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# Weed and arthropod communities in soyabean as related to crop productivity and land use in the Rolling Pampa, Argentina

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## Summary

In the Rolling Pampa, Argentina, changes in crop management caused changes in weed and arthropod communities and reductions in weed diversity in soyabean. Loss of landscape heterogeneity, caused by an increase in the area planted to soyabean, and herbicide treatment of field margins, may affect weed and arthropod assemblages and reduce species richness. This study focused on the effect of land use in neighbouring fields, weed management of field margins and crop productivity and history on weed and arthropod communities and their richness inside soyabean fields. Weeds and arthropods were surveyed in a total of 60 soyabean fields in 1999, 2001 and 2002. Neighbouring land use was determined in concentric circles of 500 and 1500 m radius around each field using LANDSAT images, and field margin management (sprayed or non-sprayed) was recorded. Data was analysed using regression and canonical correspondence analysis. Cropping history (number of years of cropping) and percentage of soyabean in concentric circles of 1500 m explained 23% of the variation in weed assemblages, whereas management of field margins and soyabean productivity (mean summer Normalised Difference Vegetation Index) explained 23% of the variation in arthropod assemblages. Perennial, dicotyledon and exotic weed richness and non-herbivore arthropod richness decreased with increasing percentage of soyabean in the surrounding landscape. Results show that weed and arthropod communities respond to different production and landscape variables and that increasing the area planted to soyabean and spraying field margins will put weed and arthropod species and functional groups at risk of extinction.

**Keywords:** diversity, field margins, functional groups, NDVI, species richness.

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## Introduction

In the agricultural mosaic of the Rolling Pampa (Argentina), landscape heterogeneity is mainly represented by the diversity in land use, the management of field margins and the presence of scattered areas with perennial vegetation. During the last decade, crop diversity decreased, perennial habitats were converted to arable fields and many field edge habitats were destroyed (Ghersa & León, 1999; Aizen *et al.*, 2009). Nowadays, transgenic soyabean (*Glycine max* (L.) Merr.) resistant to glyphosate, cultivated with permanent no-tillage is the main land use in this region. All these changes affected weed and arthropod community

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composition, causing a decrease in species diversity over time (de la Fuente *et al.*, 2006) and a decrease in landscape heterogeneity (Aizen *et al.*, 2009).

Although the relationship between biodiversity and agroecosystem function is an area of ongoing research and debate, many studies suggest that biodiversity supports long-term agroecosystem functioning, i.e. formation and retention of soil fertility, nutrient cycling by soil microbiota, retention of water and soil particles, resource capture by crops, resistance to pests and diseases and the ability to better withstand environmental disturbance (Balvanera *et al.*, 2006; Diaz *et al.*, 2006; Moonen & Barberi, 2008). Crop and weed plants in field and surrounding areas can host both herbivores and their natural enemies. Changes in plant productivity may cause changes in insect species richness (Bailey *et al.*, 2004). Changes in plant diversity may result in changes throughout the food chain (Marshall *et al.*, 2003; Norris & Kogan, 2005). Weeds can support auxiliary species, such as pest antagonists that could be useful in pest management. However, the benefits of weeds as a source of functional biodiversity should be weighed against the costs caused by crop-weed competition (i.e. crop yield loss) and the fact that they may host crop pests, as well as beneficial arthropods (Norris & Kogan, 2005).

Whether measured at a small or large scale, species richness is positively related with habitat heterogeneity in agricultural environments (Weibull & Östman, 2003; Purtauf *et al.*, 2005; Bennett *et al.*, 2006). Landscape heterogeneity causes bottom-up effects throughout the food chain via heterogeneity in resource distribution, plant community structure and diversity (Weibull *et al.*, 2003), plant growth and chemical composition of its tissues, the presence of refuges, and via the emission of odour and visual signals, which causes variability in the behaviour and movement of arthropods (Tilman & Pacala, 1993). The variability in land use and the degree to which habitats in the surrounding landscape are connected influence the diversity of species in a field (Aviron *et al.*, 2005; Bennett *et al.*, 2006). The landscape surrounding a crop field can serve as a source of species and signals; the degree to which the landscape influences processes and functions in the crop field depends on the nature and diversity of components in the landscape mosaic (Landis & Marino, 1999).

In the Rolling Pampa, increases in crop productivity and changes in management (number of years of cropping, tillage system, planting date) causes changes in weed and arthropod communities (de la Fuente *et al.*, 1999, 2003) and a reduction in weed diversity in soyabean (de la Fuente *et al.*, 2006). A reduction in the heterogeneity of the landscape due to a rapid increase in the proportion of the area devoted to soyabean and herbicide treatment of field margins, are expected to affect weed and arthropod community composition in soyabean and reduce within-field species richness.

The objectives of this study were: (i) to relate certain characteristics of the landscape surrounding soyabean fields, namely land use and weed management of field margins, and crop history and productivity, to weed and arthropod species assemblages in soyabean fields, and (ii) to relate the proportion of land planted to soyabean to weed and arthropod species richness in the soyabean crop, for various functional groups.

## Materials and methods

The Rolling Pampa is a sub-region of the Río de la Plata grasslands in Argentina (between 34 and 36°S and 58 and 62°W). It is uniform in appearance, topography, geomorphology, soil types and original vegetation. The landscape is a gently rolling plain (Soriano, 1991). The climate is temperate and humid; annual average rainfall is 1030 mm and annual average temperature is 16.9°C (INTA, 2009). Main crops are soyabean and, to a certain extent, maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) (INDEC, 2010).

The area chosen to perform the study is located in the central part of the Rolling Pampa and comprises a total of 600 km$^2$. This area is characterised by Argiudol soil, belonging to the Arroyo Dulce soil series (INTA, 1974), and uniform soyabean crop management practices, namely sown at the beginning of November, cultivated with GM soyabean resistant to glyphosate, no-tillage, glyphosate-based weed management (one application of 2 kg a.e. ha$^{-1}$ of glyphosate 3–5 weeks after planting) and uniform pest management (a single application of 112 g a.i. ha$^{-1}$ of cypermethrin against lepidopteran insects 3–5 weeks after planting).

A total of 60 fields, namely 21 in 1999, 19 in 2001 and 20 in 2002 of which half with sprayed and half with non-sprayed field margins were selected. The fields were selected randomly from a pool of 100 fields within the 600 km$^2$ area. Fields with large openings in the canopy cover or with different dominant species in different parts of the field were excluded. The fields covered *c.* 1500 ha per year, so 76 ha on average per field. The large sampling area ensured that practically all species present were indeed included in the survey; a field size of 76 ha is over three orders of magnitude larger than the minimum area needed to capture diversity in agricultural weed communities (Mueller-Dombois & Ellenberg, 1974).

### *Weeds and arthropods surveys*

Surveys were conducted between 15 January and 15 February each year. This time interval was chosen based on three criteria: (i) spring-summer and autumn-winter communities were present, (ii) chemical control had already been applied and (iii) the crops had reached maximum ground cover. Weed surveys consisted of a complete list of species present in the entire central area of each field and was done by two or more trained people walking across the field for at least 30 min. Headlands, 10 m into the field, and large depressions were avoided, because they may represent different habitats (i.e. different soil conditions). The percentage of cover-abundance of individual species was visually estimated, using an adapted Braun–Blanquet scale (Mueller-Dombois & Ellenberg, 1974), namely with the following intervals: 0–1%, 1–5%, 5–10%, 10–25%, 25–50%, 50–75%, 75–100% (de la Fuente *et al*., 2006; Perelman *et al*., 2007). Mean weed cover-abundance was estimated as the weed cover-abundance per field and per year, averaged over fields.

Only aerial arthropods were sampled, because they include most arthropods visiting soyabean (herbivores and non-herbivores) and they are likely to respond to landscape variables (Weibull *et al*., 2003). Arthropod sampling was carried out by means of a sweep net (Tonkyn, 1980) in three points located in the central zone of each field, avoiding headlands. Nets of 30 cm diameter were used and four net sweepings in each point. Sampling was carried out during a 7-day period, simultaneously with weed sampling, each day between 10:00 and 16:00. Arthropod morphospecies determination was performed at the level of order in all cases and at the level of family when possible. The voucher arthropod specimens documenting the morphotypes are available in the author's personal arthropod collection in the Faculty of Agronomy, University of Buenos Aires.

Weed species and arthropod morphospecies constancy were estimated as the percentage of fields containing a given species in a year. Richness was estimated as the total number of species present per year and per field, and mean field species richness as the number of species present per field and per year, averaged over fields (Whittaker, 1975; Magurran, 1988).

Functional groups, defined as clusters of species sharing resources, habitat, ecophysiological processes or life-history (Grime *et al*., 1990), are the principal determinants of communities' composition (Ghersa & León, 1999; Moonen & Barberi, 2008). Therefore and because functional groups were sensitive to within-field changes (de la Fuente *et al*., 2003, 2006), weed and arthropod species were classified into functional groups. Weed species were classified according to (i) life cycle: annual, biennial or perennial, (ii) morphotype: dicotyledons or monocotyledons and (iii) origin/distribution: native, exotic or cosmopolitan. Cosmopolitan species were defined as species occurring in at least two biogeographical regions. Arthropod morphospecies were classified into herbivores and non-herbivores. Habits and food preferences were based on anatomical characteristics and bibliography (Richards & Davies, 1984; Arroyo Varela & Viñuela Sandoval, 1991).

### *Analysis of the landscape surrounding each field*

Some characteristics of the landscape surrounding each of the soyabean fields were evaluated, namely weed management in field margins and land use in the area around each selected field. Field margins adjacent to each soyabean field were classified into sprayed or non-sprayed, based on information provided by the farmers. The proportion of the area in two concentric circles of 500 and 1500 m radius, centred around the middle of each soyabean field (78.5 and 706 ha, respectively), assigned to soyabean, maize, or pastures was estimated (see below). These radiuses were selected such that they included the soyabean field together with a small part of the adjacent fields (500 m radius) or the soyabean field area with most of the adjacent fields (1500 m radius) in the analysis.

Identification of land use was done using LANDSAT satellite images of the study area. The various crops differ in phenology and date of sowing and harvesting, such that two or three images taken at different periods during the season were sufficient to discriminate between soyabean, maize, or pastures (Guerschman *et al*., 2003). Images taken in spring, early summer and late summer dates were chosen. The choice of the exact date of the images depended on image availability, which was limited by the presence of clouds. Landsat images corresponded to path 226, row 84, in 1998–1999 and 2000–2001, and path 226 – row 84 in 2000–2001 central latitude (34°02′). Classification was done with LANDSAT 5 TM (30 m resolution) and LANDSAT 7 ETM (15 m resolution) on the following dates: 09 September 1998 (spring) Landsat 5, 12 November 1998 (spring) Landsat 5, 31 January 1999 (summer) Landsat 5, 06 September 2000 (spring) Landsat 7, 12 January 2001 (summer) Landsat 7, 05 February 2001 (summer) Landsat 5, 04 May 2001 (autumn) Landsat 7, 09 September 2001 (spring) Landsat 7 and 15 January 2002 (summer) Landsat 7.

Each selected field was located on topographic maps using drafts provided by the farmers and control points were taken with Global Positioning System. Then the Normalised Difference Vegetation Index (NDVI) was calculated for each field on each date. The NDVI was calculated as:

$$\mathrm{NDVI} = (\mathrm{NIR\text{-}R})/(\mathrm{NIR{+}R}) \qquad (1)$$

where NIR is the near-infrared light reflected by vegetation (μm) (band 4 in Landsat TM) and R is the red light reflected by vegetation (μm) (band 3 in Landsat TM). The NDVI is a measure of the 'greenness' of a field and can be used as a measure of vegetation productivity (Bailey *et al.*, 2004). Images were processed and analysed using the Arcview GIS 3.2 image processing package (ESRI, Redlands, CA, USA). Mean summer NDVI (total NDVI per field/number of pixels per field) is an indicator of the mean vegetation amount and soil cover during summer (Martínez & Gilabert, 2009).

Cropping history was determined as the number of years of continuous cropping since the conversion of pastures to crop land. This information was obtained from the farmers who owned the land.

The NDVI and the number of years of continuous cropping were chosen based on their importance in determining species richness in previous studies (de la Fuente *et al.*, 1999, 2003; Bailey *et al.*, 2004).

### Data analysis

Multivariate analysis was done using only species with constancy greater than 10%. Species with lower constancy are considered occasional (Mueller-Dombois & Ellenberg, 1974) and may obscure the analysis (ter Braak, 1987). Weeds and arthropods were analysed separately, using two ordination techniques for each group: indirect gradient analysis (correspondence analysis, CA, Hill, 1973) and direct gradient analysis (canonical correspondence analysis, CCA) using PC-ORD Multivariate Analysis of Ecological Data Version 5.0 (McCune & Mefford, 1999). Ordination helps to identify relationships between species composition at a site and the underlying environmental factors (Digby & Kempton, 1991). CCA constructs those linear combinations (axes) of explanatory variables along which the species distributions are maximally separated (ter Braak, 1987) and has a potential for examining the response of weed communities to various agronomic variables (Kenkel *et al.*, 2002). When constrained (CCA) and unconstrained (CA) ordinations display the same underlying pattern in species distribution, the explanatory variables have been correctly chosen. By applying CA ordination before CCA, the effect of canonical constraining can be objectively determined, because the ratio between the constrained total eigenvalue and the total inertia (a measure of the degree of correspondence between variables and sampling units of the matrix) measures the proportion of variation in species data explained by the environmental variables (Kenkel *et al.*, 2002).

The response variables used were cover-abundance for weeds and presence-absence (1–0) for arthropod morphospecies. The explanatory variables for both groups of response variables were the percentage of area with soyabean, maize and pastures in concentric circles of 500 and 1500 m radius centred around the centre of each soyabean fields, summer mean NDVI, field area and number of years of cropping (Table 1). Year of survey and weed management in field margins were included as dummy variables (0 = 1999, 1 = 2001 and 3 = 2002 and 0 = sprayed and 1 = non-sprayed).

**Table 1** Observed mean values (mean and standard deviation) for variables used as of the quantitative explanatory variables for the CCA of weed and arthropods

| Explanatory variables | Mean | Standard deviation |
|---|---|---|
| Field area (ha) | 76.3 | 31.6 |
| Field summer mean NDVI | 171.6 | 40.2 |
| Maize 1500 m (%) | 25.0 | 13.0 |
| Maize 500 m (%) | 13.0 | 21.0 |
| Pasture 1500 m (%) | 19.0 | 13.0 |
| Pasture 500 m (%) | 16.0 | 24.0 |
| Soyabean 1500 m (%) | 50.0 | 16.0 |
| Soyabean 500 m (%) | 68.0 | 34.0 |
| Years of cropping | 10.2 | 9.9 |

To determine associations between the data and the main explanatory variables, a biplot from the CCA was obtained by overlaying a vector diagram, based on coefficients from the canonical functions describing each canonical axis, on the ordination graph. Axis scores were centred and standardised to unit variance. A Monte Carlo randomisation test was performed to test the null hypothesis of no linear relationship between data matrices.

Regression analysis was used to relate the total richness per field of weed and arthropod species within functional groups (life cycle, morphotype and origin of weeds, herbivores and non-herbivores) with the percentage of the area in the surrounding landscape covered with soyabean.

## Results

### Weed and arthropod community composition

The total number of weed species recorded in this study was 62. More annuals (32 species) than perennials (21 species), annual-biennials (2 species) and biennial-perennials (1 species) were found. More dicotyledons (48 species) were found than monocotyledons (14 species) and more exotics (31 species) than natives (22 species) were present. Only three species, namely *Chenopodium album* L., *Cyperus rotundus* L. and *Sida rhombifolia* L., were cosmopolitan. *Triticum aestivum* and *Z. mays* were volunteer crops (Table 2). Weed species richness was 51, 27 and 48 and mean field weed species richness was 11.6, 7.3 and 9.8 in the 1999, 2001 and 2002 surveys respectively (Table 2).

**Table 2** Species list, code, function (origin, O; life cycle, C; morphotype, M), constancy, species richness per year, mean field species richness, mean constancy and mean cover-abundance of weeds surveyed in 1999, 2001 and 2002

| | | Function | | | Constancy (%) | | |
|---|---|---|---|---|---|---|---|
| Species | Code | O | C | M | 1999 | 2001 | 2002 |
| *Alternanthera philoxeroides* (Mart.) Griseb | altphi | n | p | dic | 5 | | |
| *Amaranthus quitensis* H.B.K. | amaqui | n | a | dic | 29 | 21 | 25 |
| *Ammis visnaga* (L.) Lam. | ammvis | e | a | dic | | | 5 |
| *Anoda cristata* (L.) Schtdl. | anocri | n | a | dic | 90 | 71 | 85 |
| *Artemisia annua* L. | artann | e | a | dic | 5 | | 15 |
| *Aster squamatus* (Spreng.) Hieronymus | astsqu | n | p | dic | 10 | | 10 |
| *Bidens subalternans* De Candolle | bidsub | n | a | dic | 33 | 14 | 15 |
| *Bowlesia incana* Ruiz et Pav. | bowinc | n | a | dic | | | 5 |
| *Carduus acanthoides* L. | caraca | e | a | dic | 38 | 7 | 20 |
| *Chenopodium album* L. | chealb | c | a | dic | 57 | 36 | 30 |
| *Cirsium vulgare* (Savi) Tenore | cirvul | e | a | dic | 5 | 14 | |
| *Convolvulus arvensis* L. | conarv | e | p | dic | | | 10 |
| *Conyza blakei* (Cabr.) Cabr. | conbla | n | a | dic | 19 | | 20 |
| *Coronopus didymus* (L.) Smith | cordid | n | a–b | dic | 5 | | 10 |
| *Coronopus* spp | corspp | | | dic | 5 | | |
| *Cucurbita andreana* Naudin | cucand | n | a | dic | 5 | | 20 |
| *Cynodon dactylon* (L.) Pers. | cyndac | e | p | mon | 14 | 21 | 20 |
| *Cyperus rotundus* L. | cyprot | c | p | mon | 24 | | 5 |
| *Cyperus* sp | cyspp | | | mon | 14 | 14 | 50 |
| *Dactylis glomerata* L. | dacglo | e | p | mon | | | 5 |
| *Datura ferox* L. | datfer | e | a | dic | 29 | 14 | 30 |
| *Dichondra microcalyx* (Hallier) Fabris. | dicmic | n | p | dic | 10 | | 10 |
| *Digitaria sanquinalis* (L.) Scopoli. | digsan | e | a | mon | 81 | 86 | 85 |
| *Echinochloa colonum* (L.) Link. | echcol | e | a | mon | 5 | | 10 |
| *Echinochloa crus-galli* (L.) Beauvois | echcru | e | a | mon | 14 | | 15 |
| *Eleusine indica* (L.) Gaertner | eleind | e | a | mon | 10 | | 5 |
| *Eragrostis* sp | eraspp | | | mon | 14 | | 5 |
| *Euphobia peplus* L. | euppe | a | e | dic | | 21 | |
| *Euphorbia dentata* Michx. | eupden | a | e | dic | 5 | | 15 |
| *Euphorbia lasciocarpa* Klotzsch | euplas | n | a | dic | 76 | 79 | 65 |
| *Fraxinus americana* L. | fraame | e | p | dic | 5 | 7 | 20 |
| *Galinsoga parviflora* Cavanilles | galpav | n | a | dic | 14 | | 10 |
| *Gamochaeta* sp | gamspp | | | dic | 5 | | 5 |
| *Gleditsia triacanthos* L. | gletri | e | p | dic | 10 | | |
| *Gnaphalium gaudichaudianum* DC | gnagau | n | a | dic | 5 | | |
| *Lamium amplexicaule* L. | lamamp | e | a | dic | 10 | | |
| *Lolium multiflorum* Lam. | lolmul | e | a | mon | | | 5 |
| *Medicago sativa* L. | medsat | e | p | dic | 14 | | 5 |
| *Melilotus albus* Medikus | melalb | e | a–b | dic | | | 5 |
| *Morus* sp | morspp | | p | dic | | | 15 |
| *Oxalis chrysantha* (Kunth.) Prog. | oxachr | n | p | dic | 43 | 21 | 10 |
| *Physalis viscosa* L. | phyvis | n | p | dic | 19 | 14 | 15 |
| *Polygonum aviculare* L. | polavi | e | a | dic | | 14 | |
| *Portulaca oleracea* L. | porole | e | a | dic | 52 | 86 | 60 |
| *Rumex crispus* L. | rumcri | e | p | dic | 10 | | 10 |
| *Setaria parviflora* (Poir.) Kerguelen | setpar | n | p | mon | 5 | | |
| *Sida rhombifolia* L. | sidrho | c | p | dic | 10 | 14 | |
| *Solanum chenopodioides* Lam. | solche | n | a | dic | 10 | | 5 |
| *Solidago chilensis* Meyer | solchi | n | p | dic | | | 5 |
| *Solanum* spp. | solspp | | | dic | 5 | | |
| *Sonchus oleraceus* L. | sonole | e | a | dic | 38 | 21 | 10 |
| *Sorghum halepense* (L.) Pers. | sorhal | e | p | mon | 67 | 57 | 45 |
| *Stellaria media* (L.) Vill. | stemed | e | a | dic | 48 | 7 | |
| *Tagetes minuta* L. | tagmin | n | a | dic | 48 | 14 | 20 |
| *Taraxacum officinale* Weber in Wiggers | taroff | e | p | dic | 48 | 14 | 30 |
| *Trifolium pratense* L. | tripra | e | p-b | dic | | | 10 |
| *Trifolium repens* L. | trirep | e | p | dic | 29 | 7 | 55 |

**Table 2** Continued

| Species | Code | Function O | Function C | Function M | Constancy (%) 1999 | Constancy (%) 2001 | Constancy (%) 2002 |
|---|---|---|---|---|---|---|---|
| *Triticum aestivum* L. | triaes | e | a | mon | 5 | 29 | 25 |
| *Verbena gracilescens* (Cham.) Hert. | vergra | e | p | dic | 5 | | 10 |
| *Veronica persica* Poir. | verper | e | a | dic | 29 | 14 | 10 |
| *Xanthium spinosum* L. | xanspi | n | a | dic | 5 | | |
| *Zea mays* L. | zeamay | n | a | mon | 24 | 14 | |
| Species richness per year | | | | | 51 | 27 | 48 |
| Mean field species richness | | | | | 11.6 | 7.3 | 9.8 |
| Mean constancy (%) | | | | | 22.8 | 27.1 | 20.3 |
| Mean cover-abundance (%) | | | | | 1.8 | 1.2 | 1.2 |

Weed species code: first three letters = genus, last three letters = species.
Function codes: native, n; exotic, e; cosmopolitan, c; annual, a; perennial, p; biennual, b; dicotyledons, dic; monocotyledons, mon.

Mean constancy was 22.8%, 27.1% and 20.3% in 1999, 2001 and 2002, respectively, and cover-abundance was 1.8%, 1.2% and 1.2% in 1999, 2001 and 2002 respectively. The values for constancy and cover-abundance of weeds were low and similar ($P > 0.05$) among surveys (Table 2), and were probably caused by weed control measures, which were very effective. Five species, namely *Anoda cristata* (L.) Schtdl., *Digitaria sanguinalis* (L.) Scopoli., *Euphorbia lasciocarpa* Klotzsch, *Sorghum halepense* (L.) Pers. and *Portulaca oleracea* L. had higher mean constancy values than the rest of the weed species (>50%; $P < 0.01$).

A total of 32 arthropod morphospecies, belonging to 10 different orders, were recorded. The richest orders were Hemiptera (10 morphospecies, 80% herbivores), Coleoptera (four morphospecies, 100% herbivores), Diptera (four morphospecies, 25% herbivores) and Lepidoptera (four morphospecies, 100% herbivores) (Table 3). Arthropod morphospecies richness was 25, 17 and 17, in 1999, 2001 and 2002, respectively, and mean morphospecies richness per field was 7.9, 3.1 and 3.9, in 1999, 2001 and 2002 respectively.

Most mean constancy values were low, ranging from 10 to 42% and similar ($P > 0.05$) among species (Table 3). Arthropod functional groups (herbivores and non-herbivores) could be assigned to 29 out of the 32 arthropod morphospecies (91%). Of these, 19 morphospecies were herbivores and 10 morphospecies were non-herbivores (Table 3).

### *Species–environment relationships*

Total inertia obtained with the CA was 3.8 for weeds and 5.17 for arthropods, explaining 23.2% and 22.6% of the total variation for weeds and arthropods respectively. Eigenvalues, representing the variance in the community matrix attributed to a particular axis, were 0.59 for axis 1 and 0.48 for axis 2 for the weed data, and 0.63 for axis 1, 0.49 for axis 2 for the arthropod data. Both ordination techniques (CA and CCA) showed similar contrasts of species in the first two ordination axes, and therefore only results of the CCA are shown.

The Monte Carlo randomisation test indicated significant ($P = 0.01$) linear relationship between the data matrices. The CCA provided results with regard to the main environmental variables associated with the occurrence of weeds and arthropods. Weeds were sorted in relation to the main axes, showing a total inertia of 3.81 and explaining 23.2% of the total variance. Eigenvalues were high for axis 1 and 2 (0.50 and 0.21, respectively), showing that a large part of the variation could be attributed to the measured variables. The main variables explaining weed assemblies were number of years of cropping [$r$ (inter-set correlation) = −0.81, axis 1], field summer mean NDVI ($r = -0.65$, axis 1), the proportion of soyabean ($r = -0.40$, axis 2) and maize ($r = 0.40$, axis 2) in concentric circles of 1500 m radius (Table 4). Axis 1 separated, for example, the species *D. sanguinalis* and *Echinochloa crus-galli* (L.) Beauvois, from *Euphorbia peplus* L. and *S. rhombifolia*. Cover-abundance increased with the number of years of cropping for the former set of species (Fig. 1, right), and decreased for the latter set of species (Fig. 1, left). Axis 2 separated, for example, *Cucurbita andreana* Naudin and *Artemisia annua* L., from *Eragrostis* spp. and *S. rhombifolia*. Cover-abundance increased with increasing proportion of maize and the decreasing proportion of soyabean in concentric circles of 1500 m for the former set of species (Fig. 1 top), and the other way around for the latter set of species (Fig. 1, bottom).

Arthropods were sorted in relation to the main axes, showing a total inertia of 5.17 and explaining 23% of the total variance in data. Eigenvalues were high for axis 1 and 2 (0.64 and 0.34, respectively). The main explanatory variables were field margin weed management [$r$ (inter-set correlation) = −0.74, axis 1] and soyabean

**Table 3** Order, family, code, function (herbivores, H; non-herbivores, NH), constancy, morphospecies richness per year, mean field morphospecies richness and mean constancy of arthropods surveyed in 1999, 2001 and 2002

| Order | Family | Code | Function | Constancy (%) 1999 | 2001 | 2002 |
|---|---|---|---|---|---|---|
| Araneae | | ara47 | NH | 38 | | |
| Collembola | | clb211 | NH | 44 | 14 | |
| Coleoptera | Curculionidae | col151 | H | 13 | 14 | 5 |
| Coleoptera | Chrysomelidae | col3 | H | 56 | 64 | 5 |
| Coleoptera | Melyridae | col30 | H | 44 | 21 | |
| Coleoptera | Chrysomelidae | col4 | H | 56 | 7 | |
| Diptera | | dip19 | NH | 31 | 7 | 11 |
| Diptera | Syrphidae | dip24 | NH | 31 | | |
| Diptera | Dolichopodidae | dip29 | NH | 13 | 21 | 16 |
| Diptera | | dip342 | | | | 53 |
| Hemiptera | Lygaeidae | hem121 | H | | | 32 |
| Hemiptera | Cicadellidae | hem14 | H | | 7 | 47 |
| Hemiptera | Cercopidae | hem150 | H | 13 | 14 | |
| Hemiptera | | hem161 | NH | 31 | | |
| Hemiptera | Cicadellidae | hem36 | H | | 7 | 37 |
| Hemiptera | Pentatomidae | hem39 | H | 38 | | 5 |
| Hemiptera | Membracidae | hem44 | H | 31 | | |
| Hemiptera | Cicadillidae | hem81 | H | 25 | 14 | |
| Hemiptera | Nabidae | hem89 | NH | 6 | 50 | 5 |
| Hemiptera | Aphididae | hom227 | H | 25 | 7 | |
| Hymenoptera | Scoliidae | hym10 | NH | | | 26 |
| Hymenoptera | | hym307 | | | | 21 |
| Hymenoptera | | hym336 | | | | 74 |
| Lepidoptera | | lep158 | H | 13 | | 11 |
| Lepidoptera | Pieridae | lep182 | H | 44 | | 5 |
| Lepidoptera | Noctuidae | lep193 | H | 63 | | |
| Lepidoptera | Noctuidae | lep194 | H | 25 | | |
| Neuroptera | Chrysopidae | neu65 | NH | 19 | 29 | 21 |
| Orthoptera | Acrididae | ort158 | H | 44 | 7 | |
| Orthoptera | Acrididae | ort172 | H | 13 | 7 | 16 |
| Thysanoptera | | thy202 | H | 50 | | |
| Thysanoptera | | thy203 | NH | 25 | 14 | |
| Morphospecies richness per year | | | | 25 | 17 | 17 |
| Mean field morphospecies richness | | | | 7.9 | 3.1 | 3.9 |
| Mean constancy | | | | 31.6 | 17.9 | 22.9 |

Arthropod morphospecies code: three-first letters, order; three last numbers, morphotype.

**Table 4** Inter-set correlations for explanatory variables in the two main axes of the CCA for weed species and arthropods morphospecies surveyed during 1999, 2001 and 2002

| | Inter-set correlations | | | |
|---|---|---|---|---|
| | Weeds | | Arthropods | |
| Explanatory variables | Axis 1 | Axis 2 | Axis 1 | Axis 2 |
| Field area | 0.25 | −0.15 | −0.14 | 0.18 |
| Field margins' weed management | −0.46 | −0.15 | −0.74 | −0.25 |
| Field mean summer NDVI | −0.65 | 0.05 | −0.38 | 0.62 |
| Maize in 1500 m | −0.11 | 0.40 | −0.09 | 0.17 |
| Maize in 500 m | 0.37 | 0.14 | 0.34 | 0.22 |
| Pasture in 1500 m | 0.34 | −0.22 | 0.04 | 0.17 |
| Pasture in 500 m | 0.37 | −0.13 | −0.03 | −0.34 |
| Soyabean in 1500 m | −0.55 | −0.40 | −0.26 | −0.35 |
| Soyabean in 500 m | −0.25 | −0.16 | −0.38 | 0.03 |
| Year of survey | 0.09 | −0.17 | 0.16 | −0.07 |
| Years of cropping | −0.81 | −0.21 | −0.15 | −0.12 |

NDVI, Normalised Difference Vegetation Index.

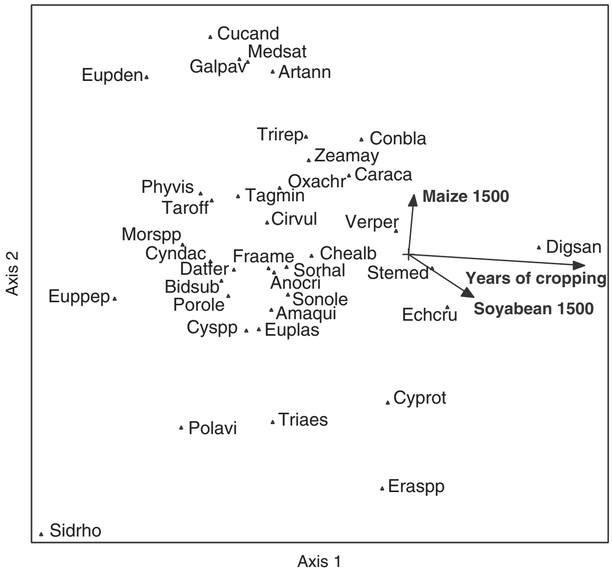

**Fig. 1** Ordination diagram of weeds (code: three-first letters, genus; two last letters, species) in the two principal axes of the CCA. The relative lengths of the arrows indicate the importance of a variable, for clarity, only major explanatory variables are included ($|r| > 0.7$, axis 1 and $|r| > 0.4$, axis 2).

mean summer NDVI ($r = 0.62$, axis 2). Non-sprayed field margins and high summer NDVI contrasted with sprayed field margins and low summer NDVI. Only a few morphospecies belonging to Hemiptera, Hymenoptera, Diptera and Neuroptera, were related to the sprayed field margins (Fig. 2, right), whereas many morphospecies belonging to Hemiptera, Lepidoptera, Coleoptera, Diptera, Orthoptera, Thysanoptera, Aranae and Collembola were related to non-sprayed field margins (Fig. 2, left). Low summer NDVI data, reflecting low crop productivity, were mainly related to Hemiptera and Hymenoptera morphospecies (Fig. 2, right and bottom). High summer NDVI were related to morphospecies belonging to Diptera, Thysanoptera, Orthoptera and Aranae and to several well-known soyabean pests, namely *Dichelops furcatus* F. and *Ceresa* sp. (Hemiptera), *Rachiplusia nu* (Guenée) and *A. gemmatalis* (Lepidoptera), *Cicloceraia* sp., *Astylus atromaculatus* Blanch. and *Diabrotica speciosa* Germar (Coleoptera).

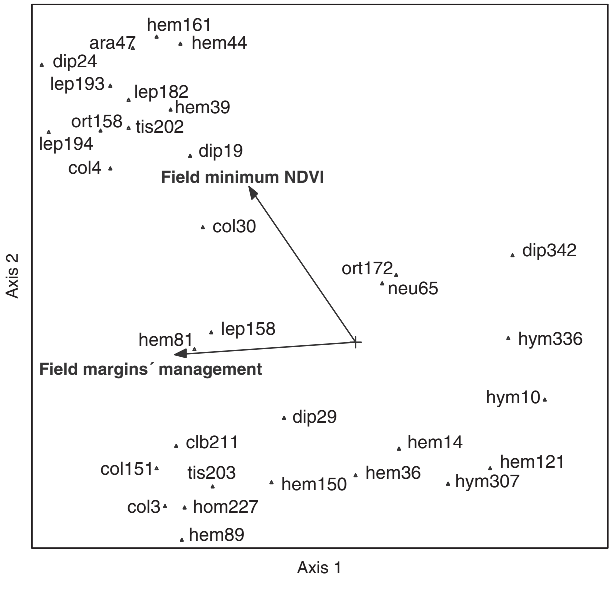

**Fig. 2** Ordination diagram of arthropods (code: three-first letters, order; three last numbers, morphotype) in the two principal axes of the CCA. The relative lengths of the arrows indicate the importance of a variable. For clarity, only major explanatory variables are included ($|r| > 0.7$ with axis 1 and $|r| > 0.4$ with axis 2).

Linear regression analysis showed that the richness of species within the functional categories of perennial, dicotyledon and exotic weeds, and of non-herbivorous arthropods decreased ($P < 0.01$) with increasing proportion of soyabean in concentric circles with 1500 m radius. Herbivorous arthropods and the other functional groups of weeds were unaffected by the proportion of soyabean (Fig. 3). Although the relationship between species richness within functional groups and the proportion of soyabean in the surrounding landscape was significant, the percentage variation accounted for by the regressions was low (0–24%). Apparently, other variables, not included in this study, were more important at determining the diversity in weed and arthropod assemblages.

## Discussion

Important explanatory variables of weed and arthropod assemblages in soyabean fields were the number of years of cropping and field mean NDVI (related to field productivity), neighbouring land use and field margin weed management (related to the landscape). Earlier studies had already indicated that weed abundance and arthropod incidence in the pampas region of Argentina were related to crop productivity (de la Fuente *et al.*, 1999, 2003, 2006; Mas *et al.*, 2010). However, there was little prior information on the relationship between weeds or arthropods and various elements of the surrounding landscape.

The relationship between the number of years of cropping and summer weed communities has been described before (de la Fuente *et al.*, 1999, 2003). Mean summer NDVI mainly reflected soyabean productivity, because mean weed cover-abundance was low. Because the NDVI is related to food quality and quantity for arthropods (Bailey *et al.*, 2004), the high number of orders and morphospecies of arthropods observed can be explained by the high NDVI values. Thus, it can be concluded that crop productivity is

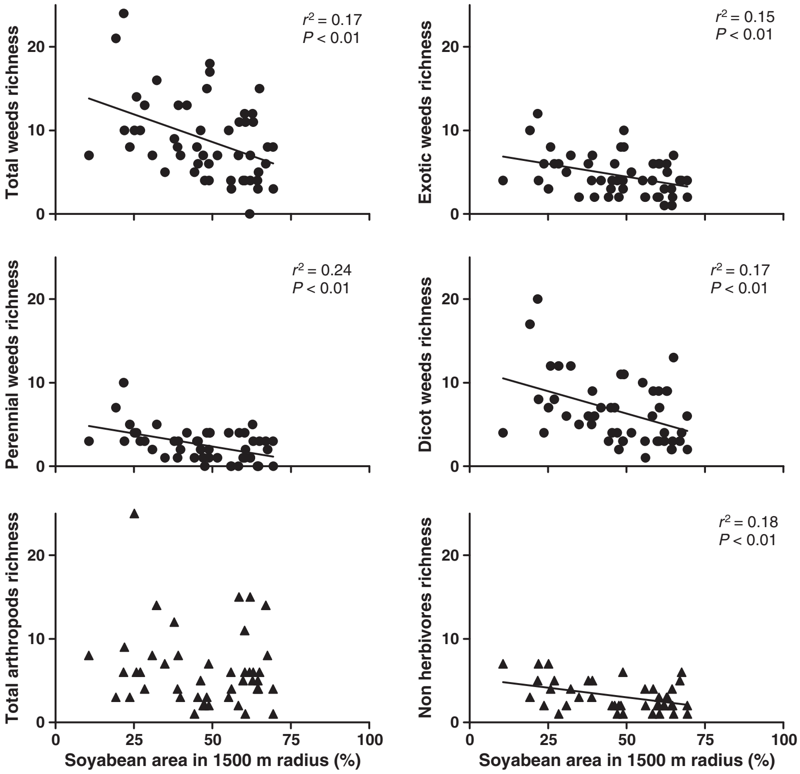

**Fig. 3** Linear regression of richness in total, perennial, dicotyledon and exotic weeds, total and non-herbivorous arthropods on the proportion of land planted with soyabean in concentric circles of 1500 m. The percentage variation accounted for and significance of the regression is included in each sub-graph.

one of the main drivers of weed and arthropod richness.

The proportion of soyabean fields in neighbouring land was negatively related to weed richness and cover-abundance, while weed management in field margins was positively related to the incidence of morphospecies of arthropods in soyabean fields. These results confirm earlier findings that the surrounding landscape influences the occurrence of species inside a crop field (Landis & Marino, 1999; Weibull & Östman, 2003; Aviron *et al.*, 2005; Bennett *et al.*, 2006). It is possible that the landscape characteristics 'neighbouring land use' and 'weed management in field margins' share characteristics, such as the diversity of habitats. A higher diversity of habitats may increase the species pool and facilitate the exchange of species that use multiple habitats during their life cycles (Purtauf *et al.*, 2005). Annual crop fields are cleared each year during harvest, so either yearly colonisation or long-term survival of durable propagules (e.g. seedbank) is required for species survival. Colonisation efficiency depends on the availability and distance to non-crop habitat and the dispersal ability of seeds and animals (Landis & Marino, 1999). The availability of multiple sources of diverse populations within the field and in the surrounding landscape, allows highly disturbed crop fields to be re-colonised annually by dispersing organisms and helps to maintain regional diversity (Weibull & Östman, 2003; Tscharntke *et al.*, 2005). For non-herbivores to reach an intensively managed soyabean crop field there must be source populations present in the neighbourhood. If the distance between refuges and the crop is larger than the dispersal capacity of the species, there will be few or no successes at colonising a site (Weibull & Östman, 2003).

Weeds and arthropods responded differently to neighbouring land use and weed management in field margins. Non-sprayed field margins are usually more diverse in habitats and experience disturbances at a lower frequency than do neighbouring crop fields. For these reasons, non-sprayed margins may favour plant species growing only in uncultivated land instead of weeds (Landis & Marino, 1999). In contrast, the yearly harvest and fallow period following harvest may favour the colonisation by weeds that infest via the influx of propagules or the persistent seedbank. The availability of nearby stable sites provided by non-sprayed field margins could help arthropods to complete their life cycle and to build up populations (Landis & Marino, 1999). The low number of orders and morphospecies of non-herbivores observed in soyabean fields surrounded by sprayed field margins suggests that many non-herbivorous arthropods are dependent on non-sprayed field margins (Pearce & Zalucki, 2006).

Properly managed field margins are known to provide alternative food sources, refuges and hibernation sites thus increasing populations of polyphagous predators (Landis & Marino, 1999). Farmers all over the world perceive non-sprayed field margins differently.

Costs of non-sprayed field margins, i.e. sources of potential weeds and pests, are perceived as being higher than benefits, i.e. reservoirs of natural enemies (Norris & Kogan, 2005). Consequently, the number of non-sprayed field margins is decreasing drastically, either because they now receive herbicide treatment, or because they are removed (Le Cœur *et al*., 2002). The current results suggest that not spraying field margins favours arthropod diversity and may save costs, because soyabean fields with sprayed and non-sprayed field margins did not differ in weed cover-abundance and costs related to herbicide application are avoided.

Complex agricultural landscapes that harbour diverse sets of activities seem to mitigate local species extinction caused by human activities (Tscharntke *et al*., 2005). If up to 70% of the surrounding landscape within a 1500 m radius of a field is occupied by soyabean fields, functional group diversity can be maintained. However, increasing the percentage of land devoted to soyabean above the 70% could result in the loss of some functional groups. Naeem *et al*. (1994) showed that the loss of species within a functional group decreases the probability that at least some species will survive in the case of changes in the environment. This increases the probability that the functionality will be lost altogether. In our case, species diversity within perennial, dicotyledon and exotic weeds and within non-herbivore arthropods decreased with increasing proportion of soyabean crops. In addition, richness of the rest of the functional groups was unaffected, resulting in a decrease in the following ratios: perennials/annuals, dicotyledons/monocotyledons, and exotics/natives for the weeds and non-herbivores/herbivores for the arthropods. The decrease in the ratio non-herbivores/herbivores may decrease the chances of non-herbivores in suppressing herbivore populations.

During the last decade, diversity in land use has declined and crop management has changed in the agricultural landscape of the Rolling Pampa, because soyabean has replaced other types of land use. As a consequence, biodiversity within fields was also reduced (de la Fuente *et al*., 2006). It is expected that this trend will continue in the future, unless the government intervenes or market factors change. The results of this work show that increasing the proportion of soyabean area in the landscape beyond 70%, or eliminating the vegetation from field margins, could put species and functional groups of arthropods and weeds at risk of local extinction and alter the relationship among some functional groups (i.e. perennials/annuals, dicotyledons/monocotyledons, and exotics/natives for the weeds and non-herbivores/herbivores for the arthropods). The role of farmers in managing biodiversity will be indispensable. They are the only ones that can diversify land use or stop spraying field margins. Their co-operation will be essential to avoid a reduction in beneficial species, such as non-herbivores, and an increase in dominant species.

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