Effect of intercropping winter peas of differing leaf type and time of flowering on annual weed infestation in deep and shallow ploughed soils and on pea pests

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Abstract

The performance of organic pea production largely depends on preventive and cultural control strategies for weeds and pests. Field experiments were carried out to study the effect of intercropping a normal-leafed (cv. E.F.B. 33) or a semi-leafless, early-flowering winter pea (cv. James) and triticale on the infestation with annual weeds, pea aphids and moths in comparison to the respective sole crops. Also, shallow ploughing (10 to 12 cm) vs. deep ploughing (25 to 27 cm) was investigated with regard to an infestation with annual weeds. The higher weed suppressive ability of normal-leafed winter pea cv. E.F.B. 33 compared with semi-leafless cv. James was due to a lower light transmission to the weed canopy level. In contrast to E.F.B. 33, intercropping James significantly reduced the weed infestation compared to the respective sole crop. The ploughing system had no significant effect on the weed infestation in crops differing in their ability to suppress annual weeds. Sole crops were found to have higher pea aphid density, incidence and cumulative aphid-days than the corresponding intercrops. Intercropping winter peas and triticale, however, was not beneficial in reducing an infestation with pea moths.

Keywords: *organic farming, ploughing system, weed suppression, Acyrthosiphon pisum Harris, cumulative aphid-days, Cydia nigricana Fabricius*

Zusammenfassung

Einfluss des Mischfruchtanbaus von Wintererbsen mit unterschiedlichen Blatttypen und Blütezeitpunkten auf das annuelle Unkrautaufkommen in tief- und flachwendend bearbeiteten Böden und auf Erbsen-Schädlinge

Die Leistungsfähigkeit des ökologischen Erbsenanbaus hängt in hohem Maße von vorbeugenden Kontrollstrategien für Unkräuter und Schädlinge ab. Untersucht wurde der Einfluss des Reinsaat- und des Mischfruchtanbaus einer normalblättrigen (E.F.B. 33) und einer halbblattlosen, frühblühenden Wintererbsen-Sorte (James) mit Triticale auf das annuelle Unkrautaufkommen sowie den Befall mit Erbsenblattlaus und -wickler. Zudem wurde eine flach- (10 bis 12 cm) mit einer tiefwendenden (25 bis 27 cm) Bodenbearbeitung hinsichtlich des Unkrautaufkommens verglichen. Die normalblättrige Sorte E.F.B. 33 wies aufgrund einer geringeren Lichttransmission zum Unkrautbestand eine bessere Unkrautunterdrückung als die halbblattlose Sorte auf. Der Mischfruchtanbau von James führte im Gegensatz zur Sorte E.F.B. 33 zu einer signifikanten Reduzierung des Unkrautaufkommens. Die Bodenbearbeitung hat das Unkrautaufkommen in Kulturen mit unterschiedlichem Unkrautunterdrückungsvermögen nicht signifikant beeinflusst. Die Blattlausdichte, der Anteil befallener Pflanzen und die kumulierten Blattlaustage lagen in den Reinsaaten über den Werten der Mischsaaten. Der Befall mit dem Erbsenwickler konnte durch den Mischfruchtanbau mit Triticale jedoch nicht wirksam reduziert werden.

Schlüsselwörter: *Ökologischer Landbau, Pflugsystem, Unkrautunterdrückung, Acyrthosiphon pisum Harris, kumulierte Blattlaustage, Cydia nigricana Fabricius*

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1 Introduction

Weed and pest management largely influences crop performance and organic farmers rely first of all on cultural and other preventive management strategies. Effective weed and pest management therefore is a challenge and often a weakness in organic farming. Intensive tillage, e.g., deep mouldboard ploughing is known as an effective preventive weed management strategy in organic farming (Kouwenhoven et al., 2002). The need to reduce the environmental impact of agricultural management practices and to improve soil quality has increased the interest in a reduction of tillage intensity, e.g., shallow ploughing. Shallow ploughing was found to decrease fuel consumption and CO_2 release from the soil, and to increase soil aggregate stability and topsoil microbial activity (Børresen and Njøs, 1994; Chen and Huang, 2009; Curci et al., 1997; Kouwenhoven et al., 2002; Reicosky and Archer, 2007; Vian et al., 2009). However, the results of most studies indicate that shallow ploughing results in an increase in annual, and in particular perennial, weed infestation in organic and conventional farming (Børresen and Njøs, 1994; Brandsæter et al., 2011; Håkansson et al., 1998). Pranaitis and Marcinkonis (2005) reported that the grain yield of semi-leafless peas (*Pisum sativum* L.) decreased with decreasing ploughing depth which was attributable to an increase in weed infestation.

Normal-leafed peas have a better weed suppressive ability than semi-leafless pea cultivars and their yield performance is therefore less affected by weed competition (Spies et al., 2011). Owing to the low lodging resistance, aeration and harvest of normal-leafed pea crop stands is often problematic. An intercropping with cereals improves the lodging resistance of normal-leafed winter peas (Urbatzka et al., 2011) and the weed suppressive ability of semi-leafless peas (Begna et al., 2011; Corre-Hellou et al., 2011; Poggio, 2005), which deserves special attention in reduced tillage systems under organic management.

Pea aphids (*Acyrthosiphon pisum* Harris) cause direct damage to pea plants by sucking plant sap. Honeydew excretion by pea aphids facilitates colonisation of saprophytic moulds on the plant surface (Biddle, 1985). Much more critical, however, is their ability to vector plant viruses (Brisson and Stern, 2006; Seidenglanz et al., 2011). Aphid feeding on peas causes a decrease in yield performance and nitrogen-fixing activity (Hinz, 1991; Maiteki and Lamb, 1985; Sirur and Barlow, 1984). The pea moth (*Cydia nigricana* Fabricius) larva feeds on the developing pea seeds in the pod and a high infestation reduces grain yield and quality (Huusela-Veistola and Jauhiainen, 2006). Although pea moth related damages are more relevant in green pea and pea seed production than in grain pea production for feeding purposes, a reduction of a moth infestation in grain peas is important to reduce the risk for neighbouring pea fields (Huusela-Veistola and Jauhiainen, 2006). The severity of pea aphid and moth infestations and thereby related damages are dependent on environmental and weather conditions as well as on the coincidence of pest occurrence and sensitive pea growth stages (Huusela-Veistola and Jauhiainen, 2006; McVean et al.,

1999; Schultz and Saucke, 2005). McVean et al. (1999) and Thöming et al. (2011) suggested that peas should be sown early and only early-maturing cultivars should be used for pea production as one preventive management strategy to avoid coincidence and therefore high pea aphid and moth infestation levels. Owing to the fact that time of flowering and maturity is earlier than in spring peas, cultivation of winter peas could be advantageous to minimize pea aphid and moth damages in grain pea production. Moreover, the data that do exist indicate that intercropping peas and cereals can be effective in reducing an infestation with some pea pests, e.g., pea aphids (Bedoussac et al., 2008; Bedoussac, 2009; Seidenglanz et al., 2011).

The aim of this study was to: (1) evaluate the effects of ploughing system and intercropping on the annual weed infestation in semi-leafless and normal-leafed winter peas and their underlying causes, (2) determine whether winter pea cultivars differing in leaf type, as well as in time of flowering and maturity, vary in their susceptibility to pea aphid and moth attacks and (3) examine the impact of pea sole and pea-triticale intercropping on an infestation with pea aphids and moths.

2 Material and methods

2.1 Site characteristics, experimental design and crop management

The field experiments were conducted at the experimental station of the Thünen Institute of Organic Farming at Trenthorst, Northern Germany (53°46'N, 10°30'E, 43 m a.s.l.) in the seasons 2009/10 and 2010/11. According to the World Reference Base for Soil Resources, the soil type at the experimental site was classified as a Stagnic Luvisol and the soil texture as a loam. Post-sowing soil characteristics are presented in Table 1. The 30-year mean annual precipitation at the nearest National Meteorological Service weather station in Lübeck-Blankensee (53°52'N, 10°42'E) is 706 mm with a mean temperature of 8.8 °C. The weather conditions during the experimental years were recorded at the experimental site and are given in Table 2. Triticale (2009/10, *Triticosecale* Wittmack) and oilseed rape (2010/11, *Brassica napus* L.) were the previous crops at the experimental site.

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Table 1

Characteristics of the topsoil (0 to 20 cm) at the experimental site in 2009/10 and 2010/11

	2009/10	2010/11
pH ($CaCl_2$)	7.0	6.5
P (CAL, mg kg^{-1})	92	96
K (CAL, mg kg^{-1})	133	147
Mg ($CaCl_2$, mg kg^{-1})	169	121
N_t (%)	0.12	0.14
C_t (%)	1.10	1.38

Table 2

Air temperature and precipitation during the 2009/10 and 2010/11 experimental year and departure from 30-year average

	2009/10				2010/11			
	Air temperature (°C)		Precipitation (mm)		Air temperature (°C)		Precipitation (mm)	
Month	Average	Departure[1]	Total	Departure[1]	Average	Departure[1]	Total	Departure[1]
August	18.9	+2.0	19	-58	17.1	+0.2	189	+112
September	15.0	+2.0	27	-45	13.2	+0.2	94	+23
October	8.1	-0.8	57	+12	9.2	+0.3	41	-5
November	8.0	+3.8	78	+19	4.2	0	98	+39
December	0.5	-1.6	56	-16	-7.0	-6.1	24	-48
January	-4.1	-5.4	8	-53	1.8	+0.5	21	-41
February	-0.8	-2.4	14	-33	0.9	+0.7	51	+5
March	4.0	+0.1	11	-50	4.3	+0.4	10	-51
April	8.4	+0.7	19	-25	11.7	+4.0	10	-34
May	9.9	-2.5	97	+56	13.4	+1.0	24	-17
June	15.5	+0.5	73	0	16.4	+1.4	77	+5
July	20.8	+3.5	11	-74	16.8	-0.5	50	-35

[1] Departure from 30-year average (1978 to 2007)

Table 3

Proportion of annual weed species in total weed ground coverage and weed species order of dominance averaged over all crop stands and ploughing systems at the experimental field in 2009/10 and 2010/11

	2009/10		2010/11	
Scientific name	% of total weed coverage	Order of dominance	% of total weed coverage	Order of dominance
Capsella bursa-pastoris (L.) Medic.	8.5	4	6.4	7
Chenopodium album L.	0	-	0.3	11
Galeopsis tetrahit L.	0	-	0.3	11
Galium aparine L.	0.2	9	24.6	1
Geranium dissectum L.	0	-	0.9	9
Geranium rotundifolium L.	0.8	7	0	-
Lamium purpureum L.	37.6	1	13.4	4
Myosotis arvensis (L.) Hill.	3.1	6	8.3	6
Matricaria chamomilla L.	5.0	5	11.4	5
Poa annua L.	0.3	8	1.6	8
Polygonum persicaria L.	0	-	0.1	-
Stellaria media (L.) Vill./Cyr.	35.8	2	17.5	2
Veronica hederifolia L.	0	-	14.4	3
Vicia hirsuta (L.) Gray	0.1	10	0	-
Viola arvensis Murr.	8.6	3	0.8	10

The experimental factor ploughing system consisted of deep (DP, stubble tillage: precision cultivator, soil depth 8 to 10 cm; primary tillage: mouldboard plough to a soil depth of 25 to 27 cm) and of shallow ploughing (SP). Stubble and primary tillage in the shallow ploughing system were performed with a skim plough (Stoppelhobel, Zobel-Stahlbau, Germany) to a soil depth of 4 to 6 cm and 10 to 12 cm, respectively. Long-term mouldboard ploughing to a soil depth of 25 to 30 cm was performed at the experimental site before the start of the experiment.

The factor crop stand included five treatments: the semi-leafless, white-flowered winter pea cultivar James and the normal-leafed, colored-flowered cultivar E.F.B. 33 (shortened EFB) were grown as sole crops (SC, James SC, EFB SC, 80 germinable kernels m^{-2}) and in intercrops (IC) with triticale (cv. Grenado, James-TR IC, EFB-TR IC). The intercrop consisted of 40 germinable kernels winter pea and 150 germinable kernels triticale m^{-2}. Component crops were arranged in alternate rows with a 12.5-cm row

distance. A triticale sole crop (Triticale SC, 300 germinable kernels m^{-2}) was grown for weed infestation comparison purposes.

The experimental layout was a split-plot design with four replicates. Ploughing systems were arranged as main plots and crop stands as subplots. The plot size was 2.75 × 15 m. Sowing was performed on September 10, 2009 and October 11, 2010. As a result of the high precipitation in late summer and autumn 2010 (Table 2), sowing was delayed by one month in the second experimental year.

Crop management occurred in accordance with European organic farming standards (Commission Regulation (EC) No. 889/2008). No mechanical weed control was performed in the experiments. The most prevalent annual weed species in 2009/10 were *Lamium purpureum* L. and *Stellaria media* (L.) Vill., whereas *Galium aparine* L. dominated the weed community in the second experimental year. The weed species composition at the experimental fields and their order of dominance are listed in Table 3.

2.2 Sampling procedures, measurements, counts and calculations

Ground coverage of weeds was estimated five times per plot using rectangular frames with an area of 0.5 m^2 at the end of stem elongation in EFB corresponding to the inflorescence emergence in James (Table 4). Annual weed biomass samplings were performed in June (pea flowering/beginning of pod development) and July (pea ripening/maturity) from an area of 0.5 m^2 and 1 m^2 per plot, respectively. The sampling dates and the corresponding crop growth stages are given in Table 4. Annual weeds were cut 1 cm above the soil surface and dried at 60 °C to constant weight. The fresh weight and the dry matter of the weed samples were measured to estimate the water content of the weed biomass. The above-ground crop biomass was as well determined at the June biomass sampling date and the proportion of weeds in total aboveground biomass was calculated. Weed and pea biomass samples were milled (0.5 mm, Foss Tecator 1093, Denmark) and analyzed to total nitrogen (N) content (CNS elemental analyzer, HEKAtech, Germany).

Simultaneous photosynthetically active radiation (PAR) measurements above the crop stand and on the weed canopy level were carried out using a SS1-SunScan Canopy Analysis System and a reference BF5 Sunshine Sensor (Delta-T Devices, UK). Five measurements per plot were taken across the rows on a weekly basis starting at the end of winter pea stem elongation. The proportion of total PAR transmitted to the weed canopy level was calculated by relating the value measured on the weed canopy level to the incident PAR above the crop stand.

The density of live pea aphids (number per shoot tip) was counted and the incidence (proportion of infested plants) was determined during the entire infestation period twice or three times a week in deep ploughed plots according to the EPPO standards (EPPO, 2005). The pea BBCH growth stages were recorded at each assessment. Cumulative aphid-days were calculated following Ruppel (1983).

Winter pea grain samples of a plot combine harvest from an area of 17.5 m^2 were used to determine the pea moth infestation level. In doing so, four times 200 grains per plot were screened for symptoms of attack.

2.3 Statistical Analysis

Owing to the differing sowing dates, the statistical analysis was conducted separately for both experimental years. Winter pea cropping system and cultivar were analyzed as combined factor crop stand, in order to allow a comparison with triticale sole crops concerning the infestation with annual weeds. ANOVA followed by Tukey's post hoc was performed by using the MIXED procedure of SAS 9.2. Weed coverage data were transformed using arcsine square root transformation, whereas data for weed biomass and weed N uptake were log transformed to achieve normality. Proc NLMIXED was used to fit nonlinear regression models. A negative binomial model was fitted to the aphid density data using Proc GLIMMIX to account for overdispersion in both experimental years (Littell et al., 2006; Liu and Cela, 2008; O'Hara and Kotze, 2010). A binomial distribution and the logit link in Proc GLIMMIX were used for the analysis of the pest incidence data (Madden et al., 2002; Piepho, 1999). Due to the fact that aphid counting and the PAR measurements were made on non-equal time intervals, unequal repeated measure analysis was performed (Littell et al., 2006).

Table 4

Dates of weed coverage estimation and biomass samplings with the corresponding crop growth stages (BBCH) in 2009/10 and 2010/11

	2009/10				2010/11			
	Date 2010	Growth stage			Date 2011	Growth stage		
		EFB	James	Triticale		EFB	James	Triticale
Ground coverage of weeds	22 April	39	55	30	4 May	39	51	31
Weed and crop biomass sampling 1	15 June	65	72	65	14 June	67	72	71
Weed biomass sampling 2	19 July	88	89	87	16 July	83	89	83

3 Results

3.1 Weeds

3.1.1 Weed ground coverage, weed biomass and weed-crop biomass relationship

The experimental factor crop stand had a significant effect on the weed ground coverage in both experimental years. The weed ground coverage was highest in James sole crops and least in triticale sole crops and did not differ significantly between EFB and James in either sole crops or in intercrops (Table 5). Intercropping winter peas and triticale tended to reduce the weed ground coverage in 2009/10 and resulted in significantly lower weed ground coverage values in 2010/11.

Also, the proportion of weeds in total aboveground biomass and the weed biomass in 2009/10 were significantly affected by the experimental factor crop stand. Additionally, the analysis of variance showed a significant sampling date × crop stand interaction for the weed biomass data in 2010/11. The proportion of weeds in the total aboveground biomass was significantly greater in James sole crops than in the other examined crop stands in both experimental years (Table 5). James-triticale intercrops exhibited significantly lower proportions of weeds in total aboveground biomass than James sole crops. There were no significant differences between EFB sole crops, triticale sole crops and winter pea-triticale intercrops in 2009/10. Unlike in 2009/10, EFB sole cropping resulted in a significantly higher proportion of weeds in total aboveground biomass compared with triticale sole cropping and intercropping in 2010/11.

The significantly highest weed biomass accumulation was determined in James sole crops in both experimental years (Table 5, Figure 1). The EFB sole and intercrops were found to have significantly lower weed biomass values than James and triticale sole as well as intercrops in 2009/10. Besides, there was no significant difference between EFB sole

and EFB-triticale intercrops concerning the weed biomass accumulation at the June as well at the July sampling date in 2009/10, whereas James-triticale intercropping resulted in a significantly lower weed biomass accumulation compared with James sole cropping at both sampling dates in the same year.

The weed infestation in 2010/11 was higher than in the previous experimental year (Table 5, Figure 1). EFB sole crops showed a significantly lower biomass accumulation than James sole crops in 2010/11 (Table 5). In contrast, no varietal difference was revealed in winter pea-triticale intercrops. Intercropping winter peas and triticale reduced the biomass accumulation at the first sampling date independent of the pea cultivar. At the second sampling date, however, a significant lower weed biomass accumulation in the intercrop than in the sole crop was solely present for cultivar James. The weed biomass accumulation in triticale sole crops was significantly lower than that in EFB sole crops at the first sampling date and comparable at the second sampling date. Moreover, no significant differences occurred between triticale sole crops and winter pea-triticale intercrops at both sampling dates in 2010/11.

Triticale was found to have a lower aboveground biomass accumulation at pea flowering in 2009/10 (Triticale SC: 335.8, EFB-TR IC: 123.5, James-TR IC: 184.4 g d.m. m^{-2}) than in 2010/11 (Triticale SC: 663.2, EFB-TR IC: 480.7, James-TR IC: 596.7 g d.m. m^{-2}). Therefore, total crop biomass accumulation of triticale sole crops and winter pea-triticale intercrops was considerably lower than that in 2010/11 (Figure 1). There was a relationship between crop and weed aboveground biomass accumulation at the June sampling date (Figure 1). Weed aboveground biomass exponentially decreased as the crop aboveground biomass increased, most notably in the second experimental year.

There was neither a significant interaction comprising the experimental factor ploughing system nor a significant

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Table 5

Effect of crop stand on the weed infestation in 2009/10 and 2010/11. Values are means ± SEM

Crop stand	Weed ground coverage (%)	Weed biomass in total aboveground biomass (%)	Weed biomass (g d.m. m^{-2})	
	April/May	June	June	July
2009/10				
EFB SC	44.0 ± 2.4 ab	1.7 ± 0.6 b	7.4 ± 2.4 d	9.1 ± 3.7 c
EFB-TR IC	33.4 ± 2.0 bc	1.0 ± 0.3 b	6.0 ± 1.7 d	6.0 ± 2.9 c
James SC	53.4 ± 4.9 a	21.0 ± 3.2 a	96.4 ± 13.6 a	76.4 ± 19.6 a
James-TR IC	43.6 ± 4.9 ab	8.4 ± 2.4 b	37.4 ± 11.8 b	32.0 ± 3.7 b
Triticale SC	26.4 ± 2.4 c	4.2 ± 1.0 b	13.2 ± 2.7 c	24.4 ± 5.3 b
2010/11				
EFB SC	16.6 ± 0.9 a	14.2 ± 2.5 b	85.9 ± 10.1 b	21.1 ± 9.6 b
EFB-TR IC	7.4 ± 0.5 b	6.1 ± 1.0 c	47.4 ± 4.3 c	25.6 ± 3.2 b
James SC	18.0 ± 1.4 a	39.2 ± 6.5 a	186.3 ± 21.2 a	202.3 ± 20.2 a
James-TR IC	6.3 ± 0.5 b	4.9 ± 0.7 c	37.1 ± 5.3 c	34.5 ± 6.6 b
Triticale SC	5.5 ± 0.3 b	6.9 ± 1.2 c	49.8 ± 10.0 c	23.8 ± 4.0 b

Means within each column and experimental year with different letters are significantly different (P < 0.05))
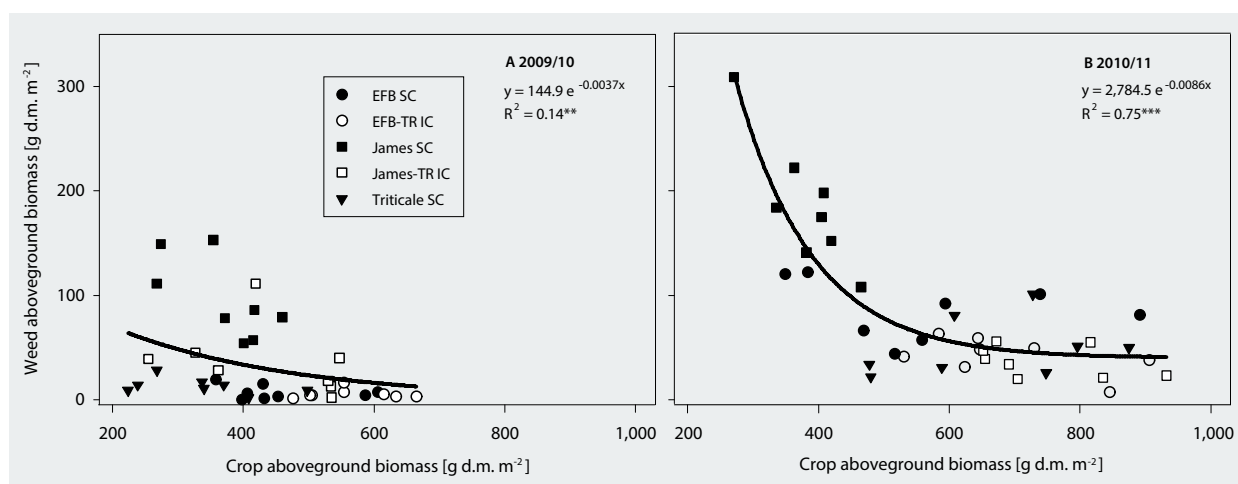
Figure 1

Relationship between weed and crop aboveground biomass at the June sampling date in 2009/10 (A) and 2010/11 (B) independent of ploughing system. ** and *** indicate that exponential regression is significant at P < 0.01 and P < 0.0001.

Table 6

Effect of ploughing system on weed parameters in 2009/10 and 2010/11. Values are means of one rating/sampling date (weed ground coverage, weed biomass in total aboveground biomass) or two sampling dates (weed biomass, N content, N uptake and dry matter content) ± SEM

	Ploughing system			
	2009/10		2010/11	
	DP	SP	DP	SP
Weed ground coverage (%)	37.4 ± 3.0 a	43.0 ± 3.0 a	10.9 ± 1.3 a	10.3 ± 1.4 a
Weed biomass in total aboveground biomass (%)	6.5 ± 2.1 a	8.0 ± 2.0 a	15.0 ± 2.9 a	13.5 ± 4.1 a
Weed biomass (g d.m. m^{-2})	26.5 ± 5.4 a	35.1 ± 6.6 a	75.3 ± 11.2 a	67.9 ± 11.7 a
Weed biomass N content (%)	1.72 ± 0.08 a	1.63 ± 0.07 a	1.48 ± 0.06 b	1.68 ± 0.07 a
Weed biomass N uptake (kg ha^{-1})	3.9 ± 0.8 a	5.0 ± 0.9 a	10.8 ± 1.6 a	10.4 ± 1.6 a
Weed biomass dry matter content (%)	27.4 ± 2.2 a	27.7 ± 2.0 a	22.8 ± 0.8 a	20.7 ± 0.7 b

Means on the same line within the same experimental year with different letters are significantly different (P < 0.05)

ploughing system main effect for weed infestation parameters. Weed ground coverage, proportion of weeds in total aboveground biomass and weed aboveground biomass after shallow and deep ploughing thus revealed comparable results (Table 6). Also, total crop aboveground biomass accumulation did not differ significantly between shallow and deep ploughing (data not shown).

3.1.2 Weed N content and N uptake in aboveground biomass

The N content of the weed biomass was significantly affected by a crop stand main effect in 2009/10 and a sampling date × crop stand interaction in 2010/11. The highest weed N content was detected in EFB sole crops in both experimental years (Table 7). At the first sampling date in June, weeds in EFB-triticale intercrops were found to have significantly lower weed N contents than EFB sole crops, whereas no significant differences in weed N content occurred

between EFB sole and intercrops at the July sampling date. Also, the weed biomass in James sole crops possessed a significantly lower N content than that in EFB sole crops. Unlike in 2009/10, the weed biomass N content in James sole and intercrops did differ significantly in 2010/11 with lower values in the intercrop at the June and higher values at the July sampling date. Triticale sole cropping resulted in a tendentially or significantly lower weed biomass N content than EFB sole or intercropping. No significant differences were found between triticale and James sole crops in 2009/10 or between triticale sole crops and James-triticale intercrops in both experimental years. The ploughing system did not affect the weed biomass N content in 2009/10, whereas significantly higher values were found after shallow ploughing in 2010/11 (Table 6).

The statistical analysis of the weed N uptake in aboveground biomass revealed a significant crop stand main effect in 2009/10 and a significant sampling date × crop stand interaction in 2010/11. James sole crops showed the

highest weed N uptake of all crop stands and significantly higher values than EFB sole crops in both experimental years (Table 7). Moreover, the weed N uptake was significantly higher in James-triticale intercrops than in EFB-triticale intercrops in 2009/10, whereas no significant differences were found between winter pea-triticale intercrops in 2010/11. Triticale sole crops took up an intermediate position between crop stands with James and those with EFB in 2009/10. In 2010/11, however, there were no significant differences between triticale sole and winter pea-triticale intercrops with regard to weed N uptake. The ploughing system had no effect on the weed N uptake in either experimental year (Table 6).

3.1.3 Weed dry matter content

A sampling date × crop stand interaction and a crop stand main effect significantly affected the dry matter content of the weed biomass in 2009/10 and 2010/11, respectively. The dry matter content of the weed biomass did not differ significantly between winter pea sole and intercrops in 2009/10, whereas winter pea-triticale intercrops had significantly higher values than winter pea sole crops in 2010/11 (Table 7). Crop stands with James showed a higher weed biomass dry matter content than those with cultivar EFB. Furthermore, the weed biomass in triticale sole crops was comparable to the level in James-triticale intercrops except for the July sampling date in 2009/10. Neither a significant main effect nor an interaction containing the experimental factor ploughing system had an impact on the dry matter content in 2009/10. In contrast, deep ploughing resulted in a significantly higher weed biomass dry matter content than shallow ploughing in 2010/11 (Table 6).

3.1.4 Transmission of incident photosynthetically active radiation to weed canopy level

The proportion of incident photosynthetically active radiation (PAR) transmitted to the weed canopy level was significantly affected by a measurement date × crop stand interaction in both experimental years and by a crop stand × ploughing system interaction in 2009/10. The PAR transmission to the weed canopy level was significantly higher with winter pea James than with EFB in sole as well as in intercrops throughout the complete period of measurement in 2009/10 (Figure 2A). James sole crops were found to have significantly higher values than James-triticale intercrops until the end of flowering in James (BBCH 67, 17 May), but thereafter lower PAR transmission was measured in James sole crops. There was no significant difference between EFB sole and intercrops at the beginning of the PAR measurement in 2009/10. Subsequently, PAR transmission was significantly lower in EFB sole crops than in EFB intercrops. This trend continued until the end of May, respectively the inflorescence emergence (BBCH 51) in EFB. Thereafter, sole and intercropped EFB crop stands showed a comparable PAR transmission. The PAR transmission to the weed canopy in triticale sole crops was between the level of James and EFB crop stands until the middle of May. After the beginning of booting, triticale sole cropping resulted in the highest PAR transmission compared with all other examined crop stands.

The 2010/11 data deviate to a large extent from data gathered in the first experimental year. The PAR transmission was as well highest in James sole crops until the end of May (BBCH 65) and tendentially or significantly higher than in EFB sole crops at all measurement dates (Figure 2B). Winter pea intercrops and triticale sole crops, however, did not differ significantly during the initial phase of measurement. Moreover,

Table 7

Effect of crop stand on weed biomass N content, N uptake and dry matter content at two sampling dates in 2009/10 and 2010/11. Values are means ± SEM

	Weed biomass					
	N content (% d.m.)		N uptake (kg ha^{-1})		Dry matter content (%)	
Crop stand	June	July	June	July	June	July
2009/10						
EFB SC	2.56 ± 0.09 a	1.82 ± 0.23 a	1.8 ± 0.6 cd	1.3 ± 0.4 b	10.9 ± 0.5 b	37.3 ± 3.7 ab
EFB-TR IC	1.95 ± 0.07 b	1.59 ± 0.13 ab	1.2 ± 0.3 d	0.9 ± 0.5 c	9.7 ± 1.7 b	31.7 ± 2.6 b
James SC	1.65 ± 0.11 c	1.23 ± 0.09 b	15.0 ± 1.4 a	9.0 ± 2.1 a	23.2 ± 0.9 a	43.7 ± 2.1 a
James-TR IC	1.54 ± 0.05 c	1.35 ± 0.08 b	5.7 ± 1.8 b	4.0 ± 0.4 a	22.6 ± 1.9 a	42.9 ± 1.1 a
Triticale SC	1.73 ± 0.04 c	1.32 ± 0.07 b	2.3 ± 0.5 c	3.2 ± 0.7 ab	22.1 ± 2.0 a	33.8 ± 2.1 b
2010/11						
EFB SC	2.33 ± 0.11 a	1.94 ± 0.06 a	19.5 ± 1.9 b	4.1 ± 1.9 b	15.4 ± 0.5 c	14.6 ± 1.5 c
EFB-TR IC	1.51 ± 0.12 bc	1.94 ± 0.06 a	6.5 ± 1.1 c	4.9 ± 0.6 b	23.6 ± 1.1 ab	21.0 ± 0.6 b
James SC	1.63 ± 0.09 b	1.11 ± 0.06 c	29.7 ± 2.6 a	22.7 ± 2.9 a	21.6 ± 0.5 b	19.9 ± 0.6 b
James-TR IC	1.30 ± 0.04 cd	1.40 ± 0.07 b	4.8 ± 0.7 c	4.8 ± 0.9 b	24.2 ± 1.0 a	26.6 ± 1.4 a
Triticale SC	1.23 ± 0.10 d	1.37 ± 0.08 b	5.9 ± 1.1 c	3.2 ± 0.6 b	25.1 ± 1.2 a	25.7 ± 2.1 a

Means within each experimental year and column with different letters are significantly different (P < 0.05)
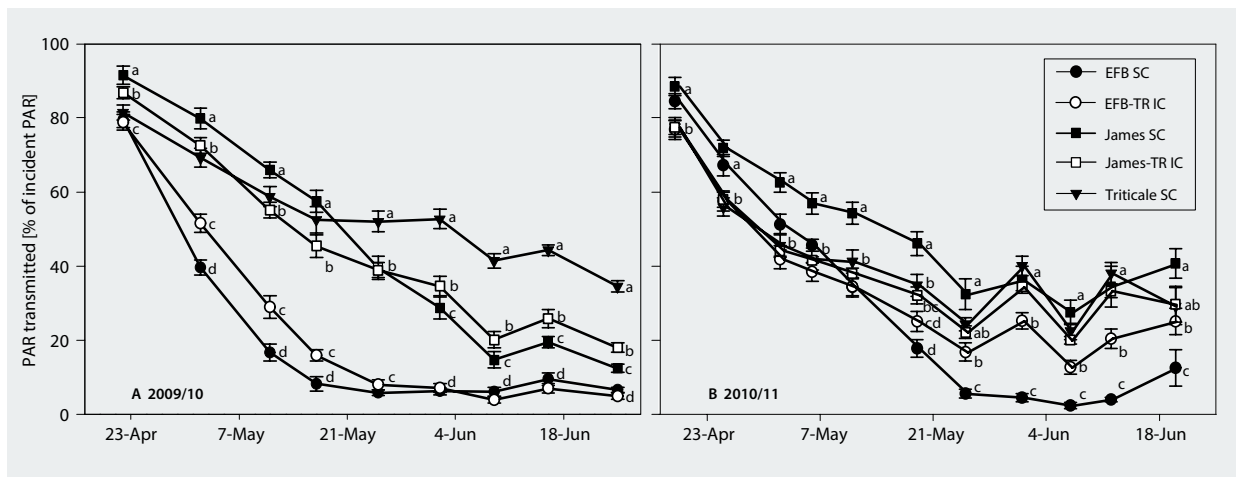
Figure 2

Proportion of PAR transmitted to the weed canopy level in sole crops (SC) and intercrops (IC) of winter peas and triticale in 2009/10 (A) and 2010/11 (B) averaged over both ploughing systems. Values are means ± SEM (error bars). Different letters indicate significant differences (P < 0.05) between crop stands at the same measurement date.

significantly lower PAR transmission was revealed in these three crop stands compared with the winter pea sole crops until the beginning of May. Thereafter, the course of the PAR transmission in intercrops paralleled the trend in triticale sole crops with EFB-triticale intercrops demonstrating the lowest and triticale sole crops the highest value. Contrary to the relatively continuous trend in winter pea sole crops, the PAR transmission in triticale sole and winter pea-triticale intercrops fluctuated all through June. At the same time, EFB sole cropping resulted in the lowest and James sole cropping mostly in the highest PAR transmission to the weed canopy level.

The significant crop stand × ploughing system interaction in 2009/10 was caused by a significantly higher PAR transmission in triticale sole crops after shallow ploughing (52.7 %) than after deep ploughing (43.4 %). In contrast, the ploughing system did not significantly influence the PAR transmission in all other crop stands. In 2010/11, any effect comprising the experimental factor ploughing system significantly affected the PAR transmission to the weed canopy level.

3.2 Pests

3.2.1 Pea aphid density and incidence

In the first experimental year, first pea aphids were observed on 2nd June at the beginning of flowering in EFB (BBCH 60) and at flowering declining in James (BBCH 67). The number of pea aphids on sole and intercropped EFB increased until the declining of EFB flowering (BBCH 67), but thereafter decreased continuously (Figure 3A). The proportion of infested EFB plants in sole and intercrops showed comparable trends to the pea aphid density data in EFB (Figure 3E). The highest proportion of infested EFB plants was detected 26 days post infestation, analogous to the

highest aphid density. Shortly after the detection of first aphids, the number of pea aphids on EFB and the proportion of infested plants were significantly lower when intercropping than sole cropping was performed. At the maximum infestation level, EFB sole crops were found to have 71 % aphid-infested plants with 21 aphids per shoot tip, whereas 8 aphids per shoot and 44 % infested plants were detected in EFB-triticale intercrops. James aphid infestation peaked 6 days post infestation in intercrops and 8 days after the detection of first aphids in sole crops at the end of flowering (BBCH 69) respectively the beginning of pod development in James (BBCH 71) (Figure 3C, G). No further aphids were detected 22 days and 26 days post infestation in sole and intercropped James, respectively. Intercropping James and triticale significantly reduced the density and incidence of pea aphids compared with James sole crops. The maximum number of aphids per James shoot tip was by 6 aphids lower than in EFB sole crops, whereas no difference was found between the maximum density in intercropped EFB and James. Pea aphids were found on 80 % of sole cropped and on 65 % of intercropped James plants at the infestation peak, which was higher than with winter pea cultivar EFB.

Low aphid infestation levels were found in 2010/11, with a maximum number of 3 aphids per shoot tip in both pea cultivars 23 days post infestation at full flowering in EFB (BBCH 65) and the beginning of pod development in James (BBCH 72) (Figure 3B, D). The pea aphid incidence fluctuated between 0 % and 26 % in EFB sole crops respectively 8 % in EFB intercrops (Figure 3F). A similar range of values was found for James sole and intercrops (Figure 3H). The aphid infestation period was simultaneous in both winter pea cultivars. Despite a low infestation level, there were significantly higher numbers of pea aphids per shoot tip and more infested plants in winter pea sole crops than in intercrops at most counting dates.
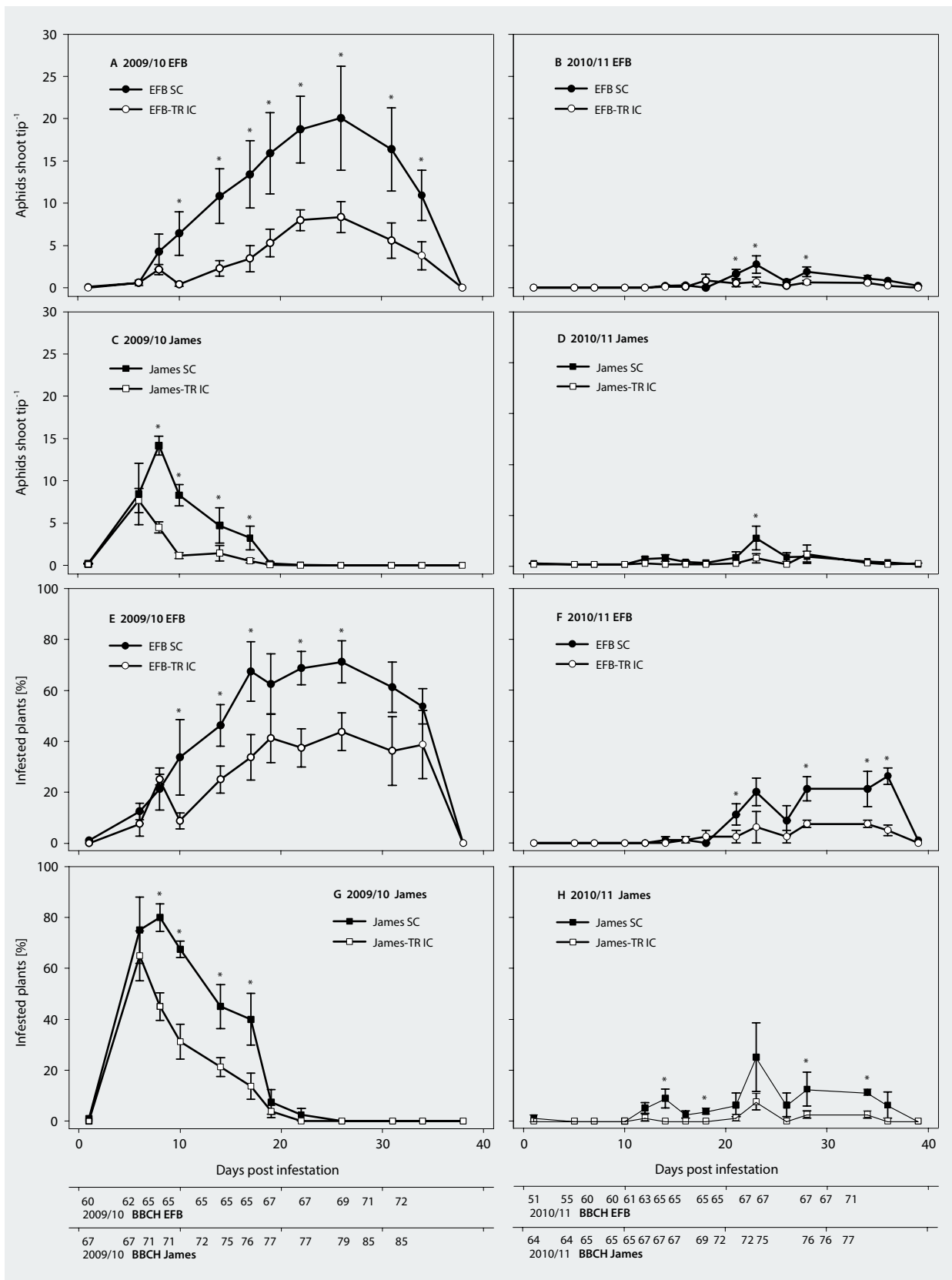
Figure 3

Density (number of aphids per shoot tip, A-D) and incidence (proportion of infested pea plants, E-H) of pea aphids in sole and intercropped winter peas in 2009/10 (A, C, E, G) and 2010/11 (B, D, F, H) with the corresponding growth stages of James and EFB. First aphids were detected on 2nd June, 2010 and 19th May, 2011. Values are means ± SEM (error bars). Asterisks indicate significant differences (P < 0.05) between sole and intercrops.

3.2.2 Cumulative aphid-days

Cumulative aphid-days were significantly higher in EFB sole crops and intercrops than in the corresponding James crop stands in 2009/10 (Table 8). In addition, intercropping winter peas and cereals significantly reduced cumulative aphid-days. Compared to the first experimental year, cumulative aphid-day values were considerably lower in 2010/11. The experimental factor crop stand did not significantly affect the values in the second experimental year. There was, however, the tendency of lower cumulative aphid-days in winter pea-triticale intercrops than in winter pea sole crops.

Table 8

Effect of crop stand on cumulative aphid-days in 2009/10 and 2010/11. Values are means ± SEM

	Cumulative aphid-days	
Crop stand	2009/10	2010/11
EFB SC	400 ± 79 a	29 ± 2 a
EFB-TR IC	139 ± 20 b	12 ± 4 a
James SC	128 ± 11 b	23 ± 9 a
James-TR IC	56 ± 3 c	11 ± 4 a

Means within each column with different letters are significantly different (P < 0.05)

3.2.3 Pea biomass N content

The pea biomass N content at the June biomass sampling date was significantly higher in sole cropped than in intercropped winter peas in both experimental years, with the exception that sole cropped James solely tended to have higher values than intercropped James in 2010/11 (Table 9). There was no significant difference in pea biomass N content between winter pea cultivars in 2009/10, whereas sole and intercropped EFB were detected to have significantly higher values than the corresponding crop stands with James in 2010/11.

Table 9

Effect of crop stand on pea biomass N content at the June biomass sampling. Values are means ± SEM

	Pea biomass N content (%)	
Crop stand	2009/10	2010/11
EFB SC	3.00 ± 0.09 a	2.78 ± 0.04 a
EFB-TR IC	2.78 ± 0.07 b	2.60 ± 0.05 b
James SC	3.10 ± 0.04 a	2.51 ± 0.04 bc
James-TR IC	2.60 ± 0.04 b	2.39 ± 0.04 c

Means within each column with different letters are significantly different (P < 0.05)

3.2.4 Pea moth larvae damaged peas

A significantly higher proportion of pea moth larvae-damaged winter peas was detected in winter pea cultivar EFB, sole or intercropped, than in cultivar James in both experimental years (Table 10). There was no difference in proportion of

damaged peas between sole and intercrops in 2009/10. Intercropping winter peas and triticale in 2010/11, however, significantly increased the proportion of damaged peas. Furthermore, winter pea cultivar EFB showed comparable values in both experimental years, whereas James was found to have a considerably higher proportion of damaged peas in 2010/11.

Table 10

Effect of crop stand on the proportion of pea moth larvae-damaged peas. Values are means ± SEM

	Pea moth larvae damaged peas (%)	
Crop stand	2009/10	2010/11
EFB SC	32.3 ± 3.2 a	32.4 ± 1.1 b
EFB-TR IC	37.6 ± 2.3 a	37.4 ± 1.6 a
James SC	7.4 ± 1.7 b	18.2 ± 1.0 d
James-TR IC	4.3 ± 0.9 b	23.0 ± 1.2 c

Means within each column with different letters are significantly different (P < 0.05)

4 Discussion

4.1 Weed infestation

The weed infestation level differed considerably between both experimental years. Annual weeds covered a higher proportion of the soil in the examined crop stands in spring in the first experimental year compared with 2010/11 (Table 5). However, the weed biomass accumulation in 2010/11 mostly exceeded the level of the first experimental year. This may be due to differences in sowing date, weather conditions and in weed species composition at the experimental fields (Table 2, 3). *L. purpureum* and *S. media*, the most dominant weed species in 2009/10, were already well-developed and covered a large part of the soil before winter, whereas few scattered weeds were present at the 2010/11 experimental field before winter and in early spring. *L. purpureum*, however, began to senesce at the end of May, which resulted in high weed biomass dry matter content at the July sampling date (Table 7). Owing to the droughty conditions in spring 2011, weed growth and development was reduced until the onset of rainfall in the middle of May 2011, but increased considerably thereafter. This was most notable for the predominant weed species *G. aparine*, which resulted in severe weed problems. Thus, an early weed infestation, with a decrease towards maturity, was present at the experimental fields in 2009/10, whereas a late-season weed infestation dominated in the second experimental year.

Weed biomass accumulation and N uptake, as well as the proportion of weed biomass in total aboveground biomass, were significantly higher in James than in EFB sole crops (Table 5, 7, Figure 1). The normal-leafed winter pea cultivar, thus, better suppressed weeds than the semi-leafless cultivar, which correlates well with the literature for spring and winter peas (Spies et al., 2011; Urbatzka, 2010; Urbatzka et al., 2011). EFB sole crops were found to have a lower PAR transmission to the weed canopy level than James sole crops

(Figure 2), which may be related to higher pea biomass accumulation (Figure 1). The better weed suppressive ability of the normal-leafed winter pea EFB may therefore be associated with lower light availability for weeds. The weed ground coverage at the end of April 2010, respectively the beginning of May 2011, however, did not differ significantly between semi-leafless winter pea cultivar James and normal-leafed cultivar EFB (Table 5). The PAR transmission to the weed canopy level in James sole crops marginally or significantly exceeded the level of EFB sole crops at the same time (Figure 2). PAR transmission values, however, were at a high level in both winter pea sole crops, which may be responsible for the slight varietal difference with regard to weed ground coverage.

The high weed biomass production in James sole crops in the second experimental year (Table 5) was related to a complete crop stand overgrowth with *G. aparine*, which indicates a good soil nitrogen supply. This was due to the short plant height of James being within a range of 23 to 31 cm at flowering. The weed growth aggravation towards maturity may as well have contributed to the increase in weed biomass in James sole crops from the June to the July sampling date in 2010/11, which stands in contrast to all other crop stands. The tall growing cultivar EFB exhibited severe lodging after flowering in sole crops. However, weed overgrowth in lodged crop stands of sole cropped EFB was observable neither in 2009/10 nor in 2010/11 and the weed biomass accumulation remained at the same level (2009/10) or decreased between the June and the July sampling date (2010/11, Table 5).

Intercropping winter pea James and triticale as well as sole cropping triticale resulted in a significantly lower weed biomass accumulation, proportion of weed biomass in total aboveground biomass and weed N uptake than James sole cropping (Table 5, 7). Moreover, James-triticale intercrops showed lower weed ground coverage values than James sole crops (Table 5). These results confirm the efficient weed suppressive ability of pea-cereal intercrops that has been shown in previous studies for intercrops of semi-leafless winter as well as spring peas and cereals (Begna et al., 2011; Corre-Hellou et al., 2011; Hauggaard-Nielsen et al., 2001; Urbatzka, 2010). Despite higher weed pressure towards maturity in 2010/11, resulting in higher weed biomass accumulation and N uptake in James sole crops compared to the first experimental year, values in James-triticale intercrops had a comparable level in both experimental years (Table 5, 7). This may be related to problems in winter triticale emergence, establishment and winter survival in 2009/10, which involved poor sole and intercropped triticale stands with only 30 % of the projected plant density and a by 49 to 74 % lower aboveground biomass accumulation than in 2010/11.

Corre-Hellou et al. (2011) suggested that the higher weed suppression in semi-leafless pea-barley intercrops compared to pea sole crops is mainly due to higher nitrogen competition in case of low soil N availability. The authors also found that high soil N availability contributes to an increase in crop leaf area. They concluded that weed suppression is under these conditions attributable to a strong light competition. Apart from the June biomass sampling in

2010/11, the weed biomass N content of James-triticale intercrops was comparable or significantly higher than in James sole crops (Table 7). In addition, triticale sole cropping resulted solely in a significantly lower weed biomass N content than James sole cropping at the first sampling date in 2010/11. Apart from that, comparable or significantly higher values were detected in the weed biomass from triticale sole crops. These results indicate that nitrogen competition does not sufficiently explain the high weed suppressive ability in James-triticale intercrops and triticale sole crops.

The PAR transmission to the weed canopy level was significantly higher in James sole crops than in James-triticale intercrops and triticale sole crops until the end of May, but did thereafter mostly not differ from or exceed the level of James sole crops (Figure 2). Thus, in the case of the early weed pressure in 2009/10, the high weed suppressive ability of James-triticale intercrops and triticale sole crops may have predominately originated from a stronger light competition than in James sole crops. The non-significant difference in PAR transmission to the weed canopy level between James sole crops and James-triticale intercrops after the end of May in 2010/11 (Figure 2B) demonstrates that shading cannot be responsible for the significantly lower late-season weed infestation in James-triticale intercrops in the second experimental year. The weed biomass dry matter content did not differ significantly between James sole crops and James-triticale intercrops at either the June or the July biomass sampling in 2009/10. In contrast to 2009/10, weed biomass in James-triticale intercrops was found to have significantly higher dry matter content than that of James sole crops in the second experimental year (Table 7). Our results suggest that the good weed suppressive ability of James-triticale intercrops was due to a higher water competition compared to James sole crops. This observation is in accordance with results of Mohler and Liebman (1987) for spring pea-barley intercrops. The presumably higher crop-weed competition for water in James-triticale intercrops than in James sole crops in 2010/11 may have resulted from the droughty conditions in spring 2011 inhibiting the biomass formation in James but not in triticale.

Despite the low triticale aboveground biomass accumulation in 2009/10, the weed infestation in EFB-triticale intercrops was comparable to the low weed infestation level in EFB sole crops and significantly lower than in the triticale sole crops (Figure 1A, Table 5). Owing to the absent competition between winter peas and triticale in the intercrop, the crop biomass accumulation in EFB-triticale intercrops obtained the level of the biomass accumulation in EFB sole crops (Figure 1A). For this reason, EFB-triticale intercrops paralleled the PAR transmission course of EFB sole crops on a higher level until the end of May, but thereafter reached the low level of EFB sole crops (Figure 2A). The tendency of lower weed biomass values in the intercrop may therefore be explained by higher crop-weed nitrogen competition than in the sole crop, which resulted in a lower weed biomass N content (Table 7).

Intercropping EFB and triticale significantly reduced the weed infestation compared to EFB sole cropping at the June

biomass sampling in 2010/11, whereas no differences were found at the July sampling date in the second experimental year (Table 5). The effective weed suppressive ability of EFB-triticale intercrops in June can be attributed, in part, to a significantly lower PAR transmission (Figure 2B). In addition, the weed biomass N content was significantly lower and the dry matter content significantly higher in the EFB-triticale intercrop than in the EFB sole crop (Table 7). We might therefore suppose higher nitrogen and water competition in the intercrop to be important factors for the low weed biomass accumulation in EFB-triticale intercrops at the June sampling date, too. The PAR transmission in EFB sole crops showed a strong decreasing trend towards maturity resulting in a significantly lower PAR transmission level than in EFB-triticale intercrops after the middle of May (Figure 2B). Moreover, the weed biomass nitrogen content was found to be identical in EFB sole and intercrops at the July biomass sampling date (Table 7). The similar weed biomass accumulation in EFB sole and EFB-triticale intercrops in July may thus be attributed to a change in PAR transmission and nitrogen availability in both crop stands.

Most studies suggest that a decrease in ploughing depth is correlated with an increase in annual, and in particular perennial, weed infestation (Børresen and Njøs, 1994; Brandsæter et al., 2011; Gruber and Claupein, 2009; Kouwenhoven et al., 2002; Pranaitis and Marcinkonis, 2005). Despite differences in weed composition and weed pressure at the experimental sites in 2009/10 and 2010/11, deep and shallow ploughing did not differ significantly in annual weed ground coverage, biomass accumulation and N uptake or in the proportion of annual weed biomass in total aboveground biomass in both experimental years (Table 6). Our data therefore differ from those reported by others. Interestingly the ploughing system neither affected crop stands with low weed suppressive ability, e.g., James sole crops nor crops stands possessing good weed suppression, as for instance EFB-triticale intercrops. Even the significantly higher PAR transmission in triticale sole crops in 2009/10 in consequence of a lower emergence and a higher winter kill rate of triticale after shallow ploughing did not influence the annual weed infestation. The weed biomass N and dry matter content were affected by the ploughing system in 2010/11 but not in 2009/10 (Table 6). The significantly higher weed biomass N content and the significantly lower dry matter content after shallow ploughing in 2010/11 did not, however, occur coupled with an increase in weed biomass. These results indicate that a reduction of the ploughing system did not alter the germination environment or considerably change the nutrient and water availability for annual weeds.

4.2 Pea pests

4.2.1 Pea aphid infestation

The occurrence of pea aphids and the duration of the infestation were closely related to the pea flowering period. Flowering occurred earlier in James than in EFB, most notably in 2009/10 (Figure 3). That is the reason why the aphid infestation

of winter pea James began at James main flowering and peaked between the end of flowering and the beginning of pod development, whereas first aphids on EFB were observed at the beginning of EFB flowering and the maximum infestation level was found to be in the period between EFB main and declining flowering (Figure 3). Owing to the late appearance of pea aphids in 2009/10, the infestation period was shorter in James than in EFB. The shorter infestation period coupled with a lower aphid density resulted in significantly lower cumulative aphid-days in sole cropped James than in sole cropped EFB (Table 8). These results indicate that early-flowering winter peas will be damaged to a lesser extent than late-flowering winter peas. McVean et al. (1999) suggested as well that spring pea sowing time should be as early as possible to avoid the coincidence of flowering and high aphid occurrence. The comparable density and incidence of pea aphids as well as the non-significant difference in cumulative aphid-days between both pea cultivars in 2010/11 (Figure 3, Table 8) resulted from the low occurrence of pea aphids and the slightly later flowering date in James. Low aphid density and incidence in 2010/11 might be attributed to spring drought. Maiteki et al. (1986) also found low pea aphid densities under drought conditions in spring and early summer.

Peak aphid density was lower in sole cropped James than in sole cropped EFB, whereas the proportion of infested pea plants tended to be higher in James sole crops compared to EFB sole crops in 2009/10 (Figure 3). Owing to the less available space on tendrils than on leaflets, the development of aphid colonies is more restricted on semi-leafless than on normal-leafed peas (Soroka and Mackay, 1990). As a consequence, James might have supported fewer pea aphids which involved a higher number of infested plants. The earlier decline of the aphid infestation in James sole crops in 2009/10 occurred in conjunction with an increase in air temperature. This observation is in accordance with other authors, who suggested that adverse environmental conditions affect pea aphids to a greater extent on semi-leafless or leafless peas than on normal-leafed peas (Buchman and Cuddington, 2009; Legrand and Barbosa, 2000; Soroka and Mackay, 1990).

In agreement with the findings of Seidenglanz et al. (2011) for spring peas, we found that pea aphids appeared at the same time in winter pea sole and intercrops (Figure 3). These data did not support the hypothesis that triticale acts as a barrier and prevents an aphid attack of intercropped winter pea cultivars with short plant height at flowering like James. Intercropping, however, significantly reduced pea aphid density and incidence as well as cumulative aphid-days most notably with the high infestation level in 2009/10 (Figure 3, Table 8). Similar results have been demonstrated by Bedoussac (2009) for semi-leafless winter pea-durum wheat intercrops.

Patriquin et al. (1988) compared the number of *Aphis fabae* in faba bean (*Vicia faba* L.) sole crops and faba bean-cereal intercrops under organic conditions. They found that the aphid density and the leaf N content were significantly higher in sole crops than in intercrops. The authors concluded that colonisation as well as reproduction of aphids may be reduced by the nitrogen competition in intercrops. We found mostly significantly lower biomass N contents in inter-

cropped winter peas during the infestation period with pea aphids (Table 9), which confirms these previous observations in faba bean-cereal intercrops. Thus, the lower pea aphid infestation in winter pea-triticale intercrops might be attributed to a lower nitrogen status in intercropped winter peas. Previous studies, however, have reported contradictory findings pertaining to the effect of pea nitrogen supply on the pea aphid reproduction under greenhouse conditions. Moravvej and Hatefi (2008) showed that the aphid reproduction increased with increasing nitrogen content in pea leaves, whereas Buchman and Cuddington (2009) did not find a relationship between pea nitrogen supply and aphid reproduction. Another possible explanation for the differing aphid infestation in sole and intercropped winter peas could be a difference in aphid feeding behaviour due to a variation in plant nitrogen status. Ponder et al. (2000) found that aphids took longer to reach the phloem sap and showed a shorter feeding period on barley under nitrogen limited than under non-nitrogen limited conditions.

Aphid density and incidence was found to decrease earlier in James-triticale intercrops than in James sole crops in 2009/10 (Figure 3C, G). This observation is in accordance with Seidenglanz et al. (2011), who reported that aphid colonies decreased earlier in semi-leafless spring pea-cereal intercrops than in pea sole crops. The authors concluded that an earlier occurrence and a higher number of predators may be responsible for this earlier decline. A considerable decrease in pea yield performance is ascribable to aphid feeding injuries on flowers and pods (Maiteki and Lamb, 1985). An earlier decline in pea aphid colonies at the end of pea flowering can thus be assumed to prevent yield losses in peas. In contrast to the findings for the semi-leafless cultivar James, a simultaneous decline of pea aphids was observed in EFB-triticale intercrops and EFB sole crops (Figure 2A, E). This fact might be attributed to the more open canopy in the semi-leafless winter pea cultivar James, which offers less protection from predators.

4.3 Pea moth infestation

The pea moth infestation level is dependent on weather conditions and the coincidence between pea moth flying period and susceptible plant growth stages (Huusela-Veistola and Jauhiainen, 2006). Thöming and Saucke (2012) reported that mated pea moth females prefer the flowering and the late bud stage in pea. Previous studies have indicated that the cultivation of early-flowering and maturing peas avoids or reduces this temporal coincidence and therefore the risk of a high pea moth infestation (Schultz and Saucke, 2005; Thöming et al., 2011; van Emden and Service, 2004). The proportion of pea moth damaged peas was significantly higher for winter pea cultivar EFB than for James, independent of the crop stand (Table 10). This fact might be attributed to the earlier time of flowering and maturity in James than in EFB. The flowering stage in EFB started at the end of May in both experimental years, whereas flowering in James was delayed by two weeks in 2010/11. This explains the similar infestation levels in EFB in both experimental years and the higher pea moth damages of cultivar James in 2010/11.

Intercropping winter peas and triticale had no effect on the pea moth damage level in 2009/10 (Table 10). On the contrary, both winter pea-triticale intercrops were found to have a significantly higher proportion of damaged peas than the corresponding sole crops. We might suppose the differing actual intercropping composition with a pea dominated intercrop in the first and a triticale dominated intercrop in the second experimental year to be responsible for this difference. Our results are consistent with Wnuk (1998), who found no beneficial effect of intercropping spring peas and phacelia (*Phacelia tanacetifolia* Benth.) or white mustard (*Sinapis alba* L.) with regard to pea moth damages on pods.

5 Conclusions

Intercropping normal-leafed or semi-leafless winter peas and triticale shows great promise in reducing an infestation with annual weeds and pea aphids. A decrease in pea moth damages could, however, not be achieved by intercropping winter peas and triticale. The weed suppressive ability was significantly higher with normal-leafed winter pea EFB than with semi-leafless cultivar James. Pea pest occurrence and infestation levels were highly dependent on pea flowering time. As a result, the early-flowering winter pea cultivar James had a distinct advantage over the later-flowering winter pea cv. EFB. Future studies are needed to separate the flowering time from the leaf type effect with regard to a pea aphid infestation. Moreover, it is necessary to evaluate the relationship between pea nitrogen status, phloem sap concentration as well as composition and pea aphid infestation in sole and intercropped peas under field conditions. The ploughing system did not affect the annual weed infestation either in sole or in intercrops. On the basis of these results, we conclude that shallow and deep ploughing are therefore both feasible in the cultivation of organic winter pea and triticale sole or intercrops with respect to annual weeds. Whole crop rotations will have to be examined in order to define the long-term effect of a reduction in ploughing depth with regard to an infestation with annual and perennial weeds.

6 Acknowledgements

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