The potential of *Coccinella septempunctata* L. and *Propylea quatuordecimpunctata* (L.) in natural control of aphids in wheat – 10-year field studies and computer simulations

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Introduction

In Germany cereal aphids are among the most important insect pests in arable crops farming. About 1 million hectares of wheat are sprayed with insecticides to control aphids in each season. Studies showed the particular significance of predators that attack aphids as varied communities of aphid-specific arthropods, especially ladybird adults and larvae (*Coccinella septempunctata*, *Propylea quatuordecimpunctata*), syrphid larvae (*Episyrphus balteatus* and some other species), chrysopids larvae (*Chrysoperla carnea*), and the guild of epigaeic predators that varied enormously between years and regions and in the course of an aphid infestation period. The natural control effects of cereal aphid predators have been studied in laboratory feeding experiments (reviewed by Freier et al., 1997) and gut content studies (Triltsch, 1999), in climate chamber and field conclusion experiments (Holland and Thomas, 1997) as well as in model simulations (Tenhumberg, 1995; Skirvin et al., 1997; Plantegenest et al., 2001; Gosselke et al., 2002). However, the most important question was never completely answered that is: How large is the aphid-infestation reducing effect of the coccinellid fraction compared to that of other predator fractions and the total predator community in defined wheat fields?

The aim of this long-term study was to

- Assess the densities of aphids and their antagonists in wheat fields in two distinct landscapes within Germany from the time of their initial appearance during the season until their decline at wheat yellowing and
- Perform statistical analyses of the 10-year field data and computer model simulations based on the assessed field data were performed to estimate the infestation-reducing effects of coccinellids compared to other predators within the aphid predator community.

Material and methods

Counts

Cereal aphids and their antagonists were counted in unsprayed winter wheat fields in Flaeming (L: low input region) and Magdeburger Boerde (**H: high input region**) from 1993 to 2002. Flaeming (**L: low input region**), a landscape in Eastern Germany, has moderately fertile sandy soils, a large forested area (38.9 %) and a relatively high percentage of nature habitats (4.2 %). Magdeburger Boerde (H), a landscape in Central Germany, has fertile soil with intensive cropping and a high wheat yield potential. The forested areas (11.6 %) and natural habitats (2.8 %) in H are smaller than in L (Kühne et al., 2000). The arthropods were counted weekly between wheat growth stages (BBCH) 49 and 87 (according to Meier, 1997), corresponding to eight sampling dates per season. The densities of aphids and antagonists (predators, mummies, moulded aphids) were recorded at five sampling points located 20, 40, 60, 80, and 100 m from one field margin. The counts were conducted on two lines into the field, thus each count covered 10 sampling points. Wheat tillers were examined for 3 m along a row at every point. Accordingly, each examination (sampling date) included approximately 2,400 tillers.

Statistics

All statistical calculations of density data were related to the spatial unit of one m² wheat area. Aphid infestation was described using the indicators seasonal density peak (individuals/m²) and aphid index (number of aphid days/m²) according to Rautapää (1966), respectively. In the present study, the assessed predator densities were converted to predator units (PU) as defined by Freier et al. (1998) for all relevant predator species or functional groups based on their surplus feeding rate at 20-22°C. For example, a female *Coccinella septempunctata* is assigned a value of 1.0 and a syrphid larva (*Episyrphus balteatus*) 0.46 PU, respectively. Thus, all individual predators of a sampling could be added to modified density values for the overall predator community potential.

Statistical analyses included the estimation of standard deviation (S.D.) and coefficient of variance (C.V.) of densities of all fractions over the years and regression analyses to describe the relationships between densities of aphid and predators and densities of the different predator fractions. SAS 8.1 statistical analysis software was used.

Computer simulations
GETLAUS01, a deterministic, discrete simulation model written in Borland-Pascal 7.0, uses separate sub-models and modules to represent different aphids and predators (Gosselke et al., 2001). GETLAUS01 is described on the homepage of Federal Biological Research Centre for Agriculture and Forestry (www.bba.de) from which it and can be downloaded. We used GETLAUS01 to simulate aphid and predator population dynamics based on their occurrence from the start of wheat flowering. A simulation was defined as successful if the simulated aphid and predator (predator unit) densities varied from the observed densities by less than 25 %. We then used the model to simulate aphid population development in the absence of predators.

3 Results

Figure 1 demonstrates the mean aphid infestation peaks and aphid indexes (sums of *Sitobion avenae*, *Metopolophium dirhodum*, *Rhopalosiphum padi*) in the low-input (L) and high-input (H) regions. The mean density peak and aphid index were considerably lower in L than in H.

There was a close non-linear relationship between aphid peaks (individuals/m²) (x) and indices (aphid days/m²) (y) used as indicators for infestation:

$y = 0.0000003x^2 + 0.0304x$ ($n = 20$, $R^2 = 0.8282$, $P<0.05$).

On average, 2.8 (peaks) and 2.7 (index) times more aphids were observed in H than in L. The infestation level at site H exceeded the injury threshold (defined by the authors as aphid index = 90,000 aphid days/m²) in 1995, 1998, 1999, and 2002. However, these remarkable regional density differences were not significant (P>0.05) due to variation between the years. Absolute density variation (S.D.) between the years was particularly high at H, but relative density variation (C.V.) was quite similar in both regions. The question was therefore to determine now, how coccinellids and other predators actually influenced the infestation levels at both sites in the different years.

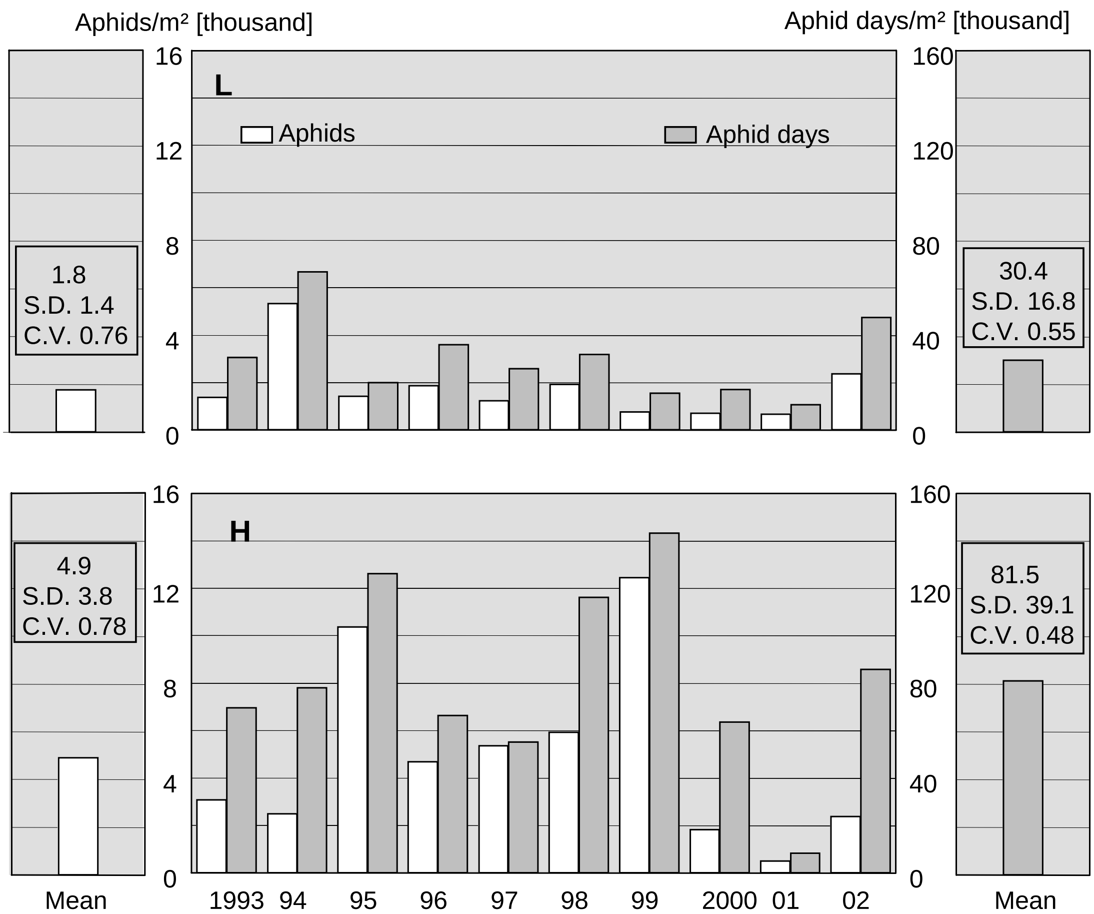

Figure 1: Aphid density peaks and aphid indexes in wheat fields

Table 1 shows the seasonal density means and 10-year means of seasonal means of aphid predators. The number of epigaeic predators was higher in the low-input region (L) and that of aphid specific predators was higher in the high-input region. *Coccinella septempunctata* adults and larvae, *Propylea quatuordecimpunctata*, adults and larvae, *Episyrphus balteatus* larvae and *Chrysoperla carnea* larvae were the most abundant aphid-specific predators within the 20 field studies, in spite of changing ranking and a tendency to a lower ratio of coccinellids compared to syrphid larvae in the last years (Table 1).

The different predators were additionally summarized as predator units (see above). The comparison between the sites indicated that the sites L and H did not actually differ with respect to the mean predator potential. Hence, we concluded that the lower aphid infestation level in L was not affected by a higher predator potential. The coccinellid potential did also not differ at the two sites.

Table 1: Seasonal means of aphid predators in wheat fields

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean	S.D.	C.V.
						Individuals/m²							
Site L													
CSA	2.0	0.4	0.3	0.2	0.3	0.3	0.2	0.4	0.0	0.1	**0.4**	0.6	1.4
CSL	0.1	0.4	0.9	0.6	0.1	0.7	0.3	0.0	0.0	0.0	**0.3**	0.3	1.1
PQA	0.3	2.6	0.6	1.1	1.9	7.3	2.2	1.1	0.1	0.5	**1.8**	2.1	1.2
PQL	0.0	1.4	0.7	4.6	1.5	9.4	5.5	1.1	0.0	2.1	**2.6**	3.0	1.1
EBL	1.6	6.5	4.1	4.9	3.6	7.7	2.8	0.9	6.9	14.9	**5.4**	4.0	0.7
CCL	0.3	0.3	0.6	1.6	0.5	1.2	0.3	0.8	0.2	0.2	**0.6**	0.5	0.8
CAA	1.1	2.5	0.7	5.9	2.0	4.4	3.7	3.5	2.4	5.2	**3.1**	1.7	0.5
STA	0.3	1.9	2.0	3.7	1.8	1.8	6.2	1.2	0.0	2.7	**2.2**	1.8	0.8
SPA	2.2	4.9	3.1	11.3	4.6	7.7	5.8	7.6	5.0	5.7	**5.8**	2.6	0.4
PU	3.0	5.6	3.2	5.2	3.5	10.8	4.2	2.0	3.5	8.1	**4.9**	2.7	0.5
PU-Cocc	2.1	2.3	1.2	2.1	1.7	6.5	2.5	1.2	0.1	0.9	**2.0**	1.7	0.8
Site H													
CSA	7.9	0.8	0.1	0.1	0.5	0.0	1.9	0.1	0.0	0.0	**1.1**	2.4	2.1
CSL	1.2	0.0	2.7	2.3	0.2	0.1	1.9	0.0	0.0	0.0	**0.8**	1.1	1.3
PQA	1.0	1.8	0.6	0.2	0.7	0.9	1.2	0.7	0.1	0.0	**0.7**	0.5	0.8
PQL	0.1	1.1	1.3	0.1	1.7	2.0	1.7	1.2	0.0	0.0	**0.9**	0.8	0.9
EBL	4.9	4.0	18.7	5.1	4.7	3.5	7.9	2.6	3.4	16.5	**7.1**	5.7	0.8
CCL	1.5	0.9	1.0	1.6	1.2	1.1	1.1	1.1	0.2	0.7	**1.0**	0.4	0.4
CAA	1.4	0.3	0.2	0.8	2.2	1.9	5.5	2.2	0.7	7.3	**2.2**	2.3	1.0
STA	0.3	0.8	0.2	2.2	1.1	3.1	2.6	2.4	0.0	0.8	**1.3**	1.1	0.8
SPA	2.2	1.9	2.6	3.2	3.1	3.3	3.2	6.0	1.6	4.3	**3.1**	1.3	0.4
PU	11.1	4.1	9.3	3.7	4.0	3.0	6.4	2.2	1.7	8.4	**5.4**	3.2	0.6
PU-Cocc	8.4	2.0	1.6	1.0	1.4	1.1	2.3	0.7	0.0	0.0	**1.9**	2.4	1.3

CSA, CSL: *Coccinella septempunctata* adults and larvae, PQA, PQL: *Propylea quatuordecimpunctata*, adults and larvae, EBL: *Episyrphus balteatus* larvae, CCL: *Chrysoperla carnea* larvae, CAA: carabids adults, STA: staphylinid adults, SPA: adult spiders, PU: predator units, PU-Cocc: predator units for coccinellids (adults and larvae)

To show whether a predator fraction benefited from a low occurrence of another fraction in the sense of intra-guild competition, numerical relationships between each predator fraction and each other predator fraction were investigated. Density relationships between coccinellid and syrphid larvae were identified. The highest syrphid larvae numbers did correspond with only low or medium coccinellid larva densities. A statistically high significant indirect relationship between the shares (%) of coccinellid adults and larvae (x) and syrphid larvae (y) within the predator community (100 %) was found:

$$y = -1.013x + 97.65 \quad (n = 20,\ R^2 = 0.9922,\ P<0.05)$$

The analysis of numerical density response of predator fractions at running date d_i or d_{i+1}(one week later) to aphid density assessed at date d_i showed significant ($P<0.05$) positive responses of predators to aphid infestation were found (Table 2).

Table 2: Significantly positive numerical responses of predators at running date d_i or d_{i+1}(one week later) to aphid infestation at date d_i in wheat fields in 1993 to 2002

Predator fraction	Data base		Dates used for data comparison	
Coccinella septempunctata adults	L,	L and H	d_i/d_i	
Propylea quatuordecimpunctata adults		L and H	d_i/d_i	
Coccinella septempunctata eggs	L,	L and H	d_i/d_i	
Propylea quatuordecimpunctata eggs	L, H,	L and H	d_i/d_i	
Coccinella septempunctata larvae	H,	L and H		d_{i+1}/d_i
Propylea quatuordecimpunctata larvae	H,		d_i/d_i	
	L, H,			d_{i+1}/d_i
Episyrphus balteatus eggs	L, H,	L and H	d_i/d_i	
Episyrphus balteatus larvae	L, H,	L and H	d_i/d_i	d_{i+1}/d_i
Chrysoperla carnea eggs	H,	L and H	d_i/d_i	
	H,	L and H		d_{i+1}/d_i
Chrysoperla carnea larvae	L, H,	L and H	d_i/d_i	
	H,	L and H		d_{i+1}/d_i
Predator community (predator units)	L, H,	L and H	d_i/d_i	d_{i+1}/d_i

Between adult coccinellid and aphid densities, either no or only weakly significant relationships were found. However, the numbers of eggs and larvae of both coccinellids, especially *Propylea quatuordecimpunctata* were significantly dependent on the aphid infestation level in most analyses. The predator community, syrphid eggs and larvae and chrysopid larvae showed the clearest numerical response to increasing aphid densities.

To determine aphid infestation-reducing effects, we investigated the relationship between the predator density at date d_i (x) and absolute aphid density (individuals/m²) change in the following week (y_1) and following two weeks (y_2). Significant aphid infestation-reducing effects were found regarding the total predator community and syrphid larvae:

Predator units LH: $y_1 = 2.356x^2 - 177.4x + 737.3$ (n = 157, R^2= 0.1948, $P<0.05$)
$y_2 = 5.615x^2 - 313.2x + 1174$ (n = 157, R^2= 0.2346, $P<0.05$)
Predator units L: $y_1 = 3.919x^2 - 155.5x + 541.4$ (n = 78, R^2= 0.2707, $P<0.05$)
$y_2 = 5.886x^2 - 218.1x + 714.1$ (n = 78, R^2= 0.2611, $P<0.05$)
Predator units H: $y_1 = 3.592x^2 - 238.8x + 952.2$ (n = 79, R^2= 0.2114, $P<0.05$)
$y_2 = 10.24x^2 - 489.5x + 1669$ (n = 79, R^2= 0.2808, $P<0.05$)
Syrphid larvae LH: $y_1 = 3.971x^2 - 262.2x + 594.9$ (n = 157, R^2= 0.2573, $P<0.05$)
$y_2 = 8.169x^2 - 412.1x + 845.1$ (n = 157, R^2= 0.2615, $P<0.05$)
Syrphid larvae L: $y_1 = 7.006x^2 - 225.6x + 358.8$ (n = 78, R^2= 0.3382, $P<0.05$)
$y_2 = 9.648x^2 - 299.5x + 442.3$ (n = 78, R^2= 0.3083, $P<0.05$)
Syrphid larvae H: $y_1 = 2.854x^2 - 299.1x + 820.8$ (n = 79, R^2= 0.3083, $P<0.05$)
$y_2 = 9.807x^2 - 539.9x + 1256$ (n = 79, R^2= 0.3212, $P<0.05$)

A tendency to infestation reduction was observed at a predator potential of more than approx. 4 to 5 predator units/m². Infestation-reducing effects were also determined for coccinellids, but without or slight statistical significance. Differences between the two sites were not observed.

The findings of the computer simulations with the model GETLAUS01 are shown in Figure 2.
The data suggest that the predators reduced aphid populations by a mean 127,900 aphid days/m² at site L and by 108,100 aphid days/m² at location H. This insignificant difference confirms the relatively comparable infestation-reducing potential of the predator community in the two regions. However, because the aphid infestation level in the low-input region (L) was only the half that in H, the simulated relative rate of aphid infestation decrease due to predators was higher at site L (reduction by 80.1 %) than at site H (57.0 % reduction).

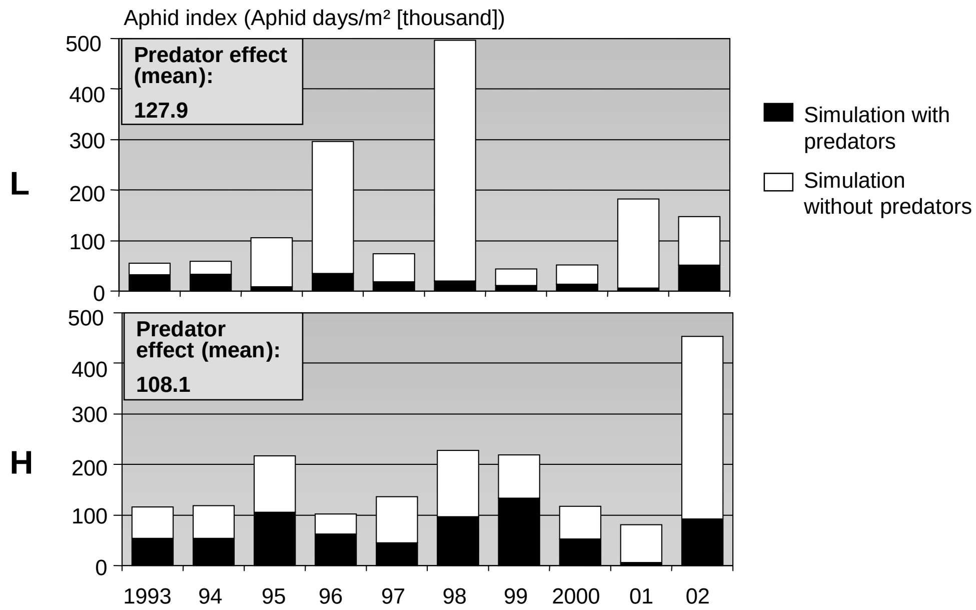

Figure 2. Simulation of aphid infestation in wheat fields with and without predator effects.

Further, simulations were performed without predator effect of coccinellid community. This was done by setting the number of coccinellids in the observed fields to zero while leaving that of all other antagonists unchanged. The same was repeated with syrphid larvae. Table 3 demonstrates the results.

Table 3: Simulation of aphid infestation in wheat fields with normal predator effects and without predatory effects of coccinellids (-) and syrphid larvae (-)

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	Mean
	Aphid index (aphid days/m²)										
Site L											
Normal	32.5	33.6	9.4	35.6	18.3	20.6	11.4	14.3	6.3	51.9	23.4
- coccinellids	34.7	35.9	10.8	59.1	24.0	60.4	26.7	25.9	6.3	52.3	33.6
Share (%) in predator community	3.9	4.0	1.4	7.9	7.7	8.0	34.5	22.4	0.03	0.3	9.0
- syrphid larvae	53.1	44.2	78.8	245.9	63.2	108.7	21.5	33.9	179.3	142.3	97.1
Share (%) in predator community	36.9	18.1	65.9	71.1	60.7	17.8	22.9	37.6	94.8	61.5	48.7
Site H											
Normal	54.5	54.7	105.5	63.1	45.9	97.2	133.4	52.6	6.0	92.2	70.5
- coccinellids	92.3	67.6	132.8	64.4	50.9	105.7	147.8	77.7	6.2	92.9	83.8
Share (%) in predator community	32.7	10.9	12.6	1.3	3.6	3.7	6.6	21.3	0.3	0.2	9.3
- syrphid larvae	86.6	102.9	183.4	97.2	129.2	212.8	180.3	77.8	77.3	448.4	159.6
Share (%) in predator community	27.8	40.8	35.9	33.4	61.4	50.8	21.4	21.4	87.9	78.6	46.0

Discussion

The 10-year field study provides a good insight into the varying numbers of cereal aphids and their predators and density relationships between both trophic levels in wheat fields. The lower level of aphid infestation observed in wheat fields in the low-input region cannot be explained by stronger predator effects because there were no significant differences between the predator densities, community composition features and climate conditions in the two regions studied. Probably, the differences in aphid density occurred due to “bottom up” effects, such as the different nutrient quality of wheat at both sites. The nitrogen content plays an important role in aphid population development (Duffield et al., 1997). The coccinellids *Coccinella septempunctata* and *Propylea quatuordecimpunctata* (other ladybird species did not occur) varied over the years, whereby the differences between the sites remained limited.

The numerical response of the two coccinellids to increasing aphid densities was rather low, but that of syrphids was as expected quite evident. Schellhorn and Andow (2005) observed different responses of coccinellid species to aphids in maize fields. In our study, both species, *Coccinella septempunctata* and *Propylea quatuordecimpunctata*, responded relatively similar.

The statistical analysis of aphid infestation-reducing effects demonstrated statistically significant effects for the total predator community and syrphid larvae. The analysis of natural control effect of coccinellids did not show such clear results. Four to five predator units/m² seemed to be a critical density for an active natural aphid control.

There are different experimental approaches to demonstrating the field-related aphid infestation-reducing effects of coccinellids and other predators, especially exclusion experiments (Lee et al., 2005). However, the results of cage experiments do not really reflect reality. The method we used was based on simulations using the model GETLAUS01, which contains very specific sub-models for the three aphid species *Sitobion avenae*, *Metopolophium dirhodum* and *Rhopalosiphum padi* and for the coccinellids *Coccinella septempunctata* and *Propylea quatuordecimpunctata* the most abundant coccinellid species in the landscapes where the samplings performed (Gosselke et al., 2001). Other models focus on the effect of entomophthoralean fungi and parasitoids (Plantegenest et al., 2001) which were clearly less important in the present study. The simulations which demonstrated the predator effects over a wide range depending on the field related situation showed that the effects of coccinellids can be extremely variable. This depends on their density relative to aphid abundance and on other factors like temperature. The model simulations indicated that syrphid larvae were the most important predator fraction in natural aphid control in the two sites. The simulated effects of the coccinellid community was lower than expected. However, it is not excluded that the model overestimated syrphid effects and underestimated the coccinellid effects. A validation of the predator related model results is not possible.

This study showed that the predatory potential of a single group of predators (e. g. coccinellids) can only be determined in context with the total active predator community.

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