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Intercropping sunflower and soybean in intensive farming systems: Evaluating yield advantage and effect on weed and insect assemblages

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ABSTRACT

Agricultural intensification has encouraged both landscape homogenization and biodiversity decline in agro-ecosystems. Intercropping may over yield sole crops and simultaneously enhance landscape heterogeneity and planned and associated biodiversity in agroecosystems. Thus, we assessed yield advantage in sunflower/soybean intercrops in the Southern Pampas (Argentina). We also expected weed and insect assemblages to differ between sole crops and intercrops and to be more diverse and productive in intercrops than in sole crops. Thus, we evaluated the effects of sunflower/soybean sole and intercrops on the composition, richness, and abundance of weed and insect assemblages. Sunflower/soybean sole crops and intercrops were sown in two experiments in the Southern Pampa during two consecutive years. Weeds and insects were surveyed and both crop yields and land equivalent ratio (LER) were calculated. Cover/abundance of weeds, abundance of insects and species frequency and richness of both taxa were also estimated. Weeds were classified according to life cycle (annual or perennial) and insects according to feeding habits (herbivores and non-herbivores). Yield advantage of intercropping was indicated by LER values higher than 1 in both experiments, indicating that intercrops were more productive than sole crops. Species compositions of weed and insect assemblages differed between sole crops and intercrops because some particular species characterized each cropping system. Total species number was higher in intercrops than in sole crops. However, mean richness and abundance per plot was similar among treatments for weeds and similar or lower in intercrops than in the rest of treatments for insects. Here, we show that intercropping warm-season crops constitute a feasible alternative to promote heterogeneity within-fields and therefore sustain biodiversity in conventional cropping systems in temperate regions, which have become highly simplified after agricultural intensification such as in the Southern Pampa.

1. Introduction

Agricultural intensification has considerably increased land productivity worldwide since the mid 20th century. Yield increase was mainly due to breeding few crops, often at the expense of reducing both crop type diversity and biodiversity [1,2]. Agricultural productivity was also increased by providing the resources that limit crop yield through irrigation and fertilization, and applying standardized chemical management strategies to protect crops from weeds, pests and diseases [3,4]. Spatial and temporal homogenization of agricultural landscapes may also reduce biodiversity [5]. Diversifying cropping systems by increasing the spatial and temporal heterogeneity of agricultural mosaics has been proposed as a feasible alternative to overcome the negative effects of modern agriculture [1,5–7]. Within fields, temporal heterogeneity can be achieved by growing several crops in sequences, while spatial heterogeneity can be enhanced by intercropping species differing in the patterns of resource use and their associated flora and fauna [1,4].

Intercropping is broadly defined as the agronomic practice in which two or more crops are grown simultaneously in the same area of land [8]. This farming system may be a practical application of ecological principles based on biodiversity, biotic interactions and other natural regulation mechanisms [9,10], allowing efficient

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weed and insect pest management with low reliance on off-farm inputs. In addition, intercropping may contribute not only to enhance planned biodiversity, which is associated with the crop types managed by the farmer in an agro-ecosystem, but also the associated biodiversity, which is the spontaneous biota occurring in agroecosystems [1,11].

Intercrops may suppress weed growth more effectively than sole crops mainly through competition [12]. Effective weed suppression and economic results can be similar to or higher than those of other pest management practices [13]. Although sometimes harder to manage, intercrops often produce higher and more stable yields than their sole crop components due to more efficient use of resources and reduced incidence of weeds, insect pests and diseases [8]. Successful inception of intercropping into conventional intensively managed cropping systems poses several challenges, not only regarding agronomic management, such as the choice of the optimum spatial arrangement, plant density, and sowing date of each crop in the mixture, but also for assessing the impact on the associated biodiversity. Agricultural research has an adequate tool-box of methods and models for technology development in conventional cropping systems. However, most information related to intercrops is based on low-input agriculture and there is little knowledge on managing intercrops in conventional farming systems [14].

In the Pampas of Argentina, crop diversity has notably decreased during the last decades due to agricultural intensification. Nowadays, croplands are mostly sown with transgenic soybean resistant to glyphosate by using no-tillage practices [15]. All these changes have promoted species diversity of weed and insect communities to decline over time and space [16–18]. Here, we present results of a study about how the diversification of homogeneous, intensively managed cropping systems through intercropping may increase land productivity. Using an experimental approach, we assessed the occurrence of yield advantage in sunflower/soybean intercrops in the Southern Pampas. We also evaluated the effects of sunflower and soybean sole and intercrops on the composition, richness and abundance of weed and insect assemblages. We expected weed and insect assemblages to differ between sole crops and intercrops, being more diverse in the latter.

2. Materials and methods

2.1. Study site and field experiments

Two field experiments including sole crops and intercrop of sunflower and soybean were carried out in consecutive years in the Southern Pampa, Argentina (37°20' S, 59°08' W, 188 m.a.s.l.). Experiments were set in different fields each year using the regular cropping management used by the farmers in the region. Soil was clay-loam (Typic Argiudol, USDA Soil Taxonomy) with a deep top layer (> 1.5m) rich in organic matter (c. 5%). Average annual rainfall is 940 mm with a spring-summer bias (*i.e.* 64% of rainfall in October - March). However, rainfall was 988 mm and 678 mm in the first and second experimental years, respectively.

The two experiments, henceforth referred to as Exp. 1 and Exp. 2, were set by using a completely randomized design with two and three replicates, respectively. Treatments in both experiments were the sole crops and intercrops of sunflower and soybean. Two cultivars of each crop were sown in each experiment (Table 1). Soybean cultivars were genetically modified to resist glyphosate. Thus, eight treatments were included in the experiments, being two sole crops of each soybean and sunflower and four intercrops (2 soybean cultivars x 2 sunflower hybrids). Each treatment was assigned to plots 5 m wide by 45 m long in both experiments [19]. Sole crops and intercrops were sown on the same date in each experiment (Table 1). Crops were sown with a no-tillage drilling machine in rows 0.52 m apart. Target densities in sole crops were 7.4 for sunflower and 38.5 plants m^{-2} for soybean. To sow intercrops, a sunflower row was replaced by two soybean rows (Fig. 1). The number of plants in the row was similar to that of sole crops. Sunflower rows in intercrops were sown 1.04 m apart, whereas the two soybean rows were sown 0.52 m apart from each other in the sunflower inter row and 0.26 m away from the adjacent sunflower row (Fig. 1). Sunflower sole crops and intercrops were sown on the usual optimum sowing dates, whereas in intercrops soybean was sown a month later than the usual optimum date for sole crops in the region, for agronomic and eco-physiological reasons. Late sowing of soybean contributes to mimic farmers' management and to decrease the overlapping between the critical periods for seed setting of both crop species in the intercrop [20]. Plots were fertilized at sowing of sunflower with 60 kg ha^{-1} of triple super phosphate (46% P_2O_5).

Crop management in both experiments was similar to that used by farmers (for details see Table 1).

Table 1
Crop management experiments sown with sole- and intercrops of sunflower and soybean.

	Experiment 1	Experiment 2
Sunflower		
Fertilization	Triple superphosphate (46% P2O5): 60 kg ha^{-1} at sowing.	
Hybrids	MG 60 (Dow AgroSciences, Argentina)	
	N 6860 (Nidera Semillas, Argentina)	Paraiso 68 (Nidera Semillas, Argentina)
Sowing date	29 Oct 2007	30 Oct 2008
Herbicides		
Pre-sowing	Glyphosate: 1.44 kg a.i. ha-1 2,4-D: 800 g a.i. ha-1	
Pre-emergent	Acetochlor: 670 g a.i. ha-1	
Post-emergent	imazethapyr (52.5%) + imazapyr (17.5%): 143 g a.i. ha-1	
After crop maturity	Glyphosate: 2 kg a.i. ha-1 (only in intercrops)	
Insecticides		
4 weeks after sowing	Cypermethrin: 112 g a.i. ha-1 imidacloprid: 0.019 kg a.i. ha-1 during	
Flowering	Cypermethrin: 112 g a.i. ha-1 chlorpyrifos: 0.49 kg a.i. ha-1	
Soybean		
Fertilization	Triple superphosphate (46% P2O5): 60 kg ha^{-1} at sowing.	
Cultivars (GM)	N 5009 RG (Nidera Semillas, Argentina)	
	SPS 4500 RG (Semillera SPS, Argentina)	N 4613 RG (Nidera Semillas, Argentina)
Sowing date	12 December 2007	5 December 2008
Herbicides		
Pre-sowing	Glyphosate: 2 kg a.i. ha^{-1}	
Post-emergent	Glyphosate: 2 kg a.i. ha-1 (4 weeks after crop emergence)	
Insecticides		
4 weeks after sowing	Cypermethrin: 112 g a.i. ha^{-1}	

2.2. Measurements

Grain yield of sunflower and soybean in sole crops and intercrop was measured at crop maturity. Sunflower was harvested on April 1st and soybean on May 27th at commercial maturity by using an experimental plot combine harvester. Grain yield of both crop types was calculated at 12% moisture content and expressed in kg ha^{-1}.

Weeds and insects were surveyed at sunflower full flowering in both experiments (Exp. 1: 14 January 2008, Exp. 2: 22 January 2009) considering that: (1) most weed species of both spring-summer and autumn-winter growing cycles were present, (2) herbicides and insecticides had already been applied affecting weeds

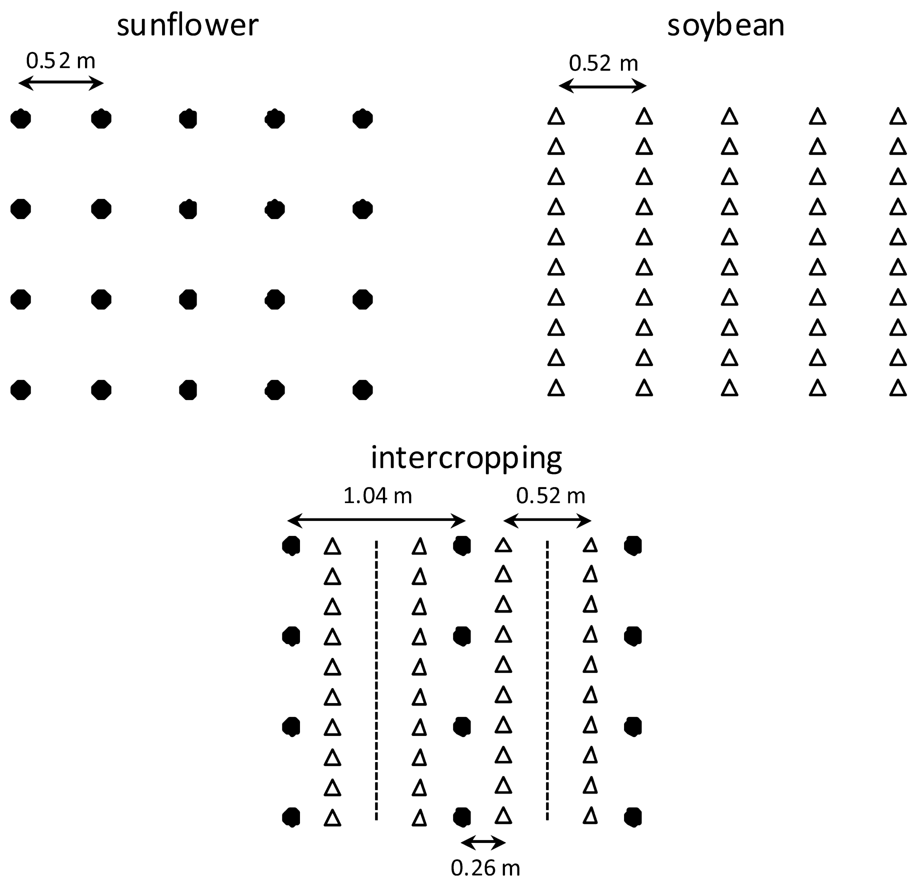

Fig. 1. Sowing pattern of sole crops and intercrops of sunflower (circles) and soybean (empty triangles). Intercrops were formed by replacing one row of sunflower by two rows of soybeans (dotted line).

and insects, and (3) crops had reached their maximum ground cover.

Weed surveys consisted of listing all species occurring in the central area of each plot avoiding a 1m wide border. Cover/abundance of each weed species was estimated using a scale adapted from the Braun-Blanquet phyto-sociological method [21]. Cover/abundance scale comprised seven percent intervals (< 1, 1-5, 5-10, 10-25, 25-50, 50-75, 75-100%; [22]). Weed species were classified according to their life cycle into annuals and perennials.

Aerial insects were sampled with a 30 cm diameter sweep net [23] in three positions along the central strip of each plot. Samplings were carried out between 10 A.M. and 3 P.M. under weather conditions allowing moderate to high insect activity (*i.e.*, sunny days, temperature above 15 °C, and null to moderate wind speed). Four net sweepings were made at each sampling point. Captured insects were killed in situ and pooled into a single sample per plot. Insects were taxonomically determined at order, family, and morpho-species levels in all cases, considering that differences between number of morpho-species and taxonomic species are in many cases very small [24]. Abundance of each insect morpho-species was obtained by counting the total number of individuals captured per plot. Each insect morpho-species was classified into herbivores and non-herbivores according to its habits and food preferences during the crop cycle, based on anatomical characteristics and bibliography [25]. All these insect specimens are preserved in the authors' insect collection in the School of Agriculture, University of Buenos Aires. Frequency was calculated as the percentage of plots of a particular treatment containing a given species. Species richness was estimated as the total number of species per plot.

2.3. Analysis

Yield advantage of intercropping was assessed by calculating the land equivalency ratio (LER), which is defined as the relative land area required for sole crops to produce the same yields as obtained by intercropping [26]. LER values greater than 1.0 indicate that intercrops are more productive than the two component sole crops. LER was computed by using the following formula [26]:

$$LER = I_{sunflower}/S_{sunflower} + I_{soybean}/S_{soybean} = L_{sunflower} + L_{soybean}$$

where $I_{\text{sunflower}}$ and I_{soybean} are yields of both crop types when intercropped, $S_{\text{sunflower}}$ and S_{soybean} are the corresponding yields in sole crops, and $L_{\text{sunflower}}$ and L_{soybean} represent the LER components for the two crops types in the mixture. Partial LER components (L) are obtained dividing the yield in intercrop (I) by the yield in the sole crop (S). The averages of sole crop yields of each crop type were used as divisors in calculating LERs as a standardizing method of intercrop yields [27]. Grain yields and partial LER components produced by each crop type in sole crops and intercrops from both experiments were analyzed using analysis of variance. Data were square-root transformed to fulfill the assumptions of normality and homogeneity of variance. Means were compared by the Tukey's significant difference test at 0.05 probability level. To evaluate if there was yield advantage in intercrops, LER value was compared to 1 by using one-tail t test ($P < 0.05$). Since cultivars did not produce significant effects on yields of both crop types, as well as on the composition, richness and abundance of weed and insect communities, this factor was removed from the analysis and data were considered as replicates.

Table 2
Mean grain yields of sunflower and soybean sown in sole crops and intercrops, and the corresponding land equivalent ratio (LER) and LER components (L) in Exp. 1 and Exp. 2. Different letters indicate that mean yields are significantly different according to Tukey's test (P < 0.05), and that L values significantly differed according to paired t test (P < 0.05).

Crop type	Cropping system	Yield (k ha^{-1})	L	LER
Sunflower	Sole crop	2738a	0.96	1.27
	Intercrop	2615a		
Soybean	Sole crop	1802b	0.31	
	Intercrop	562.3c		

The hypothesis stating no differences between species compositions of weed or insect assemblages in sole crops and intercrops was tested by using the Multi-Response Permutation Procedure (MRPP: [28]). Sole crop and intercrop treatments were used as categorical variables. The use of squared Euclidean distance is equivalent to either the two-sample Student's *t*-test or the one-way analysis of variance *F*-test. Pair-wise comparisons between treatments were also tested [28]. Treatments, weed and insects were combined in tables, where groups of weeds or insects are shown in rows and treatments are shown in columns. Groups of weed species and insect morpho-types were obtained by cluster analysis. The Bray-Curtis similarity index [29] was used as a distance measure for species and cropping treatments.

Richness and abundance of weeds and insects in both experiments were analyzed with a generalized linear model using the function normal (GLM). Data were square-root transformed to fulfill the assumptions of normality and homogeneity of variance. Means were compared by Tukey's significant difference test at 0.05 probability level. Analyses were performed with InfoStat, version 2008 [30].

3. Results

3.1. Yield advantage of intercropping

Grain yield differed among treatments ($P < 0.001$, $F = 120.38$, $d.f. = 3$) and experiments ($P < 0.0281$, $F = 5.18$, $d.f. = 1$), and it was higher in Exp. 1 than in Exp. 2. Sunflower grain yield in intercrops did not differ from that in sole crops. However, soybean yield was significantly lower in intercrops ($P < 0.01$). LER value was greater than 1 in both experiments (Table 2), which suggests an overall yield advantage of intercrops relative to sole crops.

3.2. Effects on weed assemblages

A total of 39 and 14 weed species were surveyed in Exp. 1 and Exp. 2, respectively (Tables A1 and A2). Floristic composition of weed assemblages differed between sole crops and intercrops in both experiments (Exp. 1: $P = 0.0004$; Exp. 2: $P = 0.01$). In Exp. 1, composition of weed assemblages in soybean sole crops significantly differed from that in sunflower sole crops ($P = 0.01$) and intercrops ($P = 0.002$), and the composition in sunflower sole crops differed from intercrops ($P = 0.04$). In Exp. 2, weed species compositions between soybean crops and intercrops ($P = 0.009$) and between soybean and sunflower ($P = 0.05$) were significantly different.

Richness of total, annual and perennial weeds was similar among treatments, but different among experiments, being higher in Exp. 1 than in Exp. 2. Abundance of total, annual and perennial weeds, expressed as percent ground-cover, was similar among treatments and experiments, except for abundance of perennial weeds which differed among experiments, being higher in Exp. 1 than Exp. 2 (Table 3).

3.3. Effect on insect assemblages

Insect morpho-species were 18 and 27 in Exp. 1 and Exp. 2, respectively (Table A3 and A4). Feeding behavior of all insect morpho-species was determined in Exp. 1, whereas only one morpho-species could not be identified in Exp. 2. Insect assemblages differed among cropping systems in both experiments (Exp. 1: $P = 0.03$; Exp. 2: $P = 0.006$). Insect assemblages were significantly different between sunflower crops and intercrops ($P = 0.003$) in Exp. 1, and between soybean crops and intercrop ($P = 0.01$) and sunflower ($P = 0.001$) in Exp. 2.

Total richness of insect morpho-species was significantly higher in soybean crops than in the other treatments. Regarding feeding habits, richness of non-herbivore insects was significantly higher in soybean crops than intercrops, whereas herbivore richness did not differ among cropping treatments but differed among experiments, being higher in Exp. 1 than in Exp. 2. Insect abundance was significantly lower in sunflower sole crops than in soybean crops and intercrops, in Exp 1 than in Exp. 2. Herbivore abundance did not differ among treatments but it was significantly higher in Exp. 2 than in Exp. 1. Concerning non-herbivore insects, abundance was higher in soybean than in the other treatments and similar between experiments (Table 4).

4. Discussion

4.1. Yield advantage of intercropping

Sunflower/soybean intercrops produced more grain yield per unit area than both sole crops, which indicates that intercropping is more profitable than sowing a single crop (i.e. LER greater than one, [8,26]. Over yielding observed in intercrops could be partly explained by resource use complementarity in time and space between different crops within intercrops [31]. Yield advantage of intercropping was due to yield in sunflower which did not differ from that in sole crops, while soybean yield was significantly lower in intercrops (Table 2). Contrasting yield responses in both crops could be explained by the differences in the canopy structures of sole and intercrops. On the one hand, sunlight reaching lower canopy layers would have been greater in intercropped sunflower due to wider row spacing, thus reducing self-shading and increasing the interception efficiency. Similar sunflower yields

Table 3
Weed species richness and abundance in sunflower/soybean sole crops and intercrop. Total values are means at plot level. Weed species were grouped according to life cycle into herbivores and non-herbivores. Different letters indicate that species richness or abundance means at the same row are significantly different among crop treatments to Tukey's test ($P < 0.05$).

Weeds	Richness					Abundance				
	Sole crops		Intercrops	P		Sole crops		Intercrops	P	
	Soybean	Sunflower		Treatments	Experiments	Soybean	Sunflower		Treatments	Experiments
Total	3.8a	6.5a	8.8a	ns	0.0001	0.8a	2.3a	2.4a	ns	ns
Annuals	2.5a	4.7a	6.1a	ns	0.0001	0.4a	1.6a	1.3a	ns	ns
Perennials	1.3a	1.4a	2.6a	ns	0.0001	0.4a	0.5a	1a	ns	0.0001

Table 4
Insect species richness and abundance in sunflower/soybean sole crops and intercrop. Total values are means at plot level. Insect morpho-species were arranged into feeding habit groups as herbivores and non-herbivores. Different letters indicate that species richness or abundance means at the same row are significantly different among crop treatments to Tukey's test ($P<0.05$).

Insects	Richness					Abundance				
	Sole crops		Intercrops	P		Sole crops		Intercrops	P	
	Soybean	Sunflower		Treatments	Experiments	Soybean	Sunflower		Treatments	Experiments
Total	5.6a	3.9b	3.8b	0,05	ns	15a	8b	13.8a	0.05	0.0007
Herbivores	2a	1.8a	1.8a	ns	0.04	7a	4.6a	10a	ns	0.002
Non-herbivores	3.6a	2.2ab	2b	0.03	ns	7.9a	3.3b	3.8b	0.007	ns

were obtained in crops sown at regular and at wider row spacing [32]. Since soybean sole crop was sown after sunflower, sunflower shaded soybean plants underneath, thus restricting the amount of resources available. In addition, resource demand by crops peaked during the species-specific critical period for seed number setting and seed filling, which corresponds to December-January for sunflower and February for soybean in the study region [33]. Besides, legume crops such as soybean, thanks to symbiotic fixation of atmospheric nitrogen, may alleviate soil nitrogen restrictions of accompanying non-legume crops, which may consequently improve the overall productivity. This alleviation could explain the lack of differences in weed abundance between intercrop and the respective sole crops, even tough intercrops have been observed to suppress weed growth [12,13]. Moreover, the use of relay intercropping, such as sunflower and soybean, cannot only improve land use efficiency [34], but it also prolongs the proportion of the growing season that is occupied with crops and therefore increases the overall resource capture. Thus, intercropping legume and non-legume crops appears as a feasible option for achieving a more ecological intensification of agriculture, which may help to produce more food per resource unit and simultaneously alleviate the negative effects on the environment [10].

4.2. Effects on weed assemblages

Species composition was quite different among sole crops and intercrops. Thus, when intensively managed and homogeneous cropping systems are diversified through intercropping, both planned and associated biodiversity are enhanced [1,11]. Main differences among assemblages were related to frequency or occurrence of species conforming floristic groups. Differences in species composition could be explained in the differences in weed management, canopy structure and resource capture among crops [31]. A group of species were common to all treatments whereas some group species were more frequent or occurred only in a particular cropping treatment (*i.e.* for intercrops *Convolvulus arvensis* L., *Chenopodium album* L., *Verbena gracilescens* (Cham.) Hert., *Conium maculatum* L., *Cynodon dactylon* (L.) Pers., *Gamochaeta spicata* (Lam.) Cabr., *Melica argyrea* Hack., *Plantago lanceolata* L., *Poa annua* L., *Sorghum halepense* (L.) Pers., *Verbena bonariensis* L. in Exp 1, *Sonchus oleraceus* L. *Amaranthus viridis* L. *Conyza bonariensis* (L.) Cronquist, *Trifolium repens* L. in Exp 2). However, species composition varied among years, probably related to differences in environmental conditions and field cropping histories. Weeds would have differently responded to the contrasts between crops seasons in the rainfall accumulated, which was higher in Exp. 1 (988 mm) than in Exp. 2 (678 mm). The same response was observed in previous research on sole crops in the Pampas [16,22,35–37]. On the other hand, differences could also be related to the availability of propagules, since both experiments were performed in fields belonging to different farmers.

We expected weed assemblages to be species-richer without increasing species abundance [8] because increasing crop richness enhances weed suppression through competition or allelopathy. However, weed species richness and abundance were similar among treatments. Weed abundance was very low and similar among treatments indicating that those mechanisms acted in a similar way and weed management was very effective in both cropping systems.

4.3. Effect on insect assemblages

As in the case of weeds, species composition was quite different among sole crops and intercrops. Main differences among assemblages were related to frequency or occurrence of species conforming faunistic groups and they could be explained by differences in weed communities [16], canopy structure and pest management among crops [38]. Differences in richness could be explained by variations in weed community structure, canopy structure and pest control practices among crops. A group of species were common to all treatments, whereas some group species were more frequent or occurred only in a particular cropping treatment (i.e. for intercrops Lonchopteridae, Pentatomidae in Exp 1, and Chalcididae, Chrysopidae, Empididae in Exp 2). The same response was observed in previous investigations in sole crops of the Pampas [16].

Although, as in the case of weeds assemblages, we expected insect assemblages to be richer in intercrops than in sole crops [8], we found the opposite response. The differences in insect richness may be related to the specific roles of each crop on insects. It was reported that sunflower attracts and plays host to numerous beneficial insects [39], while soybean is a good protein source for herbivores and, indirectly, for their associated non-herbivores [40]. This last mechanism could explain the higher richness of total and non-herbivore insects observed in soybean sole crops. Sunflower had the same or lower non-herbivores richness than the remaining treatments, suggesting that the attraction of beneficial insects was similar or lower than that in soybean.

Although intercrops are supposed to be richer without increasing species abundance because increasing crop richness enhances biological control or direct control of pests [40], we found higher insect abundance in intercrops and soybean sole crops than in sunflower and non-herbivores abundance was higher in soybean sole crop than in the rest of the treatments.

5. Conclusions

Current technological development in conventional cropping systems is supported by adequate agricultural research. Concerning intercropping, however, most information is based on low-input farming, while little knowledge has been produced in conventional and intensively managed farming systems. Here, we show that intercropping warm-season crops constitutes a feasible alternative to increase land productivity in conventional cropping systems in temperate regions, highly simplified after agricultural intensification, such as in the Southern Pampa. Moreover, intercropping may enhance heterogeneity within and between fields in space and time, and consequently promote higher planned and associated biodiversity at regional scale considering that species composition was quite different among cropping systems. Hence, our findings also show that intercropping promotes increasing yields per land unit, concurrent with previous findings in the subject. This practice in spatial or temporal rotation with sole crops, allows a rise in species richness at system scale and, in many cases, without increasing abundance of weeds competing with the crop or herbivores affecting crop yields. In addition, our results highlight that the main effect of intercropping on biodiversity is related to an increment of both planned and associated biodiversity, sustaining different weed and insect assemblages when compared with sole crops, as well as in cropping systems exclusively relying on chemical control practices to protect crops from biotic adversities. We conclude that intercropping sunflower and soybean is a feasible alternative for increasing land productivity in intensive farming systems, and hence farm income, in a more sustainable way than growing monoculture.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at http://dx.doi.org/10.1016/j.njas.2014.05.002.

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