

Influence of Intercropping with Spring Cereals on the Occurrence of Pea Aphids (*Acyrtosiphon pisum* Harris, 1776) and their Natural Enemies in Field Pea (*Pisum sativum* L.)

MAREK SEIDENGLANZ¹, IGOR HUŇADY¹, JANA POSLUŠNÁ¹ and ANNE-KRISTIN LØES²

¹Department of Plant Protection, AGRITEC, Research, Breeding & Services Ltd., Šumperk, Czech Republic; ²Bioforsk Økologisk, Tingvoll, Norway

Abstract

SEIDENGLANZ M., HUŇADY I., POSLUŠNÁ J., LØES A.-K. (2011): **Influence of intercropping with spring cereals on the occurrence of pea aphids (*Acyrtosiphon pisum* Harris, 1776) and their natural enemies in field pea (*Pisum sativum* L.).** Plant Protect. Sci., **47**: 25–36.

Occurrences of pea aphids and their natural enemies (syrphids, mummies caused by entomopathogenic fungi *Beauveria* sp. and by the parasitic wasp *Aphidius ervi*) were compared in monocultures and mixtures of field peas and spring cereals in three seasons (2008–2010). At the beginning of colonisation, the occurrence of aphids was not substantially influenced by intercropping with cereals. However, the numbers of pea aphids located on inflorescences started to decline earlier in mixtures compared with monoculture. More syrphids (eggs + larvae) were found in mixtures than in monoculture, and more syrphid eggs were found in young aphid colonies (10 to 20 individuals) in mixtures. Intercropping did not influence the occurrence of fungal mummies (*Beauveria* sp.), but mixtures tended to have more aphid colonies infested by *A. ervi* in 2008 and 2009.

Keywords: *Acyrtosiphon pisum*; syrphid eggs; syrphid larvae; field pea; cereals; aphid mummies; *Beauveria* sp.; *Aphidius ervi*

The pea aphid (*Acyrtosiphon pisum* Harris, 1776) is probably the most important insect pest of field pea (*Pisum sativum* L.) in the Czech Republic (CR). The threshold value is very low for pea aphids in field pea: 3–5 individuals of this pest per plant are enough to cause serious damage on the crop level, not so much due to direct injuries but to the transmission of virus diseases, *Pea enation mosaic virus* (PEMV) and *Pea seed-borne mosaic virus* (PSbMV). The virus diseases can decrease seed yield by up to 80% (HOUBA *et al.* 2009). However, direct effects of the pest on pea plants can also be very important. Many farmers consider it to be impossible to grow field pea successfully without insecticides in the CR.

Hence, it is desirable to look at some alternative approaches to the problem.

Organic farming systems and their wide exploitation of intercropping and other means to increase the biodiversity in agricultural fields and landscapes may serve as a source of inspiration. The levels of insect pest infestation may differ substantially depending on whether the host plant is grown as monoculture or in a mixture. According to VANDERMER (1989) and KINANE and LYNKJÆR (2002), the intercropping of pea with wheat can reduce aphids and weevils (*Sitona* spp.) as compared to pea monoculture. BEDOUSSAC *et al.* (2010) proved positive effects of pea intercropped with wheat only on pea aphids and not on weevils. The positive effects of

Supported by Ministry of Agriculture of the Czech Republic, Project No. QH82027, and by Norwegian Grant No. A/CZ0046/1/0024.

intercropping to reduce insect pests may be due to the more complicated localisation of host plants in mixtures by insect pests, especially by females, or to the higher abundance and earlier presence of natural enemies in the mixtures (GILBERT 2005).

Pea aphids have several commonly occurring natural enemies, whose importance as biological control agents was widely discussed in many scientific studies (e.g. BUDENBERG & POWELL 1992; GILES *et al.* 1994; EIGENBRODE *et al.* 1998; FRANCIS *et al.* 2004; GILBERT 2005; EKBOM 2009). In the present study, we recorded (1) aphidophagous syrphids, whose larvae can plunder aphid colonies very effectively, (2) entomopathogenic fungus *Beauveria* sp. inducing successive dying of infected aphids and their mummification, and (3) parasitic wasp *Aphidius ervi* Haliday also inducing successive dying and mummification of attacked aphids. In the CR, *E. balteatus* and *S. pyrastris* have been recorded as the most frequent syrphid species in field pea (HÝBL & SEIDENGLANZ 2009). Populations of pea aphids are often infected by various entomopathogenic fungal species, such as *Beauveria bassiana* (Ascomycota: Hypocreales), *Pandora neoaphidis* (Zygomycota: Entomophthorales), *Entomophthora planchoniana* (Zygomycota: Entomophthorales) (BAVERSTOCK *et al.* 2005; RADCLIFFE & RAGSDALE 2007). Pea aphid nymphs are often attacked by egg-laying females of *A. ervi*. Many studies described relationships among the host plant (field pea), its herbivore (pea aphid) and the parasitoid (*A. ervi*) (e.g. GUERRIERI *et al.* 1993, 1999, 2002; DU *et al.* 1996, 1998).

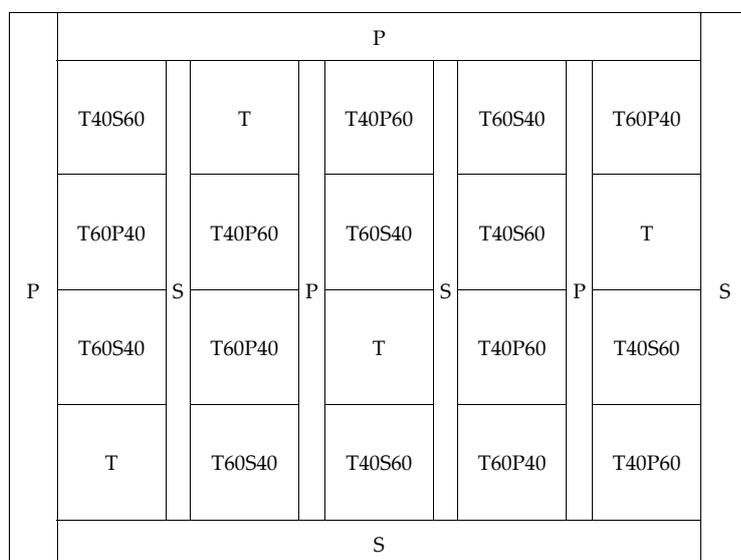
Studies comparing the occurrences of natural enemies of the pea aphid in field pea (infested by

pea aphids) in monoculture and intercropped with cereals are scarce, at least for Czech conditions. The aim of the paper is to investigate the effect of growing peas in mixtures with cereals on the occurrence of pea aphids and some of their important natural enemies under Czech conditions. We attempt to answer the following question: Is the development of occurrences of pea aphids and their predators (syrphids) and parasitoids (mummies caused by entomopathogenic fungi or by parasitic wasps) located on inflorescences different when the pea is grown in monoculture compared to mixtures with spring cereals?

MATERIAL AND METHODS

Occurrences of pea aphids and their natural enemies were recorded in plot trials (PT) with monocultures and mixtures of field pea and spring cereals in 2008, 2009 and 2010 on an experimental farm of AGRITEC at Rapotin (RA), and in 2010 on a nearby organically managed farm at Postrelmov (PO). Neither pesticides nor fertilisers were used in field trials (Figure 1).

The occurrence of pea aphids (*A. pisum*) was assessed from the first appearance of small colonies (winged and unwinged females + nymphs) until the population started to decline (2008, 2009) or declined (2010). The numbers of aphids on inflorescences of individual plants were repeatedly counted, without damaging the plants. In 2008, counting was made on June 7, 13, 20 and 27, in 2009 on June 12, 15, 20 and 26, and in 2010 on June 15, 22, 29 and on July 14. The total number of aphids (sum of



T = Terno – pea semileafless cultivar

S = Sirael – non-baking spring wheat cultivar

P = Pribina – non-malting spring barley cultivar

The numbers show seed ratios in compared mixtures. The width of assessed plots: 2.5 m; the width of cereal buffer zones 1.25 m; the length of plots 10 m

Figure 1. The design of plot trials in Rapotin and Postrelmov in 2008–2010

winged females + unwinged females + nymphs of various instars) per inflorescence was recorded on 20 randomly selected plants per plot. In 2009 and 2010, the absolute numbers of aphids in colonies were compared. In 2008, the occurrence of aphids was too high to record absolute numbers. Hence the degree of infestation was determined for each plant: 1 = without infestation; 2 = 1–20 aphids per inflorescence, 3 = 21–50 aphids per inflorescence, 4 = 51–100 aphids per inflorescence, and 5 = more than 100 aphids per inflorescence.

For the natural enemies of aphids, the total numbers of eggs, and later larvae and pupae of syrphid flies (*Syrphidae*) were recorded on the same inflorescences as the aphids. Additionally, inflorescences with colonies containing 10 to 20 living aphids were selected, and the numbers of syrphid eggs were counted within or near the colonies, in 20 colonies per plot. For larvae, numbers were recorded within 5 × 10 colonies per plot. We do not present any absolute numbers, but the percentage (%) of colonies with one or more larvae. In 2008, the recording dates were June 7, 13, 20 and 27, in 2009 June 12, 20 and 26, and in 2010 on June 16, 23, 29 and on July 14. The assessments of syrphid larvae occurrences

were carried out in the morning (by 9 a.m.). The total numbers of aphid mummies caused by entomopathogenic fungi were counted on selected inflorescences with aphid colonies with more than 100 living aphids in 2008 and 2009. In 2010, the counts were made in colonies with more than 30 living aphids due to lower levels of aphid occurrence in that year. Fifteen counts per plot were always made. In 2008, the recording dates were June 20 and 27, in 2009 June 20 and 26, and in 2010 June 29 and July 14. Mummies caused by the braconid wasp *Aphidius ervi* were recorded in clusters of 10 inflorescences with a colony containing more than 50 living aphids, at five sites per plot in 2008 and 2009. In 2010, the counts were made in colonies with more than 30 living aphids due to lower levels of aphid occurrence in that year. In all years absolute numbers of mummies were recorded, but the percentages of colonies at each site with two or more aphid mummies were used as the measure to compare differences among treatments. In 2008, the recording date was June 27, in 2009 June 26, and in 2010 June 29. The growth phases of pea on each recording date are described in Table 1.

Table 1. The growth stages of pea plants on recording dates for aphids and their natural enemies in RA and PO in 2008–2010

2008 ¹		2009 ²		2010 RA ³		2010 PO ⁴	
Date of assessment	growth stage	date of assessment	growth stage	date of assessment	growth stage	date of assessment	growth stage
7.6.	(BBCH 51)	12.6.	(BBCH 51 - 55)	15.6.	(BBCH 51)	16.6.	(BBCH 51–55)
13.6.	(BBCH 61)	15.6.	(BBCH 55 - 61)	22.6.	(BBCH 55– 61)	23.6.	(BBCH 61–63)
20.6.	(BBCH 65)	20.6.	(BBCH 59 - 61)	29.6.	(BBCH 65)	29.6.	(BBCH 65)
27.6.	(BBCH 65–67)	26.6.	(BBCH 65)	14.7.	(BBCH 71)	14.7.	(BBCH 71)

¹More detailed description of growth phases in 2008: 7.6. – green flower buds evolved on lower nodes; 13.6. – the first open flowers evolved on lower nodes; 20.6. – flat pods evolved on nodes I – II; higher nodes with flowers; 27.6. – green pods evolved on nodes I–IV; higher nodes still with flowers

²More detailed description of growth phases in 2009: 12.6. – green flower buds evolved on plant inflorescences; 15.6. – approx. 5% of plants with open flowers on lower nodes; 20.6. – approx. 90% of plants with open flowers on lower nodes; 26.6. – nodes I–II with flat pods, higher nodes with flowers

³More detailed description of growth phases in 2010 RA: 15.6. – green flower buds evolved on lower nodes; 22.6. – buds with visible petals and the first open flowers evolved on lower nodes of inflorescences; 29.6. – flat pods evolved on nodes I–II; higher nodes with flowers; 14.7. – green pods evolved on nodes I–IV; the plants do not flower any longer

⁴More detailed description of growth phases in 2010 PO: 16.6. – green flower buds and the first buds with visible petals evolved on inflorescences; 23.6. – the first open flowers evolved on nodes II and III; 29.6. – flat pods evolved on nodes I–III; higher nodes with flowers; 14.7. – green pods evolved on nodes I–VI; the plants do not flower any longer

The results of the trials were analysed using Statistica version 8 software. The percentage values (comparison of the percentage of aphid colonies with one or more syrphid larvae and comparison of the percentage of aphid colonies with two or more insect mummies) were first transformed (arcsine transformation) to follow a normal distribution. Then for all sets of data, one-way ANOVA tests (LSD) for analysis of variance were performed, followed by Tukey's tests for multiple comparisons between treatments ($P < 0.05$). For the ANOVA, the homogeneity of variance was previously checked using Bartlett's tests ($P < 0.05$).

RESULTS

Pea aphids and syrphids 2008

In 2008 in Rapotin, the first colonies appeared on June 7, and the aphid populations started to decline on June 27, when the last counts were made. The sequence of the most infested treatments varied during that period. On June 7, T60S40 had the lowest level of infestation. However, the differences among treatments were not statistically significant ($F_{4, 295} = 1.9005$; $P = 0.11035$). The infestation increased rapidly in all treatments between June 7 and 13. Interestingly, on June 13, T100 had the lowest level of infestation. The T40P60 treatment was significantly more infested than T100 at that time ($F_{4, 295} = 4.9687$; $P = 0.00069$). During the next week, the levels of infestation decreased in

T60S40, T60P40 and T40P60. However, the infestation slightly increased in T40S60, and in T100 it increased markedly. Again, the differences were not significant ($F_{4, 295} = 1.2749$; $P = 0.14942$). In the last week, a decline of aphid populations was observed in all treatments except T100. At the end of counting, significantly less aphids were found in T60S40, T40S60 and T40P60 than in T100 ($F_{4, 295} = 7.3217$; $P = 0.00023$). It shows that the decline in aphid populations occurred earlier in mixtures than in pea monoculture.

No statistically significant differences among treatments in the occurrence of syrphids were recorded on June 7. However, the mean value for T100 was markedly lower than that for the other treatments ($F_{4, 295} = 1.9036$; $P = 0.11321$). By June 7, the recorded syrphids were mainly eggs and some larvae. The differences between T100 and the other treatments became more evident at the 2nd and 3rd assessments, when the occurrences of syrphids on inflorescences were significantly lower in T100 (June 13: $F_{4, 295} = 8.3781$; $P = 0.00021$; June 20: $F_{4, 295} = 6.1125$; $P = 0.00126$). On June 13 and 20, new eggs and active larvae of syrphids were found on pea plants. Between the 3rd and the 4th assessment, the occurrence of syrphids in T100 increased rapidly and the differences among treatments became negligible ($F_{4, 295} = 1.0012$; $P = 0.23565$). During the last week, new syrphid eggs appeared mainly on plants in T100. In the other treatments, syrphid pupae were found, demonstrating more rapid development of the syrphid population in these treatments. Development of the pea aphid

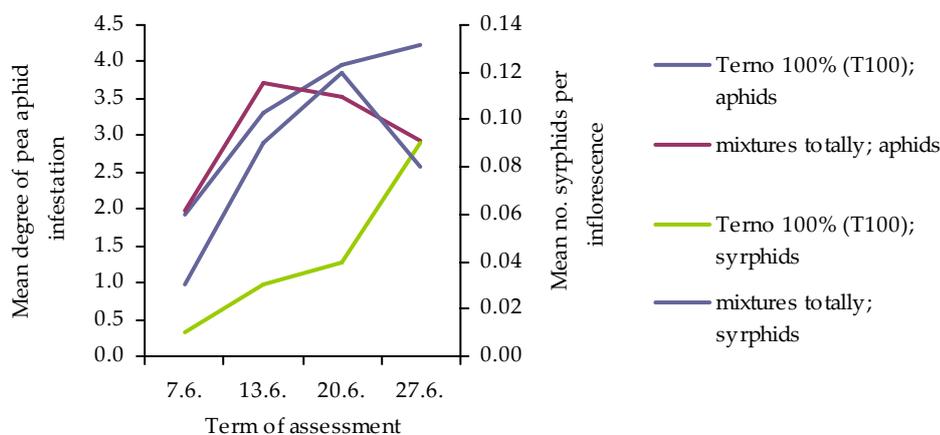


Figure 2. Development of the pea aphid (*A. pisum*) numbers and syrphid (Syrphidae) occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals (Pribina barley cultivar, Sirael wheat cultivar) in 2008. Infestation assessed on a scale from 1 to 5 where 1 = without infestation, 2 = 1–20, 3 = 21–50, 4 = 51–100, and 5 = more than 100 aphids per inflorescence

Table 2. Mean numbers of syrphid eggs per aphid colony of 10–20 individuals in size (2008, 2009, 2010 PO, 2010 RA)

Treatment	2008				2009				2010 PO				2010 RA				
	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	
T100	0.15 (0.44)	0.22 (0.59)	0.35 (0.69)	0.52 (0.85)	0.12 (0.42)	0.28 (0.67)	0.48 (0.85)	0.80 ^a (0.78)	0.68 ^a (0.89)	0.80 ^a (0.78)	0.68 ^a (0.89)	0.93 (0.84)	0.67 (0.91)	0.25 ^a (0.57)	0.37 ^a (0.69)	0.38 ^a (0.69)	0.15 ^a (0.52)
T60S40	0.37 (0.82)	0.58 (1.08)	0.52 (0.93)	0.43 (0.83)	0.33 (0.75)	0.68 (1.13)	0.57 (0.93)	1.35 ^b (0.97)	1.43 ^b (1.13)	1.35 ^b (0.97)	1.43 ^b (1.13)	1.27 (0.88)	0.72 (0.81)	0.58 ^{ab} (0.96)	0.70 ^{ab} (1.05)	0.73 ^{ab} (1.07)	0.48 ^b (0.87)
T40S60	0.40 (0.83)	0.42 (0.79)	0.55 (0.83)	0.45 (0.77)	0.37 (0.82)	0.48 (0.81)	0.62 (0.85)	1.43 ^b (0.85)	1.38 ^b (1.01)	1.43 ^b (0.85)	1.38 ^b (1.01)	1.25 (0.90)	0.83 (0.76)	0.72 ^b (1.04)	0.83 ^{ab} (1.06)	0.87 ^{ab} (1.07)	0.27 ^{ab} (0.63)
T60P40	0.38 (0.83)	0.42 (0.87)	0.48 (0.83)	0.48 (0.79)	0.33 (0.80)	0.47 (0.89)	0.52 (0.83)	1.23 ^{ab} (0.95)	1.32 ^b (1.11)	1.23 ^{ab} (0.95)	1.32 ^b (1.11)	1.35 (1.02)	0.75 (0.75)	0.65 ^{ab} (0.97)	0.93 ^b (1.06)	0.90 ^b (1.02)	0.20 ^{ab} (0.55)
T40P60	0.52 (1.07)	0.53 (0.91)	0.53 (0.87)	0.52 (0.73)	0.45 (1.02)	0.58 (0.91)	0.58 (0.89)	1.40 ^b (1.21)	1.33 ^b (1.00)	1.40 ^b (1.21)	1.33 ^b (1.00)	1.37 (0.97)	0.58 (0.77)	0.60 ^{ab} (1.05)	0.87 ^b (1.08)	0.78 ^{ab} (0.98)	0.27 ^{ab} (0.55)

The mean values in columns are not significantly different (Tukey's test; $P < 0.05$); $N = 60$ counts per treatment (in 20 colonies per replication); SD = standard deviation

numbers and syrphid occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals is shown in Figure 2.

The level of syrphid egg density in aphid colonies of 10–20 individuals in size was markedly lower in T100 than in the other treatments (mixtures) on the first three dates of assessment (June 7–20, Table 2). On the first counting date, the levels were two- to four-fold higher in the mixtures compared with T100. Later, the differences diminished and by the fourth date (June 27) they became negligible. Due to a high variation between the replications, the differences among treatments were not statistically significant (June 7: $F_{4, 295} = 1.5726$; $P = 0.18155$; June 13: $F_{4, 295} = 1.6174$; $P = 0.16981$; June 20: $F_{4, 295} = 0.55534$; $P = 0.69527$; June 27: $F_{4, 295} = 0.13706$; $P = 0.96850$).

In 2008, the first syrphid larvae appeared earlier in selected aphid colonies in the mixtures with higher portions of cereals (T40S60 and T40P60, Table 3). In addition, the density of larvae in aphid colonies was higher in the mixtures during a substantial part of the period when pea aphids were present on pea plants (June 7–20). However, the differences among treatments were statistically significant only on the third counting date. The percentage of aphid colonies with one or more syrphid larvae was significantly higher in T40S60 than in T100 at that time ($F_{4, 70} = 2.7580$; $P = 0.03437$).

Pea aphids and syrphids 2009

Similarly like in 2008, no statistically significant differences among treatments were found in the numbers of aphids (females + nymphs) on inflorescences at the beginning of pea infestation on June 12 ($F_{4, 295} = 1.2749$; $P = 0.27989$). During the next three days, the numbers of aphids increased rapidly in some treatments, and the differences became close to significant on June 15 ($F_{4, 295} = 1.2953$; $P = 0.05933$). Between June 15 and 20, the mixtures with the highest shares of field pea showed the sharpest increase in the number of pea aphids, whereas the number in T40P60 increased only slightly. On June 20, T60P40 was significantly more infested than T40S60 ($F_{4, 295} = 4.2769$; $P = 0.00222$). From June 20 to 26, a sharp decline in the occurrence of aphids was observed in all treatments except T100. Here, the occurrence of pea aphids was significantly higher than in mixtures

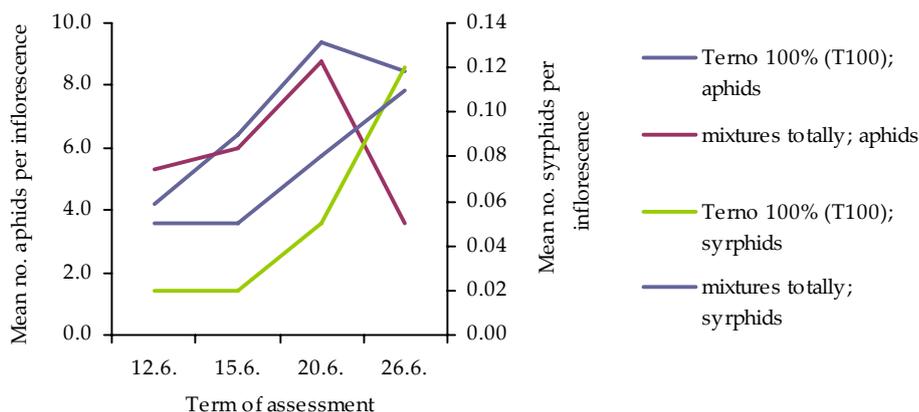


Figure 3. Development of the pea aphid (*A. pisum*) numbers and syrphid (*Syrphidae*) occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals (Pribina barley cultivar, Sirael wheat cultivar) in 2009

at the end of counting on June 26 ($F_{4, 295} = 7.7954$; $P = 0.00001$). This pattern of a more rapid decline in aphid populations in mixtures is the same as that in 2008 (Figure 3).

In 2009, no significant differences among treatments were found in the occurrence of syrphids (eggs + larvae + pupae). For the dates of counting, the probability and F values were as follows: June 12 $F_{4, 295} = 0.72660$, $P = 0.51236$; June 20 $F_{4, 295} = 2.1900$, $P = 0.11268$; June 26 $F_{4, 295} = 0.33371$, $P = 0.6915$. However, the development of occurrence varied among treatments. In the mixtures with the lowest share of peas (T40S60, T40P60), syrphids already occurred on June 12 and T40P60 showed relatively high levels of syrphids during the whole period of assessment. An increase in syrphid occurrences in T60S40 and T60P40 occurred later, but the peaks were reached earlier there (15.6.). The slowest increase in syrphid occurrences was found out in pea monoculture. Development of the pea aphid numbers and syrphid occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals is shown in Figure 3.

The results of comparison of syrphid egg numbers in aphid colonies of 10–20 individuals in size are shown in Table 2. The development of syrphid egg numbers laid by females in the aphid colonies of the size in question was very similar to the development recorded in 2008. During the time of assessment (from 12.6. to 20.6.) the aphid colonies in T100 were less attractive to egg-laying syrphid females than the same colonies in the other treatments. However, no statistical differences

among treatments were proved on any of the three dates (June 12: $F_{4, 295} = 1.4807$; $P = 0.20799$; June 20: $F_{4, 295} = 1.6690$; $P = 0.15714$; June 26: $F_{4, 295} = 0.22442$; $P = 0.92466$).

A comparison of the percentages of aphid colonies of 10–20 individuals in size with one or more syrphid larvae present is shown in Table 3. The trend obvious from the 2008 results is also documented by the results recorded in 2009. However, the differences among the compared treatments in the percentages of aphid colonies with one or more syrphid larvae were not significant on any of the three dates of assessment.

Pea aphids and syrphids 2010 (PO)

A continual growth of aphid numbers on inflorescences in T100 from June 16 to June 29 was characteristic of the development of pea aphid occurrences in PO. On the contrary, in the treatments T40P60, T60P40 and T40S60 the aphid densities gradually decreased already since June 16. In T60S40 the decrease began one week later (23.6.). On the first date of assessment the aphid density in T40S60 was significantly higher than in T40P60 ($F_{4, 295} = 3.1053$; $P = 0.01587$). On the second date of assessment the mean aphid number in T60P40 was significantly lower in comparison with T100 and T60S40 ($F_{4, 295} = 3.5184$; $P = 0.00798$). On the last two dates of assessment the occurrences of pea aphids on inflorescences in mixtures (T60S40, T40S60, T60P40, T40P60) were significantly lower than in monoculture T100

Table 3. Mean percentages (%) of aphid colonies (of 10–20 individuals in size) with one or more syrphid larvae (2008, 2009, 2010 PO, 2010 RA)

Treat- ment	2008				2009				2010 PO				2010 RA			
	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)	1. term (SD)	2. term (SD)	3. term (SD)	4. term (SD)
T100	0.00 (0.00)	0.00 (0.00)	2.00a (5.61)	6.67 (9.76)	0.00 (0.00)	3.33 (6.17)	7.33 (9.61)	7.33 (9.61)	2.00 (4.14)	9.33 ^a (9.61)	14.67 ^a (10.60)	26.00 (16.39)	5.33 (9.16)	6.67 (8.99)	14.00 ^a (12.98)	19.33 (13.35)
T60S40	0.67 (2.58)	6.00 (10.56)	13.33ab (11.75)	8.67 (10.60)	1.33 (3.52)	8.67 (11.26)	9.33 (8.84)	9.33 (8.84)	5.33 (7.43)	18.00 ^{ab} (12.65)	30.67 ^b (17.10)	35.33 (18.07)	10.00 (10.00)	16.00 (12.98)	25.33 ^{ab} (18.07)	20.67 (20.17)
T40S60	1.33 (5.16)	4.67 (9.16)	14.67b (14.08)	8.00 (13.73)	2.67 (5.94)	6.67 (9.76)	10.67 (13.35)	10.67 (13.35)	7.33 (7.99)	22.00 ^{ab} (13.73)	36.67 ^b (15.89)	33.33 (17.18)	13.33 (10.47)	18.00 (15.21)	29.33 ^{ab} (17.10)	28.00 (14.24)
T60P40	0.67 (2.58)	5.33 (11.26)	11.33ab (13.02)	6.67 (8.99)	0.67 (2.58)	8.00 (12.65)	8.67 (10.60)	8.67 (10.60)	3.33 (4.88)	21.33 ^{ab} (15.06)	36.00 ^b (15.02)	36.00 (22.30)	14.00 (12.42)	16.00 (12.42)	26.67 ^{ab} (19.52)	24.00 (16.82)
T40P60	2.00 (5.61)	4.67 (9.16)	12.00ab (12.07)	6.67 (11.13)	2.67 (7.04)	7.33 (10.33)	10.67 (12.23)	10.67 (12.23)	8.00 (11.46)	31.33 ^b (16.42)	38.67 ^b (14.57)	31.33 (18.85)	12.00 (12.07)	19.33 (13.35)	32.00 ^b (14.74)	28.67 (19.59)

The mean values in columns are not significantly different (Tukey's test; $P < 0.05$); $N = 15$ percentage values per treatment (5 per replication); SD = standard deviation

(June 29: $F_{4, 295} = 9.2913$; $P = 0.000$; July 14: $F_{4, 295} = 15.330$; $P = 0.000$) (Figure 4).

On the first date the lowest density of syrphids on inflorescences was recorded in T100 (0.32 syrphids per infl.). However, a significantly higher number of syrphids (0.74 syrphids per infl.) was observed only in the T40S60 treatment ($F_{4, 295} = 3.1043$; $P = 0.01678$). On the second date the differences among treatments appeared to be statistically insignificant ($F_{4, 295} = 3.087$; $P = 0.01636$), even if the numbers of syrphids in T60S40, T40S60 and T60P40 were more than two-fold higher (0.50; 0.55 and 0.57 syrphids per infl.) in comparison with T100 and T40P60 (0.23 syrphids per infl.). On the third date the situation was similar but the syrphid occurrences were markedly higher in general ($F_{4, 295} = 2.0900$; $P = 0.08212$). On the fourth date, the occurrence of syrphids was already very low throughout the trial and the differences among treatments were negligible ($F_{4, 295} = 0.75159$; $P = 0.55761$). Development of the pea aphid numbers and syrphid occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals is shown in Figure 4.

In comparison with the density development in 2008, 2009, and partly in RA trial in 2010 the occurrences of syrphid eggs in the selected colonies in PO trial were on markedly higher levels in the period from June 16 to June 29. On the first three dates of assessment the numbers of syrphid eggs were markedly higher in mixtures in comparison with T100. On the first date the syrphid egg densities in T60S40, T40S60 and T40P60 were proved as significantly higher if compared with T100 ($F_{4, 295} = 4.3529$; $P = 0.00196$). On the second date the syrphid egg densities in all mixture treatments were significantly higher than in monoculture (T100), ($F_{4, 295} = 5.3780$; $P = 0.00034$). On the third date the differences between T100 and the other treatments were still well pronounced but the statistical significance was not proved ($F_{4, 295} = 2.1534$; $P = 0.07432$). On the last date the differences among treatments were negligible ($F_{4, 295} = 0.81131$; $P = 0.51875$) (Table 2).

The differences among the compared treatments in the percentages of aphid colonies (of 10–20 individuals in size) with one or more syrphid larvae were significant on two dates of assessment (Table 3). On June 23 a significantly higher percentage of colonies with one or more syrphid larvae was recorded in T40P60 in comparison with T100 ($F_{4, 70} = 5.0259$; $P = 0.00128$) and in June 29 the

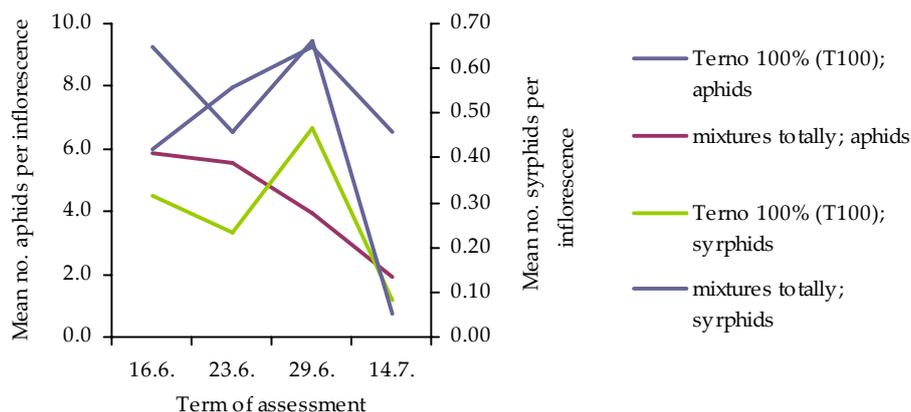


Figure 4. Development of the pea aphid (*A. pisum*) numbers and syrphid (Syrphidae) occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals (Pribina barley cultivar, Sirael wheat cultivar) in PO in 2010

percentages were significantly higher in all mixtures compared to T100 ($F_{4,70} = 6.5435$; $P = 0.00016$). In contrast to the data acquired in previous years the percentages of aphid colonies with syrphid larvae were markedly higher in PO trial.

Pea aphids and syrphids 2010 (RA)

With the exception of T40S60 treatment the numbers of aphids rose in RA trial from June 16 to June 23. Then the growth of aphid densities stopped, followed by the population decrease throughout the trial. The decline of aphid densities between June 23 and July 14 was markedly sharper

in mixtures in comparison with monoculture. At the beginning of colonisation of pea plants by aphids, i.e. on the first date of assessment, the level of infestation of peas in monoculture was significantly lower in comparison with mixtures ($F_{4,295} = 7.0962$; $P = 0.00002$). No significant differences in the aphid numbers among treatments were found out on the second date of assessment ($F_{4,295} = 1.5115$; $P = 0.19878$). However, on the third date the mean numbers of aphids in T40S60 and T40P60 were already significantly lower than in T100 ($F_{4,295} = 4.9894$; $P = 0.00066$) and on the fourth date all mixtures showed a significantly lower level of infestation compared to T100 ($F_{4,295} = 10.620$; $P = 0.000$) (Figure 5).

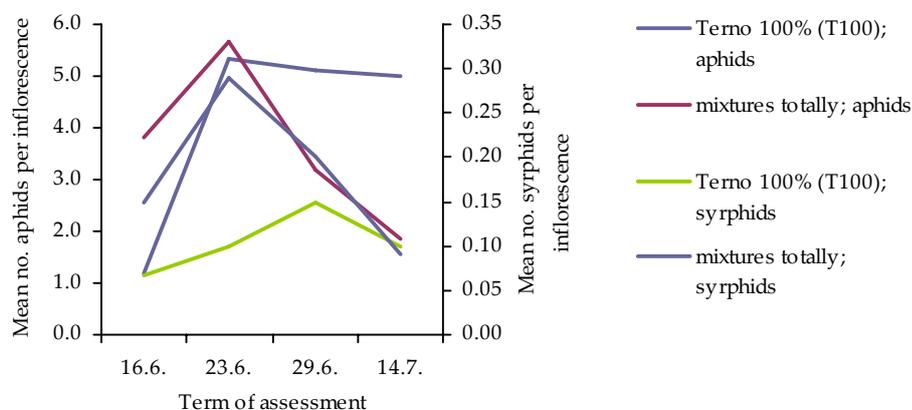


Figure 5. Development of the pea aphid (*A. pisum*) numbers and syrphid (Syrphidae) occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals (Pribina barley cultivar, Sirael wheat cultivar) in RA in 2010

The highest numbers of syrphids (especially eggs) on inflorescences occurred on the second date of assessment in most treatments (T60P40, T40P60 and T60S40) in RA trial. On the contrary, the peak in T100 was not reached until the third date of assessment. At that time the syrphid larvae were very frequent in aphid colonies throughout the trial. The recorded peak in T100 (June 29: 0.15 syrphids per infl.) was 1.33-fold lower than in T40S60 (June 16: 0.20 syrphids per infl.), 1.67-fold lower than in T60S40 (June 23: 0.25 syrphids per infl.), 2.00-fold lower than in T40P60 (June 23: 0.30 syrphids per infl.) and 3.20-fold lower than in T60P40 (June 23: 0.48 syrphids per infl.). On the first date of assessment the differences among treatments were insignificant ($F_{4, 295} = 1.6158$; $P = 0.17023$). On the second date of assessment the syrphid density in T60P40 was significantly higher than in T100 and T40S60 ($F_{4, 295} = 4.0427$; $P = 0.00331$). On the third and the fourth date of assessment the differences among treatments were insignificant again (June 29: $F_{4, 295} = 0.96694$; $P = 0.42590$; July 14: $F_{4, 295} = 0.13793$; $P = 0.96813$). Development of the pea aphid numbers and syrphid occurrences (eggs + larvae + pupae) on generative organs of pea in monocultures of field pea as compared to mixtures with spring cereals is shown in Figure 5.

Especially on the first three dates (June 16 to 29) the aphid colonies (of 10 to 20 individuals in size) located in the mixtures were clearly more attractive to egg-laying females of syrphid flies than the same colonies in pea monoculture. However, on the first date the statistical difference was proved only between T100 and T40S60 ($F_{4, 295} = 2.2443$; $P = 0.03435$). On the second date statistically higher numbers of syrphid eggs were recorded

in T60P40 and T40P60 in comparison with T100 ($F_{4, 295} = 3.0619$; $P = 0.00170$). On the third date the statistical difference was proved only between T60P40 and T100 ($F_{4, 295} = 2.6912$; $P = 0.03133$) and on the fourth date between T60S40 and T100 ($F_{4, 295} = 2.3947$; $P = 0.04961$) (Table 2).

Differences among the compared treatments in percentages of the aphid colonies with one or more syrphid larvae were significant on one date of assessment. On June 29 a significantly higher percentage of colonies with one or more syrphid larvae was recorded in T40P60 in comparison with T100 ($F_{4, 70} = 2.5787$; $P = 0.04473$). The trend obvious from the results obtained in previous years was also documented by the results recorded in RA trial in 2010 (Table 3).

Mean numbers of mummies (caused by entomopathogenic fungi) per aphid colony of specific size (2008–2010)

The majority of mummified aphids sampled for identification were infested by *Beauveria* sp. in the trials. Hence, the fungal mummies are indicated as mummies (*Beauveria* sp.) in the text. The mean numbers of mummies (*Beauveria* sp.) in aphid colonies of specific size, which were recorded in the trials assessed in 2008–2010, are listed in Table 4. Slightly higher numbers of aphid mummies in mixtures compared to monoculture were recorded in all trials. But only in PO trial (2010) were the recorded differences in the mean values significant on one date of assessment (July 14). At that time the mean number of mummies (*Beauveria* sp.) per colony was significantly higher in

Table 4. Mean numbers of mummies (*Beauveria* sp.) per aphid colony of more than 100 living aphids in 2008 and 2009 and/or 30 living aphids in 2010 PO and 2010 RA

Treat- ment	2008		2009		2010 PO		2010 RA	
	20.6. (SD)	27.6. (SD)	20.6. (SD)	26.6. (SD)	29.6. (SD)	14.7. (SD)	29.6. (SD)	14.7. (SD)
T100	3.09 (3.06)	4.76 (4.02)	4.89 (4.21)	6.93 (5.19)	1.20 (1.16)	2.22 ^a (1.89)	0.71 (1.08)	1.73 (1.89)
T60S40	3.42 (2.71)	4.98 (2.71)	4.62 (4.02)	6.87 (5.47)	1.11 (1.11)	2.91 ^{ab} (2.04)	0.98 (1.39)	1.64 (1.82)
T40S60	3.18 (1.90)	5.53 (3.24)	5.82 (3.03)	7.71 (4.74)	1.22 (1.62)	2.96 ^{ab} (2.14)	0.96 (0.95)	1.69 (1.49)
T60P40	3.13 (2.74)	4.93 (3.14)	5.76 (2.63)	7.24 (4.56)	1.47 (1.38)	3.22 ^{ab} (1.62)	1.07 (1.42)	1.87 (1.96)
T40P60	2.78 (2.34)	5.02 (3.23)	5.27 (3.32)	7.02 (5.04)	1.33 (1.11)	3.71 ^b (2.47)	1.11 (1.15)	2.22 (2.01)

The mean values in columns are not significantly different (Tukey's test; $P < 0.05$); $N = 45$ counts per treatment (15 per replication); SD = standard deviation

Table 5. Mean percentages of aphid colonies of more than 50 and/or 30 individuals (nymphs + females) with two or more insect mummies (*A. ervi*) at the end of flowering stage in 2008 and 2009 and/or in 2010 PO and 2010 RA

Treatment	27.6.2008 (SD)	26.6.2009 (SD)	29.6.2010 PO (SD)	29.6.2010 RA (SD)
T100	3.33 (8.17)	2.67 (5.94)	3.33 (4.88)	4.00 (7.37)
T60S40	7.33 (12.80)	5.33 (9.90)	3.33 (7.24)	4.00 (6.33)
T40S60	7.33 (11.63)	6.67 (11.75)	3.33 (6.17)	3.33 (6.17)
T60P40	8.00 (12.65)	7.33 (12.23)	4.00 (5.07)	3.33 (6.17)
T40P60	8.67 (13.02)	8.67 (13.56)	4.67 (6.40)	4.67 (9.15)

The mean values in columns are not significantly different (Tukey's test; $P < 0.05$); $N = 15$ percentage values per treatment (5 per replication); SD = standard deviation

T40P60 compared to T100 ($F_{4, 220} = 3.1254$; $P = 0.01583$).

Mean percentages of aphid colonies of specific size with insect mummies (*A. ervi*) (2008–2010)

The mean percentages of aphid colonies of specific size (50 and/or 30 individuals) with two or more insect mummies (*A. ervi*) recorded in the trials assessed in 2008 – 2010 are listed in Table 5. A slight trend of higher percentages of colonies with *A. ervi* mummies in the mixture treatments was found out in 2008 and 2009. It concerns especially both combinations of pea with spring barley (T60P40 and T40P60). However, the differences in the mean values among treatments were not significant (2008: $F_{4, 70} = 0.46986$; $P = 0.75765$; 2009: $F_{4, 70} = 0.64488$; $P = 0.63233$). In addition, this trend was not proved in trials founded in 2010.

DISCUSSION

Our results show that winged females of pea aphids searching for their host plants do not prefer peas in pure stands to peas grown in mixture with cereals. They were able to found colonies on pea plants in pure stands and in mixtures with cereals practically at the same time or any earlier. The occurrences of pea aphids in monoculture compared to mixtures were similar or not very different shortly after the appearance of the first aphid colonies on plants and also one (2009, 2010 RA) or two (2008) weeks later. Unfortunately, there are not any similar studies dealing with the same crops and pest among

the recent sources of available literature. HELENIUS (1991) and EBWONGU *et al.* (2001) recorded similar development of aphid occurrences during the first phase of plant infestation in monocultures compared to mixtures. However, they worked with different plants and aphid species.

Peak aphid densities were higher in monoculture than in mixtures only in two trials (2008 and 2010 PO). In other two trials the peaks were recorded in T60P40 and T60S40 and/or in T60P40 (2009 and/or 2010 RA). These results are contrary to BEDOUSSAC *et al.* (2010), who assessed the effects of intercropping winter pea with durum wheat on pea aphid occurrences. They reported that peak aphid densities were always significantly higher in pea monoculture than in mixtures.

In this study, the colony decline started either markedly earlier (2008, 2010 PO, 2010 RA) or was clearly sharper (2009, 2010 RA) in mixtures compared to monoculture. Hence, differences in the pea aphid occurrences between monoculture and mixtures became significant two or three weeks after recording the first living aphids on pea inflorescences. Unfortunately, there is not any similar study among the recent sources of available literature which could be used for comparison with the obtained results.

If syrphid larvae occur on pea plants shortly after their colonization by pea aphids, they can act as an effective tool to control the aphid population (HÝBL & SEIDENGLANZ 2009). Our results indicate that syrphid fly females are able to localize the pea aphid colonies in mixtures earlier than in monocultures. This fact was confirmed by higher numbers of syrphid eggs on pea inflorescences and especially by higher numbers of syrphid eggs laid in (or close to) young aphid colonies (colonies of

10–20 individuals in size) in mixtures. In addition, the specified aphid colonies in mixtures remained more attractive to egg-laying syrphid females during the first two weeks of colonization at least (Table 2). Consequently, very rapacious syrphid larvae appeared earlier in aphid colonies in mixtures compared to monoculture and the percentages of aphid colonies infested by syrphid larvae were also higher in mixtures (Table 3). This could be the reason for an earlier decline of pea aphid colonies in mixtures than in monocultures. These results are contrary to NAMPALA *et al.* (2008), who compared the occurrence of several natural enemies of cowpea pests in cowpea monoculture and its mixtures with sorghum and greengram. They stated that the abundance of syrphid larvae was not influenced by the fact if the cowpea was grown in mixture or in monoculture. The influence of the final composition (plant species, their portions) of a crop mixture on the effectiveness of syrphids as control agents was discussed in several studies (POLLARD 1971; KLOEN & ALTIERI 1990; SMITH & CHANEY 2007; DAANE *et al.* 2008). POLLARD (1971) stated that standing cereals provide shelter to adjacent plants, and thereby enhance the oviposition of syrphids. Suitable plant composition in a mixture and well-considered time (later or earlier planting of some of the components) organization of intercropping can markedly increase the effect of syrphids on aphids in such mixtures (SMITH & CHANEY 2007; DAANE *et al.* 2008). A very slight tendency of mixtures compared to monoculture to higher numbers of fungal mummies in aphid colonies was found out in our trials in 2008–2010 (Table 4). Entomologists tend to consider entomopathogenic fungi as agents of limited value in the control of aphids. The reasons for this presumed general ineffectiveness are as follows: inadequate inoculum levels, infection being too dependent upon specific environmental conditions, and dissemination being too dependent upon the presence of uniformly distributed and abundant hosts (RADCLIFFE & RAGSDALE 2007). On the basis of our results it is possible to conclude that the levels of *Beauveria* sp. infections of pea aphids in our trials (2008–2010) could hasten the start of colony decline but they did not influence the differences in the aphid occurrences between monoculture and mixtures.

We also found out a slight tendency of mixtures to higher percentages of infested aphid colonies by the parasitoid (*A. ervi*), especially in 2008 and 2009 (Table 5). In 2010 (PO, RA) the differences

were negligible. It is possible to conclude that the levels of pea aphid parasitisation by *A. ervi* in our trials (2008–2010) could hasten the start of colony decline but they did not probably influence the differences in the aphid occurrences between monoculture and mixtures.

Several conclusions arise from the results of the present study:

- (1) Winged females of pea aphids searching for their host plants did not prefer peas in monocultures to peas grown in mixture with cereals.
- (2) The decline of pea aphid colonies started either markedly earlier or tended to be clearly sharper in mixtures of peas with spring cereals compared to pea monoculture.
- (3) Syrphid fly females were able to localise the young pea aphid colonies in mixtures of pea with spring cereals earlier than in pea monoculture.
- (4) Syrphid fly females tended to lay more eggs in (or close to) pea aphid colonies of definite size in mixtures of pea with spring cereals compared to pea monoculture.
- (5) Earlier decline of pea aphid colonies in mixtures of pea with spring cereals compared to pea monoculture could be a result of earlier occurrence of higher numbers of syrphid eggs and consequently larvae in young aphid colonies in mixtures.

References

- BAVERSTOCK J., ALDERSON P.G., PELL J.K. (2005): Influence of the aphid pathogen *Pandora neoaphidis* on the foraging behaviour of the aphid parasitoid *Aphidius ervi*. *Ecological Entomology*, **30**: 665–672.
- BEDOUSSAC L., HEMPTINNE J.L., JUSTES E. (2010): Winter pea – durum wheat intercrops: a solution to reduce pesticide use by decreasing grain legume pests and diseases. In: Proceedings 5th International Food Legume Research Conference (IFLRC) and 7th European Conference on Grain Legumes (AEP VII), 26 – 30 April 2010, Antalya, Turkey: 97.
- BUDENBERG W.J., POWELL W. (1992): The role of honeydew as an ovipositional stimulant for two species of syrphids. *Entomologia Experimentalis et Applicata*, **64**: 57–61.
- DAANE K.M., MILLS N.J., NELSON E.H. (2008): Supporting aphid predators through intercrops with alternative prey. Project summary. California Lettuce Research Board, April 1, 2007–March 31, 2008.

- DU Y., POPPY G.M., POWELL W. (1996): Relative importance of semiochemicals from first and second trophic levels in host foraging behaviour of *Aphidius ervi*. *Journal of Chemical Ecology*, **22**: 1591–1605.
- DU Y., GUY M., POPPY G.M., POWELL W., PICKETT J.A., WADHAMS L.J., WOODCOCK C.M. (1998): Identification of semiochemicals released during aphid feeding that attract parasitoid *Aphidius ervi*. *Journal of Chemical Ecology*, **24**: 1355–1368.
- EBWONGU M., ADIPALA E., KYAMANYWA S., SSEKABEMBE C.K., BHAGSARI A.S. (2001): Influence of spatial arrangements in mize/solanum potato intercrops on incidence of potato aphids and leaf hoppers in Uganda. *African Crop Science Journal*, **9**: 175–184.
- EIGENBRODE S.D., WHITE C., ROHDE M., SIMON C.J. (1998): Behaviour and effectiveness of adult *Hippodamia convergens* (Coleoptera: Coccinellidae) as a predator of *Acyrtosiphon pisum* (Homoptera: Aphididae) on a wax mutant of *Pisum sativum*. *Environmental Entomology*, **27**: 902–909.
- EKBOM B. (2009): Arthropod predators of the pea aphid, *Acyrtosiphon pisum* Harr. (Hom., Aphididae) in peas (*Pisum sativum* L.), clover (*Trifolium pratense* L.) and alfalfa (*Medicago sativa* L.). *Journal of Applied Entomology*, **117**: 469–476.
- FRANCIS F., MARTIN T., LOGNAY G., HAUBRUGE E. (2004): Role of (E)-beta-farnesene in systematic aphid prey location by *Episyrphus balteatus* larvae (Diptera: Syrphidae). *European Journal of Entomology*, **102**: 431–436.
- GILBERT F. (2005): Syrphid aphidophagous predators in a food-web context. *European Journal of Entomology*, **102**: 325–333.
- GILES K.L., OBRYCKI J.J., DEGOOYER T. (1994): Prevalence of predators associated with *Acyrtosiphon pisum* (Homoptera: Aphididae) and *Hypera postica* Gyllenhal (Coleoptera: Curculionidae) during growth of the first crop of alfalfa. *Biological Control*, **4**: 170–177.
- GUERRIERI E., PENNACCHIO F., TREMBLEY E. (1993): Flight behaviour of the aphid parasitoid *Aphidius ervi* (Hymenoptera: Braconidae) in response to plant and host volatiles. *European Journal of Entomology*, **90**: 415–421.
- GUERRIERI E., POPPY G.M., POWELL W., TREMBLEY E., PENNACCHIO F. (1999): Induction and systemic release of herbivore-induced plant volatiles mediating in-flight orientation of *Aphidius ervi*. *Journal of Chemical Ecology*, **25**: 1247–1261.
- GUERRIERI E., POPPY G.M., POWELL W., RAO R., PENNACCHIO F. (2002): Plant-to-plant communication mediating in-flight orientation of *Aphidius ervi*. *Journal of Chemical Ecology*, **28**: 1703–1715.
- HELENIUS J. (1991): Insect numbers and pest damage in Intercrops vs. Monocrops. *Journal of Sustainable Agriculture*, **1**: 57–80.
- HOUBA M., HOCHMAN M., HOSNEDL V. (2009): Luskoviny pěstování a užití. 1st Ed. Kurent, České Budějovice: 134.2
- HÝBL M., SEIDENGLANZ M. (2009): Pěstování hrachu a pelušky v EZ. *Úroda*, **LVII** (12): 34–36.
- KINANE J., LYNKJÆR M.F. (2002) Effect of barley-legume intercrop on disease frequency in an organic farming system. *Plant Protection Science*, **38**: 227–231.
- KLOEN H., ALTIERI M.A. (1990): Effect of mustard (*Brassica hirta*) as a non-crop plant on competition and insect pests in broccoli (*Brassica oleraceae*). *Crop Protection*, **9**: 90–96.
- NAMPALA P., ADIPALA E., OGENGA-LATIGO M.W., KYAMANYWA S., OBUO J. E. (2008): Effect of cowpea monocultures and polycultures with sorghum and greengram on predatory arthropods. *Annals of Applied Biology*, **135**: 457–461.
- POLLARD E. (1971): Hedges. VI. Habitat diversity and crop pests: A study of *Brevicoryne brassicae* and its syrphid predators. *Journal of Applied Ecology*, **8**: 751–780.
- RADCLIFFE T., RAGSDALE D. (2007): Fungicides impact aphid control. In: Radcliffe's IPM World Textbook, CFANS, University of Minnesota. Red River Valley Potato Growers Association, Washington.
- SMITH H.A., CHANEY W.A. (2007): A survey of syrphid predators of *Nasonovia ribisnigri* in organic lettuce on the Central coast of California. *Journal of Economic Entomology*, **100**: 39–48.
- VANDERMER J.H. (1989). *The Ecology of Intercropping*. Cambridge University Press, Cambridge.

Received for publication August 9, 2010
Accepted after corrections January 11, 2011

Corresponding author:

Ing. MAREK SEIDENGLANZ, AGRITEC, výzkum, šlechtění a služby s.r.o., oddělení ochrany rostlin,
Zemědělská 16, 787 01 Šumperk, Česká republika
tel.: + 420 583 382 203, e-mail: seidenglanz@agritec.cz
