphid mortality after 24 h was measured. The five different pest densities were considered satisfying for data analyses

and suitable for second-degree models according to common experimental procedures such as data distribution and correlation based on least-square method (SNEDECOR and COCHRAN, 1980; WILLIAMS and JULIANO, 1985; FOGLAR et al., 1990).

The measurements on the predatory effect of *C. septempunctata* were based on the percentage of aphids consumed by the predator to their initial number, before the introduction of the predator.

Statistical analysis was based on both the original data and transformed data according to the formula:

$$x' = \sqrt{x + 1} \text{ (Fasoulas, 1979)}$$

3 Results

Analysis of variance on the original and transformed data revealed statistically significant differences at level < 0.001 (table 1). Total number of aphids consumed by *C. septempunctata*, increased as initial number of aphids in the cage increased (table 1), but the rate of this increase was not linear but declining according to the second degree model in fig. 1. The equation of the model is $y = -0.0164x^2 + 1.3921x - 2.45$ (y = number of aphids consumed by *C. septempunctata*, x = initial number of aphids, $r^2 = 0.998$). The percentage (%) of aphids that survived is described by the second-degree equation: $y = 0.0329x^2 - 0.4403x + 1.82$ (y = % aphids that survived, x = initial number of aphids, $r^2 = 0.979$). No mortality was found in the control cages after 24 h (100% survival of aphids).

Predictions according to the second-degree model (in fig. 1) describing the relation between the initial number of aphids (Initial Nr of Aphids) and the percentage (%) of aphids that may survive (Survived Aphids %) are presented in fig. 2. The theoretical maximum linear models show that, when initial number of aphids in the cage is 35, the expected linear model has a $b = 1$. As percentage (%) of aphids that may survive represents (according to the model) the number of aphids that may escape, this b value $= 1$ indicates equal rate of aphids that may escape and number of aphids added initially. Additionally, the percentage (%) is considered an easily understandable presentation of data, instead of absolute numbers, and can be used for general purpose indexing.

No of Aphids	Srv. Aphids	EAP	√EAP + 1	Cons. Aphids	CAP	√CAP + 1
10	0	0	1	10	1	1.414
15	0.625	0.042	1.021	14.375	0.958	1.4
20	1.125	0.056	1.028	18.875	0.944	1.394
25	2.625	0.105	1.051	22.375	0.895	1.377
30	5.625	0.187	1.090	24.375	0.813	1.346
Gen. Average	2	0.078	1.038	18	0.922	1.386
LSD.05	1.156	0.048	0.023	1.156	0.048	0.018
CV exp %	56.46	60.19	2.15	6.27	5.09	1.23

Comparisons are significant at P < 0.001.
Srv. Aphids, total number of aphids that survived; EAP, the percentage of aphids that survived; Cons. Aphids, total number of aphids consumed by *C. septempunctata*; CAP, the percentage of consumed aphids, the general average (Gen. Average) and the Coefficient of variation of the experimental analysis (CV exp %).

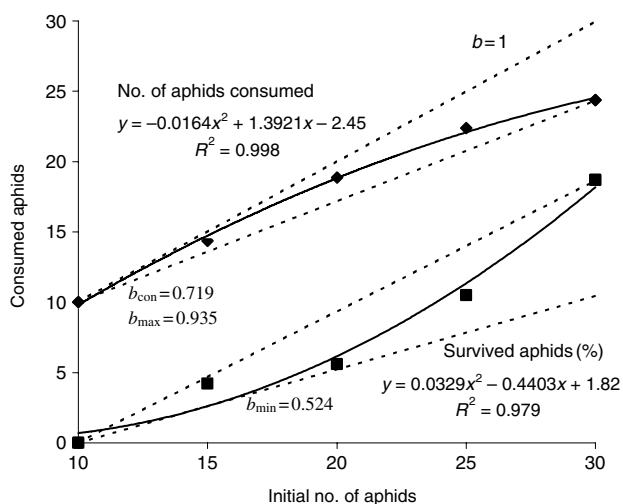*Table 1.* Initial number of aphids in the experiment (No. of Aphids)

Fig. 1. The relation between the initial number of aphids in the experiment (Initial No. of Aphids) and the aphids consumed by Coccinella septempunctata (No of Aphids consumed) or the percentage (%) of aphids that survived (Survived Aphids %). Minimum and maximum linear models included
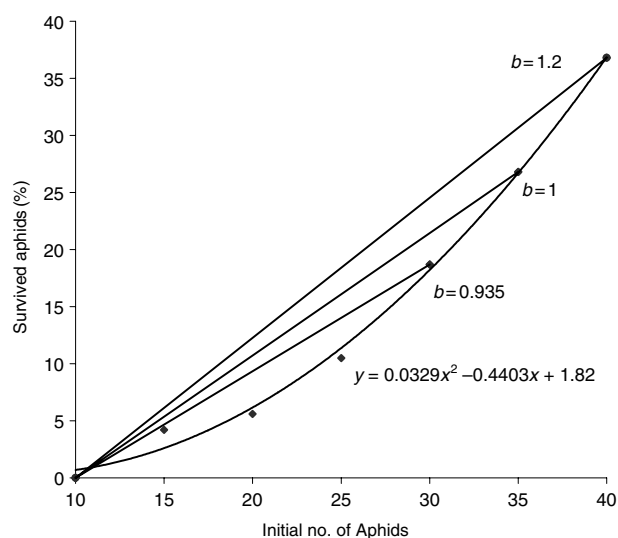

Fig. 2. Predictions according to the second-degree model describing the relation between the initial number of aphids (Initial No. of Aphids) and the percentage (%) of aphids that may survive (Survived Aphids %). Theoretical maximum linear models included

4 Discussion

The female adults of *C. septempunctata*, that were used in the laboratory in order to prey on *M. euphorbiae*, proved to be very capable predators. This was expected to happen because *M. euphorbiae* is preferred by the predator *C. septempunctata* (SHANDS and SIMPSON, 1972) and adults or late-instars larvae are more capable predators (HAGEN, 1962; SETHI and ATWAL, 1964; SINGH and MALHOTRA, 1979; AGRAWALA and SAHA, 1986; MAHMOOD and MAHMOOD, 1986; SINGH et al., 1994; KUMARI and SINGH, 1999). VAN LENTEREN and WOETS (1988) reported that the predators of the genus coccinellids are commercially used as biological control agents against whiteflies, thrips and aphids because of their efficiency.

In this study, the behaviour of predators described by the second-degree models, involving number of aphids that consumes *C. septempunctata* or the percentage of aphids that escape, reveals more than one factors for reducing efficiency of predation. If 100% efficiency of predation was present, then a line that coincides with *X*-axis starting from point 10 (line symptosis with *X*-axis has a $b = 0$ and $y = 0$) would describe the percentage of aphids that may escape (no escapes). The second-degree model describing the percentage of aphids that escape has an upward direction (the coefficient of x^2 is positive) and the departure from linearity is significant. As the total number of aphids increase, the second-degree (polynomial) line deviates from the *X*-axis. The authors consider two main factors to explain such behaviour: (a) the predator's failure because aphids are moving away, (b) the hunger satiation of the predator. The first assumption is based on other researchers' findings, which showed that it is possible greater populations of aphids may assist individuals to escape by higher production of alarm pheromone (LOSEY and DENNO, 1998) and thus survive by dropping away in the cage or hiding on the leaf until hunger of the predator is satiated. The second assumption is based on hunger satiation, which means a number of aphids ignored by the predator. In caged field experiments, hunger of the beetles decline with the decreasing aphid availability (FRAZER and GILL, 1981). These two parameters lead to a second-degree model (instead of a linear one), but the restrictions on the percentage of aphids that may escape are defined by two distinct boundaries, one upper linear model and one lower linear model (as shown in figs 1 and 2). The lower line is defined as the tangent to the curve of the second-degree model that passes through point 10 on the *X*-axis ($y = 0$ and $b = 0.524$). This kind of second-degree models are in agreement with the (second-degree) functional response models of type II. The time interval is fixed at 24 h, because the first 24 h are essential in biological control programmes, assuming equal probabilities of predators to search for and finally find the prey individuals. The model proposed by FOGLAR et al. (1990) for controlled environments was based on HOLLING's (1959) findings and assumptions, for unchanged prey density. Prey density is correlated to individual predator consumption of prey and consequently eaten prey were replaced. Natural deaths (or other sources of mortality) of prey were ignored and this may lead to approximate measurements (WIEDENMANN and O'NEIL, 1990). In our paper there were no deaths encountered by other reasons. The rate of discovering the prey individuals by the predator (HOLLING, 1959), is obviously depended on a more apparent biological reaction: escape to survive the predator's attack, that may vary depending on total prey densities, especially in low prey densities where lack of data or extensive experimentation is considered a weakness (FREIER, 1983; FREIER et al., 1996). These parameters were incorporated in the models used here, to attribute predation rates to prey densities. This is

difficult to be accomplished when prey density is changed during experiments of functional response (Triltsch and Roßberg, 1997).

When aphids are moving away, the predator's failure may increase handling time because of the predator's tiredness. The second assumption (hunger satiation of the predator) is depicted by many researchers. The first assumption is almost a linear phenomenon (Losey and Denno, 1998) when concerning two kinds of aphids over all parameters studied. From this point of view, if no hunger satiation is present, the minimum percentage of aphids that may escape could be defined by this line with $b_{min} = 0.524$. We propose that the term b (the slope) constitutes the Predator Failure Index, meaning that no matter what really happens the predator cannot catch a number of aphids that can escape and this is the minimum percentage of aphids that may survive. The total percentage of aphids that may escape could be defined by the upper (maximum) linear boundary passing through point 10 on the X-axis ($y = 0$) and the maximum value found in our experiment ($y = 18.7\%$ when total number of aphids is 30). The slope of this line is $b_{max} = 0.935$. We propose that the term b (the slope) constitutes the Survival Rate Index, defining the maximum percentage of aphids that may survive. Going further, based on the predictions according to the second-degree model (shown in fig. 2), the expected limit of effective predation can be determined. The predatory effect is an important parameter for a predator to be used in biological control programmes (Frazer and Gill, 1981; Triltsch and Roßberg, 1997; Deligeorgidis, 2002). As the linear models shown in fig. 2 define the theoretical maximum Survival Rate Index, then the expected limit of effective predation can be determined with accuracy. In this experiment, this limit was determined at 35 aphids per cage where the expected linear model has a $b = 1$, indicating equal rate of aphids that may escape (%) and number of aphids added. When initial number of aphids is great, C. septempunctata is less effective. The proportion close to 1 : 35 predator/aphids is considered satisfying for biological control in controlled conditions. Triltsch and Roßberg (1997) reported that predation rate of C. septempunctata on cereal aphids was higher when aphid density was higher and was depended on temperature conditions without determining upper limit. From this point of view, Survival Rate Index can also be described as Efficient Predation Index, and must be ≤1 for effective predation in biological control. The hunger satiation rate can be determined indirectly, as the difference between b_{max} and b_{min} in linear models of fig. 1 (in our experiment equals to 0.414). We propose that this difference may refer as Hunger Satiation Index and it depends mainly on Efficient Predation Index and the proportion: predator/aphids. In other words, the aphid density determines hunger satiation. In absolute numbers, the rate of aphids consumed by C. septempunctata decreases as total number of aphids in the cage increases. Thus, the theoretical maximum possible rate is described by the line with $b = 1$, passing through $x = 10$, $y = 10$ (100% effective predation). The line passing through $x = 10$,

$y = 10$ and $x = 30$, $y = 24.375$ (maximum realized consumption) has a slope $b_{con} = 0.719$. We propose that this may refer as Active Consumption Index and indicates the deviation from maximum possible consumption rate ($b = 1$). Additionally, Active Consumption Index determines how many aphids can actually one single beetle consume. Values around 1 represent effective predation.

As a conclusion, the female adults of C. septempunctata have been proved, according to the results of this research, an effective predator for the biological control of M. euphorbiae in controlled conditions. This is in agreement with the findings of Kumar et al. (2002), Deligeorgidis (2002) and Wiedenmann and O'Neil (1990), for controlled environments where climate is managed within certain ranges and this makes prediction of the population development of pest and various natural enemies easier and more reliable (Van Roermund et al., 1997). These researchers related the laboratory experiments to field and greenhouse practice. It is proposed to use starved female adults of C. septempunctata in biological control programmes in greenhouses, as a specialized predator of M. euphorbiae in proportions near 1 : 35 predator/aphids. The predator's behaviour in open (field) agrosystems may be different according to the literature, because hunger and predatory effect are influenced by many factors (Van Lenteren, 2000; Wiedenmann and O'Neil, 1990).

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Author's address: P. N. Deligeorgidis (corresponding author), Department of Crop Production, Technological Education Institute of Western Macedonia/Branch of Florina, Terma Kontopoulou, 53100 Florina, Greece. E-mail: tm00078@kozani.teikoz.gr