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Impact of large strip cropping system (24 and 48 rows) on soybean aphid during four years in organic soybean

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ABSTRACT

Strip cropping could be used to deliver several eco-services, including reducing pest pressure. The objective of this study was to evaluate the impact of the management of a strip cropping system of soybean, wheat, corn and vetch on soybean aphid *Aphis glycines* Matsumura, its natural enemies and on the harvest of soybean. Experimental set up of 18 m and 36 m strips were installed in 2006 on an organic farm at Les Cèdres, Québec, Canada and compared with control plots of 180 m of soybean. Each plot was replicated two times on the farm and measured 1 km long. Observations of soybean aphid and natural enemies were carried out on 18 plants per replicate strips and control plots during summer 2007–2010. Abundance of soybean aphid was reduced between 33 and 55% in strips compared with the control plots during both high infestation years (2007 and 2009), while natural control (prey/predator ratio and parasitism rate) was more efficient in strips in 2009 and 2010. Land equivalent ratio (LER), an indicator of yield production was higher in 18 m strips than in control plots. Strip cropping could be envisaged as an effective managing tool against soybean aphid in North America.

1. Introduction

Overuse of pesticides to control pest species is leading to environmental, health and economic costs all around the world (Pimentel, 2005). To reduce reliance on pesticide use, researchers are exploring alternative and more sustainable strategies for managing pest populations (Wang et al., 2011). Many studies have shown that insect pests are less problematic in areas with increased plant species diversity (e.g. Altieri 1999; Brust et al., 1986; Hummel et al., 2009; Lopes et al., 2015; Ratnadass et al., 2012; Zehnder et al., 2007). A simple within-field solution to increase plant species diversity is mixed species cropping, such as intercropping or strip cropping.

Mixed species cropping (or intercropping) is the growing of two or more plant species in the same field in the same year and, at least in part, at the same time during the season (Gliessman, 1985; Rämert et al., 2002). Intercropping takes various forms, from culture without distinct row arrangement (mixed intercropping) to alternate single-row patterns (row intercropping) and alternate multiple-row patterns (strip cropping) (Capinera et al., 1985). Strip cropping involves growing two or more plants in strips sufficiently wide to allow separate management regimes, but sufficiently close to influence each other (Gliessman, 1985; Rämert et al., 2002). These kind of mixed species cropping can be used to deliver many eco-services such as nitrogen supply, improvement of soil structure, improvement of weed control, reduction of erosion, increase yield and nutrient uptake, and microclimate manipulation (e.g. to provide a wind barrier) (Gliessman, 1985; Glowacka, 2013; Lesoing and Francis, 1999; Li et al., 2001; Rämert et al., 2002). They can also help to reduce pest colonization rate, reduce pest tenure time, increase natural enemies abundance and diversity and increased natural control due to predators and/or parasitoids (Brust et al., 1986; Capinera et al., 1985; Koch et al., 2015; Hummel et al., 2009; Lopes et al., 2015; Ma et al., 2007; Ponti et al., 2007; Root 1973; Tahvanainen and Root, 1972; Theunissen et al., 1995; Zehnder et al., 2007). Intercropping wheat with oilseed rape has been demonstrated to significantly reduce the density of wheat aphids when compared with wheat monoculture (Wang et al., 2008, 2009, 2011) and to reduce oviposition by *Delia* spp. (cabbage fly) females on oilseed rape (Hummel et al., 2009; Parsons et al., 2007). Strip intercropping of soybean and sorghum reduce abundance of Japanese beetles *Popilia japonica* and their dispersal (Holmes and Barrett, 1997). Mixed cropping studies are most often conducted at the garden scale (−0.1 ha) which is not necessarily

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representative of modern conventional or sustainable agricultural practices (Altieri et al., 1977; Karieva, 1983).

Soybean aphid, *Aphis glycines* Matsumura (Hemiptera: Aphididae), is a soybean, *Glycine max* L., pest from Asia first observed in United States in 2000 (Hartman et al., 2001; Macedo et al., 2003), and in Ontario and Quebec provinces of Canada in 2001 (Hunt et al., 2003; Mignault et al., 2006). Outbreaks of soybean aphid reduce yields and seed quality (Beckendorf et al., 2008; Diaz-Montano et al., 2007) and the arrival of the species resulted in a 130-fold increase in insecticide applications in less than 10 years in United States (Ragsdale et al., 2011). Several variables can affect soybean aphid population and dynamic. Plant nutrition can affect abundance of this species. Walter and Difonzo (2007) demonstrated that a deficiency in potassium can lead to higher soybean aphid populations. Landscape structure, through highest diversity, for example density of hedgerows, demonstrated to reduce abundance of soybean aphid (Bahlai et al., 2010; Noma et al., 2010). Soybean aphid dynamic is characterized by a two-year oscillation cycle in abundance, even year presenting low abundance and odd year high abundance (Rhainds et al., 2010). Authors suggested that cultural practices enhancing the conservative biocontrol of Coccinellidae may contribute to the preservation of the periodicity of aphid infestation (Rhainds et al., 2010). A study on strip cropping of soybean and corn in China, 6 rows versus 2 rows, demonstrated a reduction of 80% of soybean aphid, an increase of two times more natural enemies and an increase of 16% in soybean yield (Wang and Ba, 1998).

The objective of the present study was to evaluate the effect of wide strip cropping of corn, vetch, wheat and soybean on dynamics and natural control of soybean aphid in an organic field crop system, at large scale. Our hypothesis were that (1) soybean aphid abundance will be reduced in soybean strips compared with control plots; (2) the impact of natural enemies will be higher in strips than in control plots, and (3) soybean yield will be higher in strips than in control plots.

2. Material and methods

2.1. Experimental site

This study was conducted at an organic farm of 600 ha at Les Cèdres, Québec, Canada (45°19′N; 74°06W) between 2007 and 2010. Organic farming has been used on this farm since the end of 1990s, and strip cropping has been used on a part of the farm since 2006. Wheat, common vetch, corn and soybean are in rotation on the farm. Common vetch is sown as green manure the year before corn. Experimental and agronomic aspects of the experimental plots are presented in Table 1.

For this study, two widths of strips were studied, widths of 18 m (~24 rows) and 36 m (~48 rows), which accommodate the machinery used commonly in North American farms. Control plots are composed of plots of 180 m (~240 rows) width. All strips and control plots measured 1 km long and were replicated two times on the site (Fig. 1).

2.2. Entomological sampling

In each experimental plot, three transects of 6 stations were installed at 250 m of field edge, with 10 m between stations on each transect (Fig. 1). Soybean aphid and natural enemies' abundances (ladybeetles, cecidomyid fly larvae, syrphids larvae, nabids and anthocorids adults and nymphs, lacewings larvae, parasitoids) were noted by visual observation on one plant at each station, for a total of 18 plants observed per station weekly. Sampling began mid-June and ended at the beginning of September (between 10 and 14 weeks of sampling each year). Mean total number of aphids or natural enemies was averaged within plots for each sample date. A prey/predator ratio was calculated on each plant based on the number of soybean aphid per plant/predator number. Parasitism rate was assessed based on the number of mummified aphids: percentage parasitism = total parasitized aphids × 100/parasitized and non-parasitized aphids.

2.3. Soybean yields

For year 2007–2010, yield of soybean was evaluated by combine's on-board computer and yield meter. Three replicates

Table 1
Experimental and agronomic aspects for each crop of the experiment to evaluate impacts of soybean grown in strips or control plots on *Aphis glycines*.

	2007	2008	2009	2010
Farming system	Organic	Organic	Organic	Organic
Plot size 18 m strip (ha)	1.8	1.8	1.8	1.8
Plot size 36 m strip (ha)	3.6	3.6	3.6	3.6
Plot size 180 m (ha)	18	18	18	18
Replications	2	2	2	2
Soybean variety	Nikko	91M10	91M10	91M10
Soybean planting date	May 23	May 14	May 24	May 21
pop/ha	450,000	450,000	450,000	450,000
Soybean row spacing (cm)	76	76	76	76
Soybean harvesting date	October 03	September 25	October 15	October 15
Corn variety	39D81	39D81	39D81	39D81
Corn planting date	May 23	May 14	May 24	May 20
pop/ha	88,000	88,000	88,000	88,000
Corn row spacing (cm)	76	76	76	76
Corn harvesting date	October 18	October 15	October 29	October 30
Wheat variety	Ac brio	Sable	Sable	Sable
Wheat planting date	April 25	April 23	April 17	April 15
Wheat seeding rate (kg/ha)	200	220	215	230
Wheat row spacing (po)	6	6	6	6
Wheat harvesting date	August 9	August 5	August 14	July 30

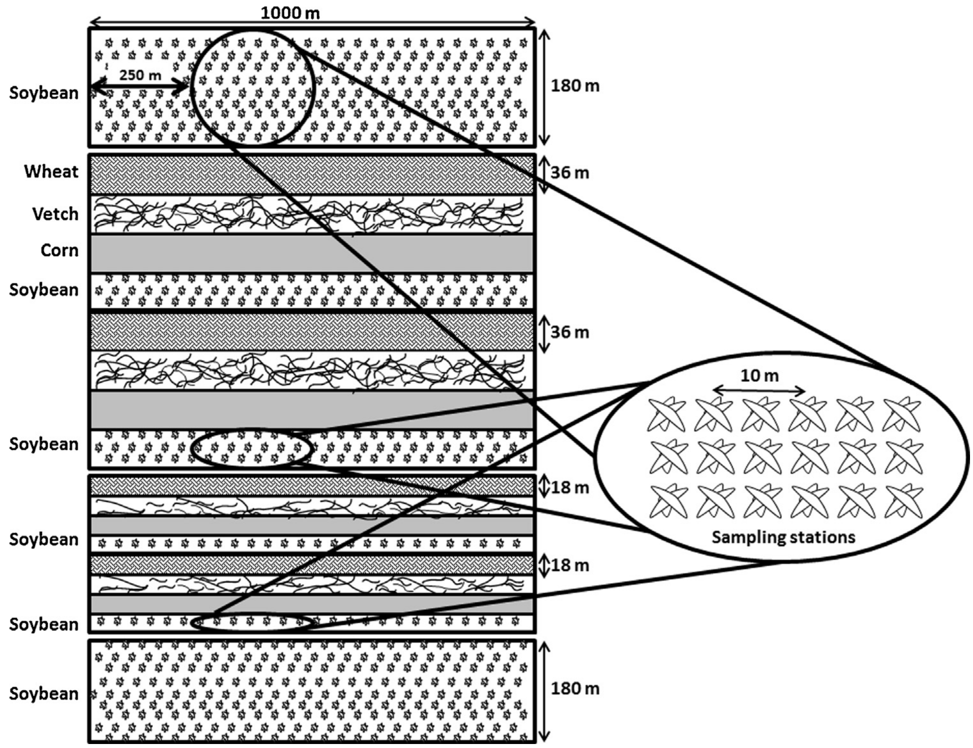

Fig. 1. Experimental design of the strip cropping system and control plots on the farm. Note: Crops are in rotation each year and changed following this scheme: Vetch–corn–soybean–wheat. Strips remained at the same place while control plots could be distant from a maximum of 1 km of the strips on other parts of the farm.

of yield were collected on each experimental plot. Additionally, land equivalent ratio (LER) was calculated to compare strips of soybean, corn and wheat to monoculture of these three crops (Lesoing and Francis, 1997; Wiley, 1985). Yield of corn and wheat was evaluated the same manner than soybean to be able to calculate the LER. Vetch was not included in this index as it is sown only for green manure purpose. Land equivalent ratio is calculated as the sum of the ratios of intercrop yields to monocrop yields of component crops (divided by the number of crops in the strip cropping system). LER higher than 1.0 indicates that strips provide higher yields than sole crop (Francis et al., 1986; Lesoing and Francis, 1997; Wiley, 1985).

2.4. Statistical analysis

As population dynamics was different between years, mean number of insects were compared separately for each year. First week of arrival and number of weeks of presence of soybean aphid in each treatment were compared with chi-square test. The mean total aphid number, natural enemies' count (predators and parasitoids), prey/predator ratios, parasitism rate and soybean yields were analysed by one-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) as a post-hoc test by JUMP 8.0 statistical software (SAS Institute, 2008). Normality of data was assessed by Kolmogorov–Smirnov test and data were log-transformed when necessary.

3. Results

3.1. Soybean aphid

Soybean aphids were first observed in 36 m strips in 2007, in 18 m strips in 2008 and 2009 and in 36 m and control plots in 2010 (Table 2). There was no differences in first week of arrival of aphids between treatment in each year (2007–2009: χ^2 = 2,4; df = 2; P = 0.30; 2010: χ^2 = 1,5; df = 2; P = 0,47). Number of weeks where soybean aphids were present in the experimental plots were similar across treatments for each year of study (Table 2; 2007: χ^2 = 0,74; df = 2; P = 0.69; 2008: χ^2 = 0,91; df = 2; P = 0.63; 2009: χ^2 = 1,68; df = 2; P = 0.43; 2010: χ^2 = 0,16; df = 2; P = 0.92).

Soybean aphid abundance presented a two-year oscillation cycle, with high infestation in 2007 and 2009, and low infestation in 2008 and 2010 (Fig. 2). Peak of population was observed on July 31st in 2007 and July 28th in 2009, while it was observed on September 8th in 2008 and September 5th in 2010 (Fig. 2). In 2007 and 2009, soybean aphid were less abundant in both strips than in control plots, while there was no differences in 2008 and 2010 (Table 3A). Winged soybean aphid abundance was higher in

Table 2
First presence and number of weeks of presence of soybean aphids in 18 m, 36 m strips and control plots during summer 2007–2010.

	18 m		36 m		Control	
	1st presence	Nb of weeks	1st presence	Nb of weeks	1st presence	Nb of weeks
2007		12/14	X	13/14		13/14
2008	X	9/12		9/12		8/12
2009	X	9/10		9/10		8/10
2010		7/10	X	7/10	X	8/10

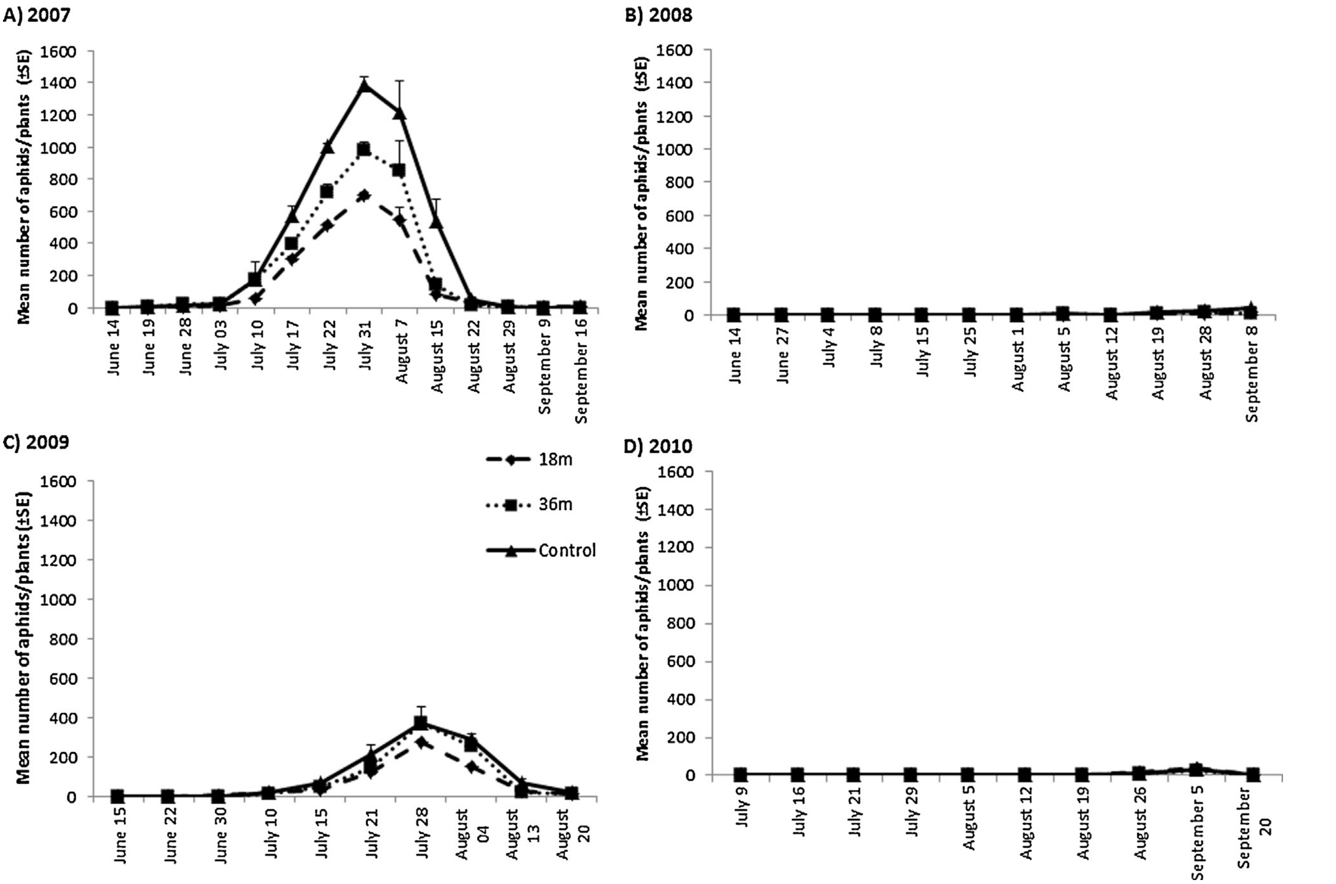

Fig. 2. Mean abundance of soybean aphids in strips of 18 m, 36 m or in control plot during summer 2007 (A), 2008 (B), 2009 (C) and 2010 (D). Note: Different letters indicate significant differences between treatments for the same week.

control plots than in 18 m strips in 2007 (Table 3B, Fig. 3), but was similar between treatments in 2008 to 2010 (Table 3B).

3.2. Natural enemies

Natural enemies observed during the four years of study were ladybeetles (*Harmonia axyridis* Pallas, *Coccinella septempunctata* L., *Propylea quatuordecimpunctata* L., *Coleomegilla maculata lengi* Timberlake and *Hippodamia convergens* Guérin-Méneville), cecidomyiid larvae (*Aphidoletes aphidimyza* Rondani), syrphid fly larvae (unidentified species), neuropteran larvae (Chrysopidae and Hemerobidae larvae), hemipteran bug (Nabidae, *Orius* sp., *Podisus maculiventris* (Say)), spiders and parasitoids (*Aphelinus* sp.).

During the four years of the study, there were no differences in predators' abundance between treatments (Table 4A; Fig. 4).

Parasitized aphids abundance (e.g. black mummified aphids) was not different between treatments during the four years of study (Table 4B).

3.3. Prey/predator ratios

In 2009, higher ratio was observed in control plots than in strips (Table 5A; Fig. 5). High ratio indicates that there is high number of aphid to consume for each predator on the plant, reducing the efficiency of the predator to control aphid population. In 2007, 2008 and 2010, prey/predator ratio (number of soybean aphid/number of predators on each plant) was similar between treatments (Table 5A; Fig. 5).

In 2010, parasitism rate was highest in both strips than in control plots (Table 5B). In 2007–2009, parasitism rate (number of parasitized aphids/total aphids on each plant) was similar between treatments (Table 5B).

3.4. Yield

No differences in yield were observed for 2007–2009 ($P > 0.05$; Table 6). Soybean mean yield was between 2.26 and 3.53 MT/ha (Table 6). In 2010, a significantly higher yield was harvested in 36 m strips compared with control plot ($F_{2,5} = 13,10$; $P = 0,03$), with 3.12,

Table 3A
Mean total abundance of *Aphis glycines* apterous and winged over time on soybean grown in 18 m strips, 36 m strips or control plots between 2007 and 2010.

Year	Soybean aphid (mean ± SEM)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	159.2 ± 6.4 a	237.0 ± 23.1 b	355.2 ± 7.2 c	2, 5	48.41	0.006
2008	3.8 ± 0.5	3.7 ± 0.6	7.6 ± 1.8	2, 5	3.84	0.15
2009	62.4 ± 3.2 a	85.4 ± 3.8 b	104.5 ± 0.5 c	2, 5	51.95	0.005
2010	5.9 ± 1.1	3.8 ± 0.06	4.9 ± 0.8	2, 5	1.84	0.30

Note: Different letters indicate significant differences between treatments.

Table 3B
Mean total abundance of winged aphids, over time on soybean grown in 18 m strips, 36 m strips or control plots between 2007 and 2010.

Year	Winged soybean aphid (mean ± SEM)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	9.8 ± 0.9 a	14.9 ± 2.8 ab	20.5 ± 0.8 b	2, 5	9.49	0.05
2008	0.02 ± 0.0	0.0 ± 0.0	0.1 ± 0.06	2, 5	3.00	0.19
2009	1.9 ± 0.03	2.9 ± 0.09	4.4 ± 1.04	2, 5	4.18	0.14
2010	0.08 ± 0.04	0.2 ± 0.1	0.07 ± 0.0	2, 5	0.74	0.55

Note: Different letters indicate significant differences between treatments.

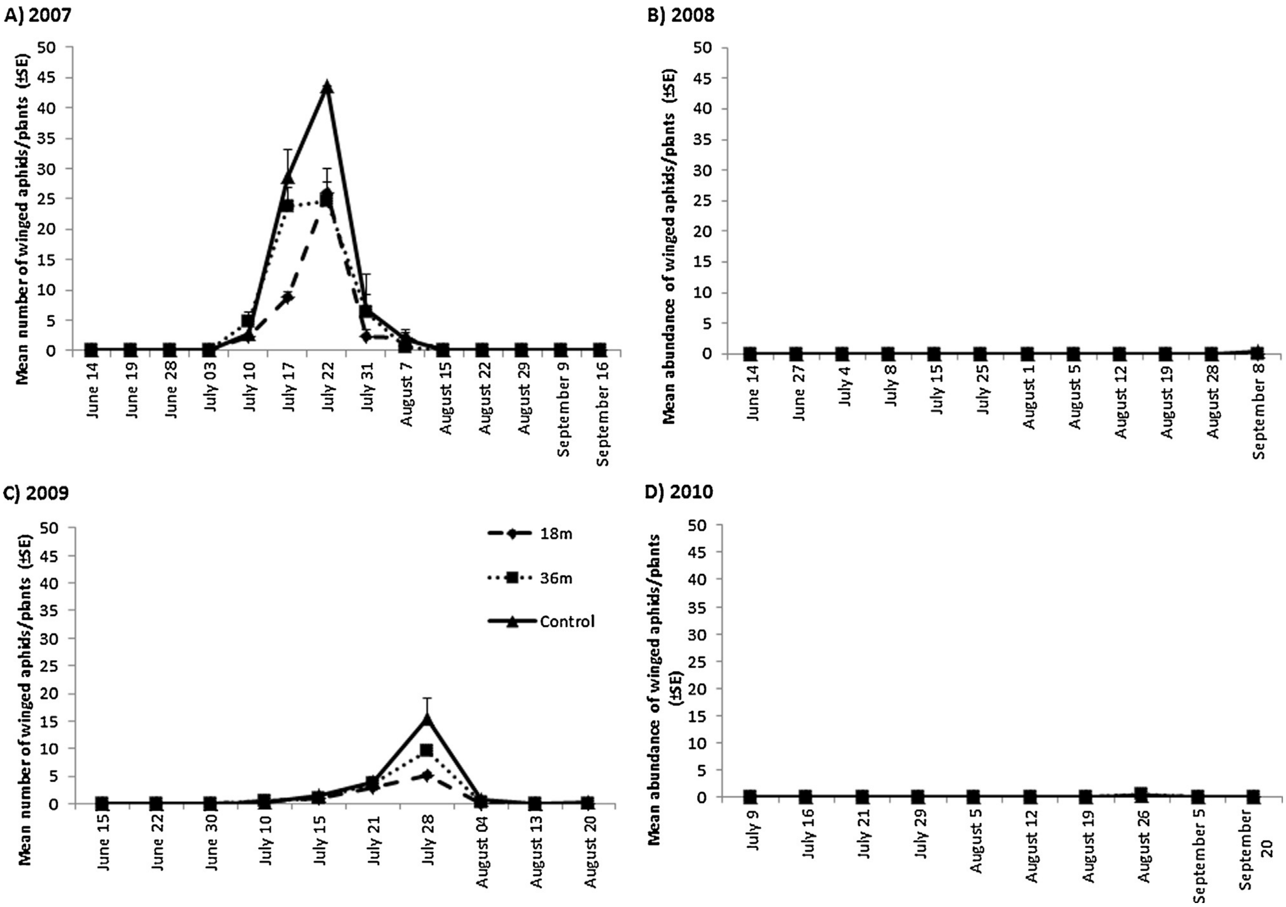

Fig. 3. Mean abundance of winged soybean aphids in strips of 18 m, 36 m or in control plot during summer 2007 (A), 2008 (B), 2009 (C) and 2010 (D). Note: Different letters indicate significant differences between treatments for the same week.

2.97 and 2.83 MT/ha in 36 m, 18 m and control plots respectively (Table 6).

LER was highest in 18 m strips each year of study, ranging between 1.18 and 1.69, while it was near 1.0 for 36 m strips (Table 6).

4. Discussion

Our study demonstrates a strong impact of strip cropping system on soybean aphid infestations. Our three hypotheses were confirmed, (1) soybean aphid abundance was reduced in strips than in control plots both years of high infestation; (2) natural enemies had a higher impact on aphids in strips, with lowest prey/predator ratio in 2009 and highest parasitism rate in 2010; and (3) LER was highest in 18 m strips all years of study.

4.1. Effect of strip cropping on soybean aphid

Strip cropping was efficient to reduce populations of soybean aphid between 45% and 60% during high infestation years; i.e. when this pest can generate economic damages. Our results are similar to Wang and Ba (1998) or Wang et al. (2000) in China, where a reduction of 80% of soybean aphids was observed in intercrop system of soybean and maize. Wang and Yue (1998) showed also a decrease from 11.4 to 81.4% in several soybean pests abundance in intercropped or soybean mixed with maize in China. Hasibuan and Lumbanraja (2012) demonstrated also a reduction of soybean aphid abundance in soybean intercrop with maize compared with monoculture of soybean in Indonesia. Our study is however the first that demonstrates an impact of strip cropping of four different crops on soybean aphid abundance. Furthermore, contrary to those studies, which are on 4–6 rows of crops, our study have been done on large strip (24 and 48 rows), more convenient for north American machinery.

Table 4A
Mean total abundance of generalist foliage-foraging predators over time on soybean grown in 18 m strips, 36 m strips or control plots (180 m).

Year	Predators (mean ± SEM)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	0.8 ± 0.1	1.07 ± 0.3	1.4 ± 0.3	2, 5	1.43	0.37
2008	0.2 ± 0.003	0.1 ± 0.01	0.2 ± 0.01	2, 5	4.03	0.14
2009	0.6 ± 0.1	0.4 ± 0.1	0.5 ± 0.07	2, 5	0.52	0.64
2010	0.1 ± 0.01	0.1 ± 0.006	0.1 ± 0.01	2, 5	0.80	0.53

Note: Different letters indicate significant differences between treatments.

Table 4B
Mean total abundance parasitoids (mummified aphids) over time on soybean grown in 18 m strips, 36 m strips or control plots (180 m).

Year	Parasitoids abundance (mean ± SEM)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	0.04 ± 0.1	0.01 ± 0.0	0.2 ± 0.1	2, 5	2.25	0.25
2008	0.009 ± 0.009	0.05 ± 0.009	0.05 ± 0.02	2, 5	8.27	0.06
2009	1.0 ± 0.4	1.6 ± 0.5	1.6 ± 0.06	2, 5	1.03	0.46
2010	0.2 ± 0.03	0.2 ± 0.008	0.1 ± 0.003	2, 5	8.19	0.06

Note: Different letters indicate significant differences between treatments.

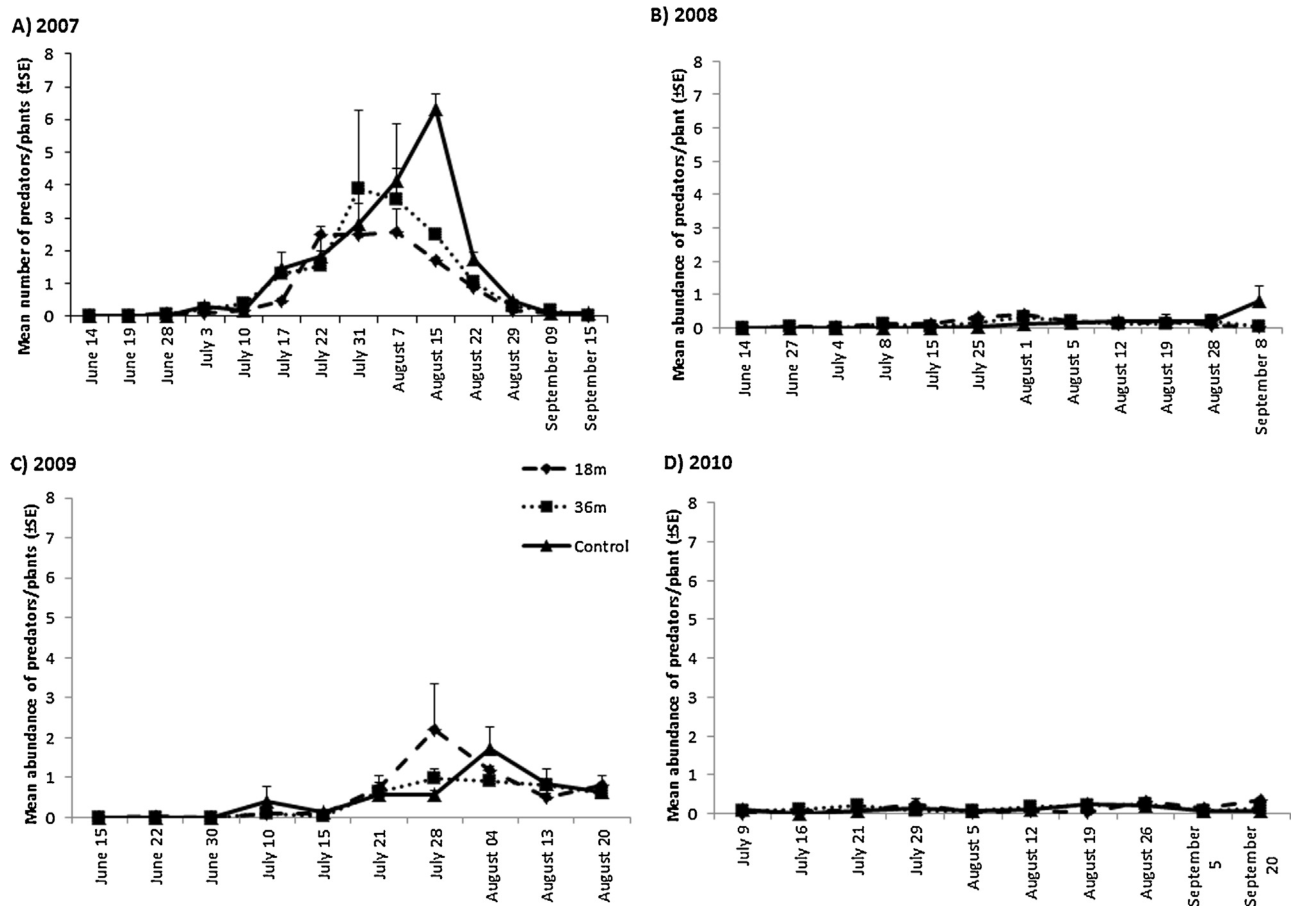

Fig. 4. Mean abundance of predators in strips of 18 m, 36 m or in control plot during summer 2007 (A), 2008 (B), 2009 (C) and 2010 (D). Note: Different letters indicate significant differences between treatments for the same week.

Numerous hypotheses have been proposed to explain the impact of such systems on pest populations. The response of soybean aphid to strip cropping in the present study seems not related to *appropriate/inappropriate landing hypothesis* at the beginning of season (Finch and Collier, 2000). This hypothesis involve generally that lower numbers of specialist insects may be found on the main crop in intercrop setting because the companion crops can (1) make the host plants harder to find (*disruptive-crop hypothesis*), (2) act as alternative host–plant (*trap-crop hypothesis*), or (3) serve as a *repellent crop* to the pest (Aiyer, 1949; Finch and Collier, 2011; Vandermeer 1989; Zhao et al., 2014). In our study, we did not fulfill to the disruptive-crop hypothesis (1) or to the repellent crops (3) at the beginning of season, as we observed our first soybean aphids in strips of 18, or 36 m and not in control plots the four years of study. Soybean aphid could also be found on other crops than soybean, such as leguminous crops (clover, bean, alfalfa etc.) (Alleman et al., 2002; Hill et al., 2004). However, the companion crops in this study (corn, vetch, wheat) are not hosts of soybean aphid and in additional observations of insects' pests in wheat, corn and vetch strips, soybean aphids were never found (Labrie, unpublished data). We then reject the alternative host-plant hypothesis.

A possible alternative explanation is the physical barrier hypothesis. During the season, other crops in strips, such as corn, can act as barriers to dispersion during peak population of soybean aphid. Other studies demonstrate physical barriers when insects encounter higher vegetation, such as 2 m tall Napier grass used in a Kenyan system with maize as intercrop, which reduce abundance of pest insects in maize (Johnson, 1969; Lewis and Stevenson, 1966). Risch (1981) showed that cornstalks interfered with flight movement of chrysomelids beetles pest of squash and bean, reducing abundance of these pests on squash in polyculture systems. In those systems, cornstalks could have created a pattern of shape, shade or color that resulted in decreased ability to locate the host (Risch, 1981). Another study showed that sorghum strips created a barrier to movement for Japanese beetles in strip

Table 5A
Exposure of aphid population to natural enemies, measured as mean total prey/predator ratio on soybean grown in 18 m strips, 36 m strips or control plots (180 m) between 2007 and 2010.

Year	Prey/predator ratio (mean ± SEM)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	41.6 ± 6.5	52.0 ± 13.2	74.1 ± 6.5	2, 5	3.19	0.18
2008	0.4 ± 0.09	0.8 ± 0.4	2.3 ± 0.5	2, 5	6.79	0.08
2009	20.5 ± 0.7 a	24.4 ± 0.4 a	29.3 ± 1.9 b	2, 5	13.97	0.03
2010	0.9 ± 0.1	0.6 ± 0.001	0.7 ± 0.9	2, 5	4.46	0.13

Note: Different letters indicate significant differences between treatments.

Table 5B
Exposure of aphid population to natural enemies, measured as parasitism rate on soybean grown in 18 m strips, 36 m strips or control plots (180 m) between 2007 and 2010.

Year	Parasitism rate (mean %)			df	*F*	*P*
	18 m	36 m	Control (180 m)			
2007	0.008	0.002	0.02	2, 5	2.09	0.27
2008	0.1	0.53	0.54	2, 5	0.66	0.58
2009	2.68	2.12	3.07	2, 5	0.35	0.73
2010	5.34 a	5.57 a	2.5 b	2, 5	17.25	0.02

Note: Different letters indicate significant differences between treatments.

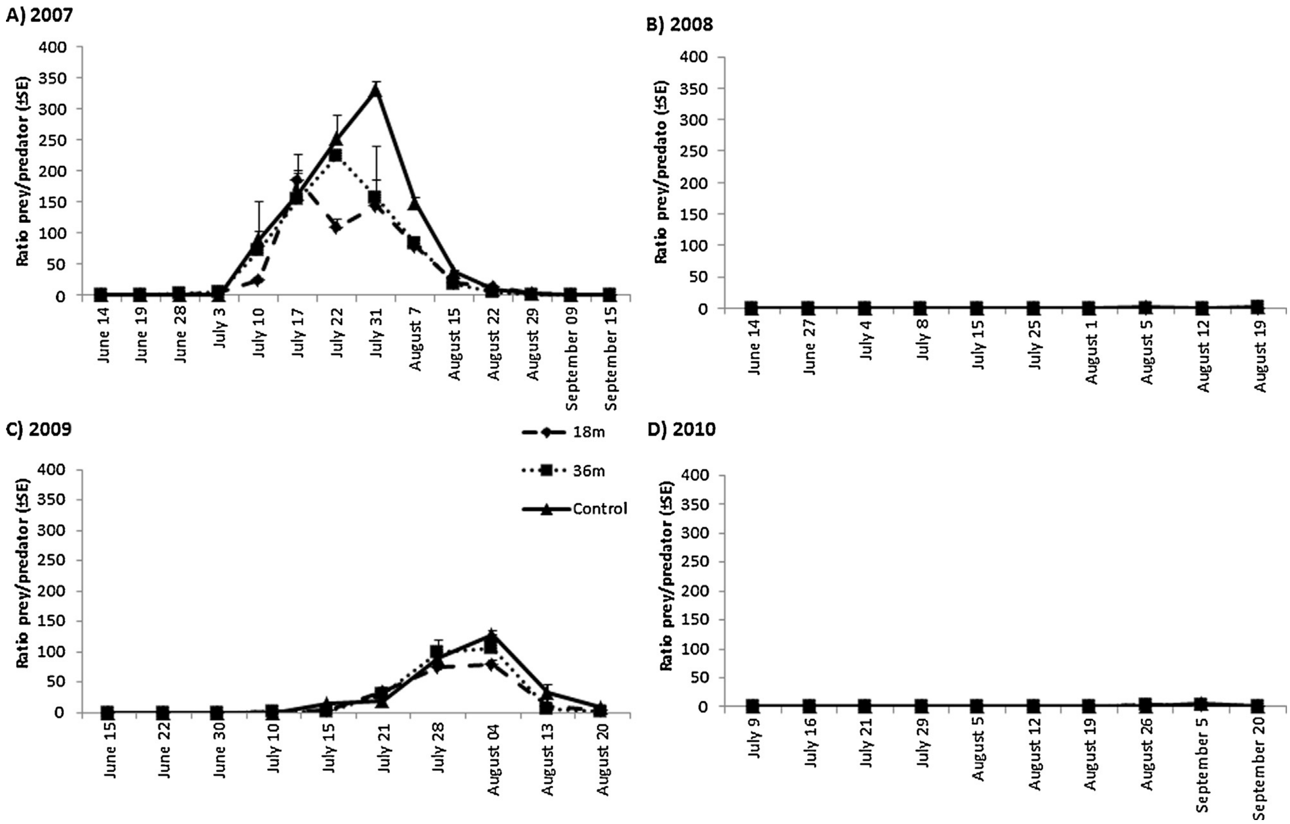

Fig. 5. Mean prey/predator ratio (number of soybean aphid per predator on each plant) in strips of 18 m, 36 m or in control plot during summer 2007 (A), 2008 (B), 2009 (C) and 2010 (D). Note: Different letters indicate significant differences between treatments for the same week.

intercropping system with soybean (Holmes and Barrett, 1997). In our study, we observed fewer winged aphids during peak of population in strips than in control plots in 2007. These winged aphids could be flying to other crops, or just landing in these plots in search of better food source. Corn, which was between 1.25 and 1.75 m tall at that time, could thus have acted as a physical barrier against soybean aphid infestation during the peak of population in July.

4.2. Effect of strip cropping on natural enemies

The impact on soybean aphid populations in our study may partly be explained by an effect of the cropping system on natural enemies' populations (*Natural enemies' hypothesis*; Root, 1973). Such an impact may be observed directly via an increase of natural enemies' abundance, or indirectly via a prey/predator decrease or a parasitism rate increase. We did not observe significantly highest abundance of natural enemies (predators or parasitoids) in strip crops than in control plots. Other studies demonstrated also that strip cropping did not attract and increase natural enemies'

Table 6
Yield (MT/ha) and Land equivalent ratio (LER) of soybean, corn and wheat in strips and monoculture between 2007 and 2010.

Year	Cropping system	Soybean yield	Corn yield	Wheat yield	LER
		MT ha^{-1}			
2007	Monoculture (soybean, corn, wheat)	2.63 a	9.55	3.45	1.00
	18 m strip (soybean, corn, wheat)	2.26 a	8.95	2.24	1.18
	36 m strip (soybean, corn, wheat)	2.36 a	7.28	2.77	0.78
2008	Monoculture (soybean, corn, wheat)	2.93 a	8.4	4.08	1.00
	18 m strip (soybean, corn, wheat)	3.04 a	8.15	3.68	1.68
	36 m strip (soybean, corn, wheat)	3.53 a	7.41	4.07	1.04
2009	Monoculture (soybean, corn, wheat)	2.86 a	7.03	3.33	1.00
	18 m strip (soybean, corn, wheat)	2.85 a	8.05	3.65	1.69
	36 m strip (soybean, corn, wheat)	2.77 a	7.98	3.54	1.05
2010	Monoculture (soybean, corn, wheat)	2.83 a	7.76	3.27	1
	18 m strip (soybean, corn, wheat)	2.97 ab	7.56	3.01	1.54
	36 m strip (soybean, corn, wheat)	3.12 b	7.59	3.2	0.93

Note: Different letters indicate significant differences between treatments.

abundance (Budenberg and Powell, 1992; Björkman et al., 2010; Coll and Bottrell, 1995). Sheehan (1986) already predicted that specialist enemies will respond to mixed cropping differently than generalist predators and parasitoids, because of the importance of alternate prey for generalists. When the pest species is the main food item and when this species is also reduced in the mixed cropping system, predators are expected to be more abundant in the monoculture (Björkman et al., 2010).

However, beyond the similar abundances of predators and parasitoids, the potential of biological control, measured by the prey/predator ratio and the parasitism rate in our study, was highest in strip crops one year out of four for both indices. In 2009, the prey/predator ratio was lower in both strips than in control plots, indicating that each predator has a fewer number of aphids to consume in strips. Other studies demonstrated such results, with similar predator densities in monoculture than in polyculture, but with different predator efficiency in both systems (Coll and Bottrell, 1995). Parasitism of soybean aphid was also highest in 2010 in both strips than in control plots. The recent history of soybean aphid parasitism in North America (Frewin et al., 2010), could explain this lack of parasitism in first years of study. A drastic increase in parasitism rate was clearly observed throughout years in strips, passing from a minimum mean rate of 0.002% in 2007 to maximal mean rate of 5.34% in 2010. These results could demonstrate that natural enemies' could be more present after a few years of installation of a system of strip cropping.

4.3. Impact of strip cropping on yield

Highest yield in 36 m strip crop compared with monoculture of soybean were observed in 2010. This difference could not be caused by soybean aphid, as populations were very low that year. In China, Wang and Ba (1998) observed an increase of 16% of soybean yield in their system, while Wang and Yue (1998) observed an increase in yield around 33%. In these studies, other aphid species were present in soybean, which could impede higher pressure on soybean and reduce yield even if soybean aphids were lower on mixed or intercropped system (Wang and Yue, 1998). In our study, the intensity of the infestation by soybean aphid could explain the lack of differences in yield two years out of three (2008–2009), as peak infestation did not reach the economic threshold of 675 aphids/plant (Ragsdale et al., 2007).

The absence of yield differences in soybean in our study could however be modulated when considering the entire strip crops (soybean, corn, wheat). Many studies calculated the land equivalent ratio (LER) (Francis et al., 1986; Lesoing and Francis, 1999; Wiley, 1985) when intercropping two or more different crops, which gave an index of total system performance compared with sole crops. A LER higher than 1.0 indicates that strip crop system is more efficient than monospecific crop (Francis et al., 1986; Lesoing and Francis 1997; Wiley, 1985). In our study, calculating LER indicates that 18 m strips were between 18 and 69% more efficient (LER between 1.18 and 1.69) compared with sole crop (LER of 1.0), while 36 m were similar to control plots (LER of 1.0).

5. Conclusion

Our study demonstrated that natural enemies efficiency, combined with the absence of other host plant for soybean aphid and the presence of physical barriers may explain the impact of strip cropping system on soybean aphid abundance.

A key question linked to strip cropping system is the width of strip-cropped patterns necessary to obtain the benefits of intercropping (Capinera et al., 1985; Francis et al., 1986). The smaller width of row seems the best system to obtain benefits on pest reduction and agronomic parameters (Capinera et al., 1985; Zhang et al., 2007). In our study, we observed the main effect on abundance of soybean aphids and yield (LER) in 18 m width (24 rows). Almost all studies on strip cropping used a maximum of 8 rows (approx. 6 m) of the same crop (Francis et al., 1986), but our study demonstrated for the 1st time that 24 rows, adapted to north American machinery, is also efficient to control soybean aphid during high infestation year, while retaining natural enemies in the local landscape in the last years of study and maximising yield in global agroecosystem.

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