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Beneficial thresholds for *Coccinella 7-punctata* L. (Col., Coccinellidae) as a predator of cereal aphids in winter wheat – results of population investigations and computer simulations

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Abstract: Syrphid larvae as well as adults and larvae of *Propylaea 14-punctata* (L.) and *Coccinella 7-punctata* L. are the most dominant aphid predators in winter wheat of Middle and Eastern Germany. The aphid-coccinellid interaction was investigated in a 4-year project aimed at the definition of beneficial thresholds (density of a predator guild necessary to keep a pest under control) for these species. Eight field studies and four cage experiments were performed to calculate the infestation reducing effect of coccinellids, particularly *C. 7-punctata*. The obtained data were used to estimate beneficial thresholds for the whole predator complex and especially for coccinellids whereby all predators have been converted into predator units (PU), e.g. fertile female of *C. 7-punctata* = 1.00 PU, larva = 0.33 PU, *Episyrphus balteatus* larva = 0.46 PU. In the field studies the calculation of the coccinellid related effect within the antagonist potential has not yet succeeded. The cage experiments have to be seen as case studies under special conditions. Therefore activities concentrated on the improved and validated simulation model GTLAUS including the submodels COCCISEP and WHEAT. Simulation runs with this tritrophic interaction model including the field count and cage trail data have shown that the beneficial threshold of *C. 7-punctata* to control cereal aphids under average conditions in Middle and Eastern Germany varies likely between 8 and 20 PU/m^2. However, an isolated evaluation of *C. 7-punctata* or another single predator species within the beneficial potential is undoubtedly not realistic. It seems to be better to calculate summarized effects of the whole predator community weighted as PU.

1 Introduction

In Germany, adults and larvae of coccinellids, *Coccinella 7-punctata* L. and *Propylaea 14-punctata* (L.), and syrphid larvae are the most abundant and important natural enemies of cereal aphids in wheat fields (Poehling, 1988; Wetzel, 1995; Freier et al., 1996a). Although an enormous knowledge of population dynamics, behaviour and feeding of coccinellids has been accumulated, an exact situation-related evaluation or calculation of the predatory effect of coccinellids has been impossible until now. Clear relationships between coccinellid density and changes of cereal aphid infestation development in wheat fields could not be demonstrated. For this reason, doubts about the regulatory importance of coccinellids have increasingly been mentioned in recent years (e.g. Hemptinne et al., 1992).

The aim of our investigations was to calculate the beneficial effect of coccinellids in regulating cereal aphids in wheat between DC 61 and 85 (decimal code by Stauss, 1994). Special interest was given to defining beneficial thresholds. A beneficial threshold represents a critical density of a predator or predator guild necessary to keep a pest under control, i.e. beneath the economic threshold (Freier, 1994). A 4-year investigation programme on the tritrophic wheat–aphid–predator (especially *C. 7–punctata*) interaction covering field studies, cage experiments and computer simulations has been done to calculate beneficial thresholds.

2 Materials and methods

2.1 Field counts on the population dynamics of cereal aphids and their antagonists

The studies were performed in winter wheat fields near Magdeburg (M93 . . . M96), a very fertile and poorly structured site, and in Flaeming (F93 . . . 96), a moderately fertile and well structured site from 1993 to 1996. Altogether eight fields were investigated. Starting at wheat stage DC 61, the tillers and their corresponding soil areas were controlled weekly at five points at distances of 20, 40, 60, 80 and 100 m from one field margin. Each point contained an average of $\approx$300 successive tillers in a drill row, about 1500 tillers per counting. Aphids and predatory insects were counted to estimate their density with individuals/m^2.

2.2 Cage experiments on the predatory efficiency of *C. 7-punctata*

Between 1993 and 1996 four cage experiments were carried out. The 2 m^2 ground area cages were set up in winter wheat fields at stage DC 35 combined with an insecticide application. At DC 61–69 mixed populations of *Sitobion avenae* (Fabr.), *Rhopalosiphum padi* (L.) and *Metopolophium dirhodum* (Walk.) were initialized. Some days later adult *C. 7-punctata*

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Table 1. *Evaluation of some aphid predators in form of predator units (PU) calculated from maximal consumption rates at 20–22°C (according to* FREIER *et al., 1997)*

Predator	Stage	PU
C. 7-punctata	Females	1.00
	Adults	0.94
	Larvae	0.33
P. 14-punctata	Adults	0.58
	Larvae	0.23
Episyrphys balteatus Deg. and other syrphids	Larvae	0.46
Pterostichus melanarius (Ill.) and other large carabids	Adults	0.18

males and females in a ratio of 1:1 were placed in each cage. To control aphid population development, aphids were counted weekly at 40 tillers/cage.

2.3 Scenario studies with the simulation model GTLAUS

GTLAUS is a discrete simulation model (written in TURBO-PASCAL) describing the population dynamics of the cereal aphid *S. avenae* in its interaction with winter wheat and natural enemies, particularly *C. 7-punctata* (FREIER et al., 1996b). It is now established as a demonstration and learning model. All calculations were made with the latest version 4.0. The initial abundance values used for aphids and antagonist and weather data represent actual field conditions in Middle-Eastern Germany (FREIER et al., 1996a).

2.4 Analyses of density data

For statistical analyses the density data of the three cereal aphid species, *S. avenae*, *M. dirhodum* and *R. padi*, were summed up. The assessment and evaluation of densities and predatory effects of coccinellids within the predator community required a different evaluation of all the predators. Therefore in our study we used predator units (PU) which we calculated from maximum consumption rates at 20°C (FREIER et al., 1997; table 1).

Statistical analyses including variance, correlation and regression analyses were performed with EXCEL 5.0 and SAS 6.11.

3 Results

3.1 Field counts on the population dynamics of cereal aphids and their antagonists

First of all we were interested in the dimension and the deviation of predator abundance in present surveys. Table 2 demonstrates the considerable variance of predator density peaks in the eight fields investigated. The following findings show that while the estimated density of a certain predator calculated as individuals or PU varied enormously, e.g. *C. 7-punctata* adults as PU with C.V. = 1.59, the whole predator potential calculated in PU varied only with C.V. = 0.55, i.e. in an obviously smaller range.

On average in these investigations, 17.3 PU/m^2 was registered as field maximum while the mean predator occurrence (average of all the counts and fields) was 5.6 PU/m^2. The proportion of the coccinellid population, within the whole predator community calculated as PU reached 44.9%. The mean cereal aphid infestation peaked at 6.7 individuals/tiller, which is clearly below the injury level of 12–15 aphids/tiller (HOLZ et al., 1994). However, the registered mean PU-potential does not completely represent the critical density (beneficial threshold) for natural aphid control because other factors like initial density of aphid population, mortality due to pathogenic fungi, parasitoids and rain additionally reduce aphid infestation.

The statistical analysis of the eight field studies did not indicate a natural aphid control by coccinellid community. There were no negative relations between coccinellid occurrence and aphid density or density changes ascertainable. A weak negative relationship between density of coccinellid larvae calculated in PU (x) and absolute density change (y) were observed:

$$y = -224.34x^2 + 670.06x + 116.38,\ r^2 = 0.0823 \quad (n = 60,\ P < 0.05).$$

However, an isolated evaluation of coccinellids or another predator group within the beneficial potential is undoubtedly not realistic.

In consideration of the whole predator community calculated as PU, no relationship between predator density in period to the date of aphid peak and level of aphid population peak was found. As established previously for coccinellid larvae, infestation reducing effects of summarized predator potential calculated in PU were noted ($P < 0.05$) when the aphid density changing rates were examined. Figure 1 shows the close relationship between PU/m^2 (x) and absolute aphid density changing rate (y). It displays a relationship between a predator potential of more than 8 PU/m^2 and decreasing aphid infestation in winter wheat. But this is not yet an evidence of beneficial threshold because other biotic influences on aphid infestation, particularly wheat ripening, were not considered.

3.2 Cage experiments on the predatory efficiency of *C. 7-punctata*

The four cage experiments on the cereal aphid-*C. 7-punctata*-interaction were carried out as case studies. Each experiment represented a special situation depending on biotic and abiotic factors so that rather varying results were obtained. However, the aspect of reducing aphid days per PU was interesting. Under the present caged conditions a PU/m^2 calculated from adults and larvae densities of ladybirds reduced the cereal aphid infestation by 5.4 (1993), 7.6 (1994), 20.9 (1995) and 8.8 (1996), on average 10.7 aphid days/tiller. It means in simple calculation that an infestation level of double the injury threshold of cereal aphids (mixed population) on wheat ($\approx$200 aphid days/tiller) could be reduced below the injury threshold by 18.7 PU of *C. 7-punctata*/m^2.

3.3 Scenario studies with the simulation model GTLAUS

All scenario calculations with different initial density conditions and weather runs have shown an extremely varying demand of coccinellids to keep the cereal aphid infestation below the injury threshold. Figure 2 demon-

Table 2. *Density peaks of coccinellids and syrphids in winter wheat at the sites Flaeming (F) and Magdeburger Boerde (M) 1993–1996*

Predator		Density peaks Absolute max.	Absolute min.	Average (n = 8)	S.E.	C.V.
C. 7-punctata						
Adults		M93	M96			
	Individuals	24.6	0.6	5.04	2.85	1.60
	PU/m²	23.1	5.6	4.75	2.67	1.59
Larvae		M96	M94			
	Individuals	18.0	0.01	6.01	2.33	1.10
	PU/m²	5.9	0.01	1.96	0.77	1.10
P. 14-punctata						
Adults		F94	F93			
	Individuals	9.2	0.8	3.38	1.10	0.92
	PU/m²	5.3	0.5	1.96	0.63	0.91
Larvae		F96	F93			
	Individuals	15.2	0.01	4.34	1.73	1.13
	PU/m²	3.5	0.01	0.99	0.4	1.14
Syrphids						
Larvae		M95	M94			
	Individuals	64.0	7.9	23.50	6.58	0.79
	PU/m²	29.4	3.6	10.80	3.02	0.79
Predator community (aphid specific and polyphagous predators)						
	PU/m²	31.8	8.8	17.31	3.36	0.55

S.E. = standard error, C.V. = coefficient of variation

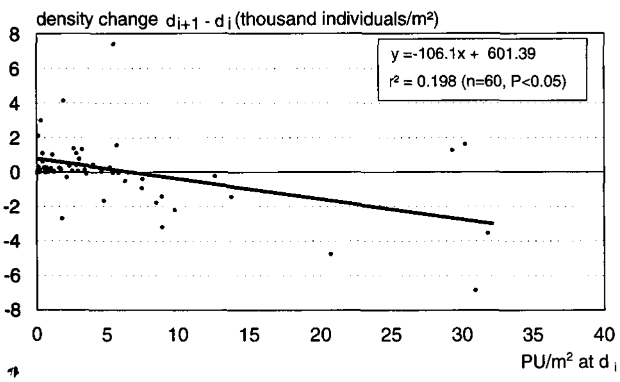

Fig. 1. *Relationship between density of predator units (PU) and density changes of cereal aphids in winter wheat fields at the sites Flaeming and Magdeburger Boerde in 1993–1996*

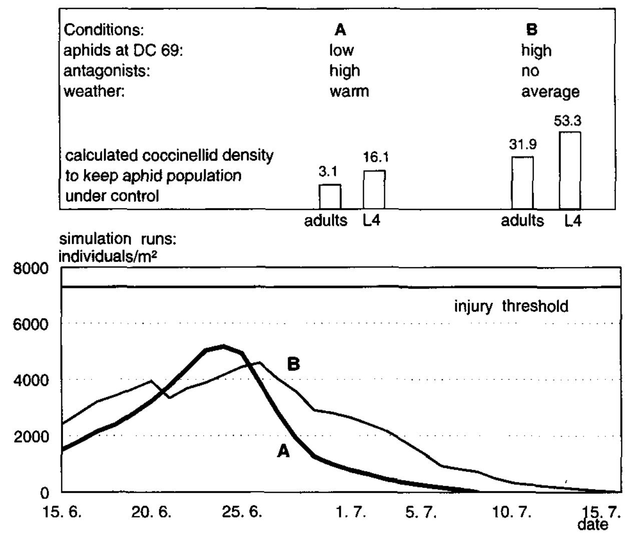

Fig. 2. *Simulated beneficial thresholds for* Coccinella 7-punctata *(adults and fourth instar larvae) as antagonist of Sitobion avenae in winter wheat with the model GTLAUS*

strates two constellations for quite different levels of beneficial thresholds as a result of simulations with GTLAUS. In the first scenario (A) with an initial aphid infestation below the control threshold at the end of flowering, abundant occurrence of additional beneficials and warm weather 3.1 adults and 16.1 fourth instar larvae (=15 PU)/m² reduced the infestation below injury threshold. However, in simulation B with an initial aphid density above control threshold, without any other beneficials and moderate weather, 31.9 adults and 53.3 old larvae of *C. 7-punctata* (=72.6 PU)/m² were necessary to keep the aphid population under control. In this calculation a fourth instar larva was evaluated with 0.8 PU.

4 Discussion

In the last 20 years numerous investigations have been performed to calculate or evaluate the controlling effect of coccinellids in field crops (Neuenschwander et al., 1975; Rautapää, 1975; Frazer and Gilbert, 1976; Wetzel et al., 1981; Kring et al., 1985; Honek, 1986; Hodek and Kindlmann, 1988; Hemptinne and Dixon, 1991; Hemptinne et al., 1992; Skirvin, 1995). The results demonstrate a wide range of several findings which cannot be reproduced under other field conditions. It seems that significant coccinellid effects controlling harmful aphids in crops are likely to be the exception, although often an infestation reducing effect of *C. 7-punctata, P. 14-punctata* and *Adalia 2-punctata* (L.) and other species is expected.

In the present investigations in wheat fields on the benefit of *C. 7-punctata* and *P. 14-punctata* we did not find clear incidences of its natural control. Significant relationships between coccinellid density and aphid infestation did not exist. Because the effective part of coccinellids within the effective predator potential of cereal aphids could not be evaluated individually, a feeding rate related evaluation of all aphid specific and polyphagous predators as PU were used. This method can help to calculate proportionate field effects of special predator groups. On the basis of PU-calculations the effect portion of coccinellids was in average of all surveys in the eight fields 44.9%.

Considering the predator community calculated as PU, the field and cage data on *C. 7-punctata* have brought only some outlines on the likely variance of beneficial threshold to our attention. The problem in the field is that predators are only a part of the infestation reducing influences of biotic and abiotic factors. Therefore under average conditions the beneficial threshold for the whole predator potential must be higher; under special aphid infestation supporting conditions it could even be as high as the registered average predator potential of 5.6 PU/m^2. The determination that already >8 PU/m^2 caused infestation decreasing effects is only a limited proof because the running ripeness of wheat plants after DC 77 represents the most important reason for infestation reducing phenomena. Consequently, the true PU-threshold for infestation decreasing effects has to be higher. The interpretation of field cage results is also problematical because the protecting conditions in the cages is advantageous to cereal aphid infestation development.

The great variance of coccinellid efficiency was very clear in simulations with the dynamic model system GTLAUS. The scenario calculations have shown that the critical coccinellid density keeping cereal aphids under control can differ greatly according to situation related conditions. In model scenarios considering normal and extreme conditions, significant aphid controlling effects of coccinellids were presupposed at more than 15 PU/m^2. Higher values have to be expected under very unfavourable conditions for coccinellid feeding, without other natural control agents and low aphid mortality. In this connection the enormous impact of temperature on coccinellid hunger and voracity must be mentioned (SKIRVIN, 1995; FREIER et al., 1996a; TRILTSCH, 1997).

According to the results of our investigations, beneficial thresholds for coccinellids as antagonists of cereal aphids in winter wheat seem to have a wide PU-range and can be determined only as part of the whole predator community taking into consideration all the other biotic and abiotic influences on wheat-cereal aphid–predator interaction. Including the several data and empirical calculations, it is possible that under average conditions 8–20 PU of coccinellids/m^2 are able to keep a cereal aphid infestation under control.

These insufficient results suggest that the model method offers the best chance of calculating infestation reducing effects of coccinellids or other predator guilds. However, the reliability of the tritrophic model GTLAUS is not yet sufficient to explain the situation related benefit of coccinellids in wheat with high significance.

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