SIMULATION APPROACH OF THE ROLE OF THE PINE LADYBIRD (*EXOCHOMUS QUADRIPUSTULATUS* L). AND THE EARWIG (*FORFICULA AURICULARIA* L). IN CONTROLLING THE WOOLLY APPLE APHID (*ERIOSOMA LANIGERUM* HAUSSMANN)

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Keywords: simulation models, woolly apple aphid, *Exochomus quadripustulatus*, *Forficula auricularia*.

Summary

By means of simulation the role the Coccinellid *Exochomus quadripustulatus* L. and the earwig *Forficula auricularia* L. in controlling the Woolly apple aphid *Eriosoma lanigerum* Haussmann was investigated. To be able to implement the models experiments have been carried out to get information on feeding behaviour of the adult stage of the coccinellid and on searching and feeding of the earwig.Together with their phenology the models showed the impact of these predators on population development of the woolly apple aphid.

INTRODUCTION

In apple orchards aphids play an important role. The most important species are the rosy-apple aphid (*Dysaphis plantaginea*), the woolly apple aphid (*Eriosoma lanigerum*), the green apple aphid (*Aphis pomi*), the apple grass aphid (*Rhopalosiphum insertum*) and the rosy leaf curling aphid (*Dysaphis devecta*). Their numbers fluctuate strongly from year to year depending on biotic (natural enemies, host plant) and abiotic factors (temperature, rainfall etc). To gain more insight in the role of the various factors on the population dynamics of apple aphids, research has been started with unraveling on the population dynamics of the Woolly apple aphid (*Eriosoma lanigerum* Hausmann), one of the important aphid pests in the Netherlands.

To be able to quantify the role of these factors on population fluctuations of WAA, a simulation model has been developed which aims at explaining quantitatively the influence of these various factors on population density of WAA. Feeding experiments have been executed with earwigs and ladybird beetles to assess their potential role as controlling agent. Especially to make an assessment of the WAA/natural enemy ratios at the moment that the natural enemies emerge or become active in the tree. This is important for the decision whether a chemical treatment is necessary or not.

WOOLLY APPLE APHIDS AND THEIR NATURAL ENEMIES.

Woolly apple aphid (WAA) originates from North- America and has spread over the fruit growing areas of the world during the last centuries. The life cycle of WAA in the Netherlands is complete asexual because the winterhost (*Ulmus americana*) is lacking here. The offspring is parthenogenic produced, males are absent. The parasitoid *Aphelinus mali* (Hald.) has been introduced in most of these areas to control WAA with more or less success, probably depending on the climatological conditions. The parasitoid *Aphelinus mali* is in general not well synchronized with WAA under the Dutch climatological conditions. After a warm winter it will be complete outnumbered by WAA if the predators are not present The WAA has 10-11 generations per year, while the parasitoid has only 4-5. The aphid is also attacked by various predator species. With exclusion experiments it is tried to qualify the relative role of the various natural enemies of WAA (Mueller et al.,1988) It seems that in springtime the Pine ladybird beetle (*Exochomus quadripustulatus* L.) and during the summer the European earwig *(Forficula auricularia* L.) and sometimes the seven-spot ladybird (*Cochinella septempunctata* L.) play an important role. Other predators like lacewings, hoverflies and the mite *Allotrombium* have sometimes be seen feeding on WAA but their role is not clear. These natural enemies may interact strongly. The earwig preys upon all stages of WAA and on other aphid species, also on parasitized aphids and on mummies of A.mali. Therefore, it may affect the role of *A. mali.* The ladybird *E. quadripustulatus* has a preference for WAA but can also be found eating on other aphids. Mummies with *A. mali* are not eaten but larval stages of *A. mali* in the aphids are. Thus we have an interesting system containing an aphid species whose population fluctuations mainly are governed by: weather factors, tree condition, a monophagous parasitoid *A. mali*, oligophagous ladybird beetles and a very polyphagous earwig.

The question here is what is the relative role of these factors in the population dynamics of WAA. Is it mainly the abiotic factors that determine the numbers of WAA or are they mainly regulated by biotic factors. Depending on the results of this research practical questions concerning effective WAA/natural enemy ratios can be answered and the role of alternate food (the other aphid species) can be estimated.

THE SIMULATION PROCEDURE

The model is implemented within the INSIM (Insect Simulation) environment (Mols, 1992; Mols & Diederik, 1996). INSIM, is menu driven and needs biological data of an insect species. It generates age-structured models and therefore includes modules that calculate the number and development of insects by use of boxcars, to account for the relative dispersion of development. The core of the program is the so-called fractional boxcar train, which mimics the dispersion of the individuals passing through a life stage. An escalator boxcar train is used to mimic reproduction through several age classes of an adult female. The number of life stages determines the basic structure of the insect model. In these models the flow of individual insects from one stage to the next is taken into account by the so-called distributed-delay process (de Wit & Goudriaan, 1978; Goudriaan & van Roermund, 1989). By means of tables, life-history data are read into the program. For a simple phenological or population model the information required is: life cycle, developmental rate and its standard deviation for each insect stage, sex ratio, life expectancy of the adult and age dependent reproduction. The stages are coupled in a spreadsheet, which makes the program flexible. For the simulation of complicated predator or parasitoid - prey interactions, an extra module is included. The program is written in Visual Basic.The minimum and maximum daily temperature, are stored in an environment file. The temperature for each time step is calculated from a sinusoidal curve through the minimum and maximum temperature. The output of the chosen variables can be presented graphically or numerically on the screen.

THE WOOLLY APPLE APHID MODEL

Firstly a model was constructed with which is was possible to simulate the population development of WAA under different sets of environmental conditions In this model the following biological data were implented:

A)The developmental rates of the nymphal stages with their dispersion (Walker,1985; Bodenheimer,1937);

B)Age dependent reproduction (Walker, 1985; Evenhuis, 1958; Bonnemaison, 1965; Ehrenhardt, 1940);

C) Mortality especially of the crawler stage, all in relation to temperature. The mortality of WAA in winter differs for the various stages of WAA. The younger the stage the higher its resistance for frost which may partly explain that after soft winters the chance for WAA outbreaks is higher (Jancke, 1935; Ehrenhardt, 1940; Kjellander, 1953). Above 15 °C the first instar nymphs (the crawlers) leave the colony and swarm out in search for the young shoots where they try to establish a new colony (Hoyt and Madsen, 1960). From our experiments it became clear that during this phase mortality is very high. In the laboratory 40% succeeds in founding a new colony, while in the field only 5% is able to do so. A single wheather factor has not yet been found it is more a combination of them.
Concerning the earwig and the ladybird: A) Survival of the adult stages in relationship to temperature;

THE WAA PINE LADY BIRD (*EXOCHOMUS QUADRIPUSTULATUS*) RELATIONSHIP

Simulations were done with ladybirds and WAA under field conditions. For the simulations the following information was necessary:
a) Break of reproductive diapause takes place at the end of February begin of March (unpubl observations).
b) Survival of the adult stages in relationship to temperature (unpubl observations).
c) Feeding rate with respect to WAA as food. With simulation models integrating digestion rates at various temperatures and maximum mealsize an estimate is made about the potential daily consumption of WAA as food for adult lady birds (Fig. 2 and 3). They feed only during daytime. Consumption by the ladybirds is assumed to be in accordance to the proportional presence of the different WAA stages in the population. Preference for different WAA stages is not included.
Although they can complete larval development they need some alternative food to reach full adult weight (otherwise they develop into small adults). Therefore, predation by the larval stages is not included in the model, besides that, numbers in the field are in most cases relatively low at the moment that WAA population growth is fast.
d) Sex ratio is 1.
At the start of the simulation at 1 March 100 WAA in stable age distribution were present on one tree. Numbers of the ladybird were varied untill control over WAA was attained at the end of April. With control is meant that numbers of WAA at the end of April are equal or smaller than the number at the beginning of March when *E. quadripustulatus* becomes active. In May mortality of the ladybirds increases strongly and WAA always escapes control of the ladybird. From a small feeding model consisting of ingestion, digestion and respiration rates an estimate of the potential impact of the ladybird on WAA was calculated. In this way a preliminary estimate of WAA/ladybird ratio could be estimated. On average 0.86 ± 0.34 (mean$\pm$SD) ladybirds were necessary to control 100 WAA, which gives a WAA/coccinellid ratio of 116 .
Growth of WAA on small apple trees (1 meter) in cages with 0,1,2 E.quadripustulatus per cage were not significant different from the outcomes of simulations. With 4 coccinellids per cage the model offers higher predation than in the experiment
In the winters of the years 1989, 1990, 1991 and 1992 *Exochomus* was present in the trees at an average 2-4 ladybirds/tree. In 1994 6 ladybirds were counted per tree while in the spring of 1995 only 0.5 per tree were present. The initial amount of WAA at that time of the year is between 50-250 aphids per tree (James Grieve, 25 years old, 3 meter tall). The conclusion is that by their feeding early in the year the ladybird *E. quadripustulatus* may reduce the initial amount of WAA considerable.

THE WAA- EARWIG (*FORFICULA AURICULARIA*) RELATIONSHIP

Earwigs are very polyphagous as they feed also on fungi, pollen and young leaves but they have a preference for aphids as food. They have one generation per year. A female can produce one or two egg batches per year. The first in January - March the second May - June. The following information is incorporated into the model.
a) Developmental rates and standard deviation of the third and fourth larval stage (Buxton et al., 1976).
b) Survival of larval and adult stages in relationship to temperature (unpubl. observations)
c) Phenology of the earwig stages and their survival in the tree. For the years 1988-1994The phenology was obtained from the field. For 19995-1998 The phenology was obtained by a model adapted from Helsen et.al (1998). At the start of the third larval stage the earwigs climb up into the tree and from than on develop there to adulthood.
d)Searching and feeding rate with respect to WAA as food (Noppert et al. 1987; and unpubl results). With simulation models integrating digestion rates at various temperatures and maximum mealsize an estimate is made about the potential daily consumption of WAA as food for the different earwig stages (Fig. 2 and 3). No preference for the different WAA stages was found. Consumption by the earwig is according to the proportional presence of the different WAA stages in the population. Preference of earwigs for alternative food is lacking . Earwigs enter the tree in the third larval stage in the course of June depending on the previous temperatures. The number of WAA present at that moment determines the amount of earwigs needed to achieve control. The average WAA/earwig ratio has to be approximately 53 to reach control. Simulations were done for these years because data about the phenology of earwigs for the years181-1994 were obtained by by personal observations.The other years the phenology was obtained by the model of Helsen et al 1998.
The results of simulations are shown in Table 1.

Table 1 The results of the simulations for the years 1988-1998 are given The simulations started at the first of January with 100WAA in a stable age distribution (e,g. N1=65, N2 = 16 N3= 8 Adult = 5.)
Day number and date refer to the date that 50% of earwigs enter the tree The Aphid number is the number of WAA aphids at that moment and the amount of earwigs needed to achieve control is reached later in the season. Ratio is amount of Aphids /earwigs.

year	daynumber	Date	Aphid number	earwig L3 larvae required to achieve control	Ratio
1981	171,6	20 June	25009	450	55.5
1984	180,5	30 June	7821	146	53.6
1985	175,2	24 June	541	10	54.1
1986	172,1	17 June	1491	28	53.3
1987	180,3	29 June	904	17	55.2
1988	154	1 June	13408	250	53.6
1989	158,4	6 June	12482	233	53.5
1990	163	12 June	49873	930	53.6
1991	165	14 June	1477	27	54.7
1992	164	12 June	8297	155	53.5
1993	150	30 May	9697	188	51.6
1994	170	9 June	13064	255	51.2
1995	165	14 June	14375	268	53.6
1996	172	30 June	3633	69	52.7
1997	159	8 June	3837	72	53.2
1998	147	27 May	18074	350	51.6

CONCLUSIONS AND DISCUSSION

The study of woolly apple aphid and its natural enemies leads to the following conclusions.
Winter conditions determine the initial amount and the stage distribution of the aphids. This determines the potentials of WAA to reach the pest status in the course of the year.
The ladybird *E.quadripustulatus* is important at the start of the growing season and determines the initial amount of WAA. *Exochomus* can live on other aphid species as well. In fact it is known as a good predator of scale insects in Southern Europe (esp. Olive scale). This implies that alternate food sources may influence its role in controlling WAA. Its number on the apple trees in spring is determined by the number of WAA in the previous year.
Earwigs are important from the moment they arive into the tree from the beginning of June to the middle of August. Their number relative to the number of aphids present at that moment determines its success.But it must be taken into account that the number of earwigs is only partly dependent of the amount of aphids in the previous year.
The combination of predators and the parasitoid controls in most years the WAA population growth. Only after warm winters in absence of Exochomus a pest status can be reached. Studies concerning interactions of natural enemies still have to be done because it is not just a summation of their seperate roles towards WAA, but they may also be counter productive, because earwigs eat *A. mali* mummies. The condition of the host, which may influence development rate and fecundity of WAA, is still an unknown factor in the system, especially when the orchard has no watering or vertigation system so that dry spells may occur that hamper the sap flow in the trees and thus the food intake of the aphids.

AKNOWLEDGEMENTS

I thank Dick Diederik who programmed the model and many students who did an exellent job collecting data at the experimental orchard "de Schuilenburg"

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