Weed Science

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Weed Biology and Ecology

Weed Communities in Semiarid Rainfed Croplands of Central Argentina: Comparison between Corn (*Zea mays*) and Soybean (*Glycine max*) Crops

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Abstract

The semiarid Espinal in central Argentina, being recently transformed from natural semiarid grasslands into agriculture, represents an interesting scenario to understand the early stages of weed community assembly and its relationship with crop identity and management. Our aim was to characterize the weed communities in corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.], the main crops of the Espinal region, under the dominant rainfed conditions. Weed surveys were carried out in 53 fields, and farmers were interviewed to collect information about crop management. Floristic composition was compared within and between crops by calculating the additive partition of the abundance-based Bray-Curtis dissimilarity. We compared the frequency and mean cover of functional groups between crops through generalized linear models. Finally, canonical correspondence analysis was carried out to analyze the associations between floristic composition and agronomic variables. Mean alpha and gamma diversity was greater in corn (10.0 and 80 species, respectively) than in soybean (7.6 and 46 species, respectively). Furthermore, species composition of weed communities was more similar among soybean fields than among either cornfields or fields of both crops. Hence, floristic differences between crops are potentially the result of different microenvironmental heterogeneity above- and belowground, with corn likely to be more permissive to weed establishment compared with soybean. The higher frequency of annual, dicotyledonous, and native species, and the high proportion of rare species, mostly native, suggest a strong legacy of the original vegetation that thrived in these recently cultivated systems. The functional composition was also affected by agronomic management, with sulfur, nitrogen, and grass herbicide application being the most important factors related to the floristic composition of weed communities. This early description can be used as a starting point for studies concerning trajectories, mechanisms, and processes of weed communities related to environment and management.

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The global increase in food demand and the inception of new agricultural technologies to further increase yields, among other factors, have favored the expansion and intensification of crops worldwide (Foley et al. 2005; Matson et al. 1997). The rise of global agricultural production has been achieved not only by increasing yields through crop breeding and greater use of off-farm inputs, but also by introducing marginal lands into annual cropping (Tilman et al. 2011). Marginal lands for agriculture are not only less productive, but they are also usually more susceptible to degradation due to continuous, intensive farming. On the one hand, in arable lands recently converted to agriculture, the high productivity levels usually achieved in the first cropping seasons are the consequence of high soil fertility and low weed pressure, due to the maladaptation of the original vegetation to continuous farming (Martínez-Ghersa et al. 2000). On the other hand, in a crop field, weed species composition is assembled in response to both periodic and episodic agricultural interventions, such as burning, plowing, fertilization, and herbicide use. (Martínez-Ghersa et al. 2000). Therefore, current species composition of weed communities is also influenced by both the floristic composition of the original vegetation and the introduction of new species. Weed seedbank entangles the species compositions of past and current weed communities, which are in turn affected by recurrent farming practices, thus determining the future composition of weed communities and soil seedbank (Cardina et al. 2002).

Weed community structure and dynamics are determined by the environmental conditions created by agricultural practices, such as tillage systems, herbicide use, and cropping history

(Booth and Swanton 2002; Martínez-Ghersa et al. 2000). Furthermore, crop dominance over weeds is also a determining factor in weed community assembly. Crop dominance is defined as the structuring influence of dense and homogeneous stands of crop plants over the subordinated, companion weeds (Poggio and Ghersa 2011). Thus, weed composition may differ between contrasting crop types as a result of their differences in canopy architecture, physiology, row spacing, different resource use patterns, and management practices (Mas et al. 2010; Poggio and Ghersa 2011; Poggio et al. 2004). Among these factors, one of the most important ecological processes involved is the environmental changes resulting from crop canopy presence. Thus, the modification of the light environment under the crop canopy has a paramount influence on the morphology and phenology of crops and weeds (Ballaré and Casal 2000; Rajcan and Swanton 2001), and it also affects both dormancy release and germination of weed seeds (Benech-Arnold et al. 2000).

The expansion of agriculture to marginal lands with short histories of continuous farming and the introduction of new crop types provide interesting scenarios for studying weed community assembly. In central Argentina, agriculture has expanded westward from the humid Pampas toward the semiarid Espinal, primarily at the expense of converting native, xerophytic forest ecosystems into croplands (Demaría et al. 2008; Viglizzo et al. 2011). Corn (*Zea mays* L.)and, more recently, soybean [*Glycine max* (L.) Merr.] are the two main crop species in this semiarid region. In spite of the higher water limitation of this region, farmers have adopted similar agronomic strategies to those applied in the more humid Pampas (Viglizzo et al. 2011), including no-tillage cultivation and the use of herbicide-tolerant varieties. Massive adoption of no-tillage to replace plowing has contributed to reduce soil erosion risks and direct soil evaporation (Mendez and Buschiazzo 2010), two factors that impose severe limitations on growing field crops in the semiarid Espinal. Indeed, no-tillage allowed for the conversion of less productive, semiarid rangelands into annual cropping systems that are more profitable for farmers. Consequently, soybean is nowadays the most important crop type in this dry region. While soybean was introduced three decades ago, the main reason explaining its rapid expansion of soybean during the 1990s is the better adjustment of soybean to climatic limitations due to genetic improvement as well as the relatively higher profitability of growing soybean rather than other summer annual crops (Appendix A). Corn, which was the most important summer crop in the region for more than a century, is currently the second crop in acreage since the expansion of soybean took place (Garay and Colazo 2015; Appendix A). However, growing corn in crop sequences is considered a key practice to reduce the negative impacts of the soybean monoculture, such as the loss of organic soil matter in the topsoil (Díaz-Zorita et al. 2002).

Weed community assembly has been largely studied by focusing on crop management within fields (Booth and Swanton 2002; Poggio et al. 2004). Moreover, the prevalence of environmental and agronomic factors on the structuring of weed communities has been recognized for cropping systems in the humid Pampas (de la Fuente et al. 2006; Poggio et al. 2004, 2013). Thus, in the Rolling Pampa, the corn belt of Argentina, weed communities differed from cereal and legume crops in both the cool and warm seasons. Such differences were attributed to different canopy dynamics and resource use patterns (Poggio et al. 2004, 2013). In the drier conditions of the Espinal region, we also expected that the weed communities occurring in corn and soybean crops would be different, mainly due to the fact that both crops differ in their agronomic management and growth potential, which result from different physiology and resource use patterns.

Environmental filtering over weed communities could be explained by functional composition, in addition to floristic composition (Díaz et al. 1998). Grouping species into functional groups may help to understand ecological processes associated with management practices and differential environmental conditions due to crop identity that act by filtering and structuring weed communities (de Bello et al. 2010). Association of weed traits with agronomic practices could allow for the identification of plant species with potential capacity for growth in cropping systems and the implementation of proper action to prevent weed development (Légère and Samson 1999).

The ability to understand and predict weed community structure related to production practices could provide us with the opportunity of being proactive in an integrated weed management program (Légère and Samson 1999). Among the factors that can be considered important could be the identification of an appropriate crop for rotation (Froud-Williams 1986). Moreover, the effect of this crop and the other agronomic variables over weed communities could be useful for designing strategies for an integrated approach to crop production, thereby reducing the high input cost for chemical use (Derksen et al. 2002; Jordan and Hutcheon 1993). Characterizing and comparing the floristic and functional compositions of a weed community related to their agricultural system in an area recently transformed from natural grasslands are a valuable contribution to the study of ecological processes under weed community assembly. Here, our aim was to compare the weed communities of corn and soybean crops grown under the rainfed conditions prevailing in the Espinal region. We first characterized the taxonomic and functional group compositions of weed communities in corn and soybean crops and then analyzed the associations between weed communities and both agronomic management and yields of corn and soybean crops.

Materials and Methods

Study Area

The study was carried out in croplands in the province of San Luis, in central Argentina. The study area is located in the phytogeographic province of Espinal, which extends between −33.3°, −66.06° and −33.7°, −65.63° (Cabrera 1976; Figure 1). The climate is dry continental with cold winters and hot summers, with an average annual rainfall ranging between 400 and 600 mm from west to east (Appendix B; Anderson et al. 1970). Soils are typic Ustortent, characterized by the sandy loam texture and low soil organic carbon (0.94 % SOC; Peña Zubiate and d'Hiriart 2000). These sandy soils have excessive natural drainage and moderate susceptibility to wind erosion (Peña Zubiate and d'Hiriart 2007; Peña Zubiate et al. 1998). Most characteristic landscapes are slightly undulating and flat plains, where the original vegetation was an open forest of xerophytic trees from 8 to 10 m in height, scattered throughout a grassland matrix.

While land use gradually changed from extensive cattle grazing to a mixed production system during the last century, the recent conversion of rangelands to more intensive agriculture occurred in about a decade. Since the 1880s, extensive livestock grazing of natural rangelands, deforestation, and especially, the

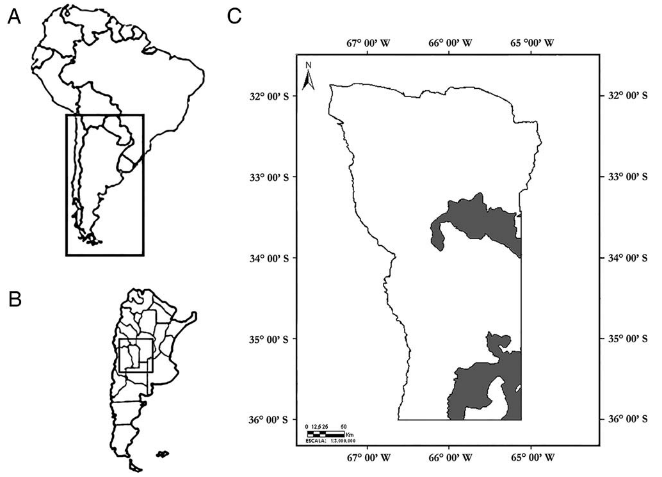

Figure 1. Study area: (A) South America, (B) Argentina, and (C) San Luis province, with the Espinal phytogeographical region shaded gray. (Adapted from soil and vegetation map in Peña Zubiate et al. 1998).

replacement of the natural vegetation by alfalfa-based pastures were the main transformations in this region. At the end of the 20th century, agriculture rapidly expanded to semiarid regions westward, which importantly promoted the conversion of both natural rangelands and pasturelands into annually cultivated croplands (Viglizzo and Frank 2006; Zak et al. 2008). Currently, the pristine Caldenal forest in San Luis represents the westernmost and driest limit of rainfed agriculture in central Argentina (Santoni et al. 2010).

Weed Surveys

All sample fields fulfilled the following requirements (Mueller-Dumbois and Ellenberg 1974): (1) survey area was large enough to contain all species belonging to the weed community (at least 25 to 100 m^2 for agricultural communities), (2) habitat conditions were uniform within the field area, and (3) crop cover was homogeneous. Field margins and low-topographic areas were excluded. Crop fields were randomly chosen by satellite image in an area of approximately 560 km^2, corresponding to the area of the same soil type (Peña Zubiate and d'Hiriart 2007; Peña Zubiate et al. 1998). Fifty-three fields were surveyed, determined principally by accessibility and by farmers' permission (24 soybean fields and 29 cornfields). Weeds in these fields were surveyed during a period of 2 wk in February 2014. This period corresponds to early and post-flowering of soybean and corn crops. In each field, three trained persons recorded weed cover in a zigzag pattern. Each person registered the weed cover in 10 parcels of 100 m^2 each, resulting in surveyed areas of approximately 3,000 m^2 in each field. Weed cover was estimated for each weed species by the adapted Braun-Blanquet method (Mueller-Dumbois and Ellenberg 1974).

Questionnaires to Farmers

After crop harvest, farmers were presented with a mixed questionnaire to collect information about current crop management and cropping history (i.e., time under continuous cropping, previous crop type, sowing date, farming type, seed type, fertilizations, herbicides, and yield). Not all farmers could be interviewed, because they were very difficult to locate after harvest, resulting in a subset of 38 sites with complete agronomic data (21 cornfields and 17 soybean fields, two or three of the same farmer in some cases).

Functional Classification of Weed Species

Weed species were classified according to their leaf type (monocotyledonous, dicotyledonous), photosynthetic pathway (C_3, C_4), and life cycle (perennial, annual) as an indicator of resource use; status (native, nonnative) as an indicator of original vegetation legacy; dispersion strategy (anemochory, zoochory, nonspecialized); and height (short, medium, tall). The grouping criteria for classifying plant height was in comparison with crops, taking the tallest crop, corn, as a reference (1.6- to 2.0-m high). The "short" category corresponds to plants shorter than 30 cm, always shaded; "medium" species are between 30 and 150 cm, slightly shaded, and almost at the same height as crops; "tall" species are taller than 160 cm. Finally, Légère and Samson (1999) determined that the classification scheme in annual/perennial, and monocotyledons/dicotyledons is particularly appropriate for describing herbicide selectivity patterns.

Data Analysis

The floristic structure of weed communities was analyzed through species diversity and composition, whereas functional structure was described by grouping species according to particular traits and common characteristics. Regional species richness (gamma diversity) was calculated for each crop and the entire survey. Gamma diversity is obtained by accumulating the total number of weed species, without repetition, that were registered in all surveyed fields. Mean species richness (field, local, or alpha diversity) was obtained by averaging the number of species found in each field of a given crop type. The frequency of species occurrence at a regional level (also denominated "constancy") and mean cover at field level were calculated for each species.

Floristic composition was compared within and between corn and soybean crops by calculating the additive partition of the abundance-based Bray-Curtis dissimilarity (Baselga 2013). Bray-Curtis dissimilarity ranges between 0 and 1, where 0 means that two fields have the same floristic composition (i.e., they share all weed species), whereas 1 means that two fields have totally different floristic compositions (i.e., they do not share any weed species). The abundance-based Bray-Curtis dissimilarity (d_{BC}) was separated into two components (Baselga 2013). One of them, the balanced variation component of the Bray-Curtis dissimilarity ($d_{BC\text{-}bal}$), represents the changes in species abundance between fields (i.e., the abundance of some species declines between two given fields in the same magnitude as the abundance of the other species increases between the same fields). The other one, the abundance gradient component of the Bray-Curtis dissimilarity ($d_{BC\text{-}grad}$), represents the decrease of weed abundance from one field to another. Values of both $d_{BC\text{-}bal}$ and $d_{BC\text{-}grad}$ were calculated with the function *bray.part* to compute the dissimilarities using the 'betpart' package (Baselga and Orme 2012). Abundance-based Bray-Curtis dissimilarity was then obtained by summing up both components ($d_{BC} = d_{BC\text{-}bal} + d_{BC\text{-}grad}$). Calculations were performed in R v. 3.3.3 (R Development Core Team 2014).

To analyze functional groups of weeds with good performance in semiarid agricultural systems, we compared the frequency and mean cover among functional groups between crops and for the whole data set. For analyzing the frequency of occurrence of weed

Table 1. Binomial and common names, family, dispersion strategy, life cycle, morphotype, origin, frequency, and mean cover for weeds species recorded in field surveys.[a]

							Frequency		Relative abundance	
Species	Common name	Family	Dispersion	Life cycle	Morphotype	Origin	Soybean	Corn	Soybean	Soybean
Amaranthus hybridus L.	Smooth pigweed	Amaranthaceae	Zoochory	Annual	D	N	33.33	37.93	0.4	0.61
Amaranthus palmeri S. Wats.	Palmer amaranth	Amaranthaceae	Zoochory	Annual	M	NN		6.9	0	1
Ambrosia tenuifolia Spreng.	False ragweed	Asteraceae	Zoochory	Perennial	D	N		3.45	0	1
Anoda cristata (L.) Schlecht.	Spurred anoda	Malvaceae	Zoochory	Perennial	D	N	4.17	10.34	0.29	0.71
Aristida mendocina Phil.	Flechilla crespa	Poaceae	Zoochory	Perennial	M	N		3.45	0	1
Bidens subalternans DC.	Greater beggarticks	Asteraceae	Zoochory	Annual	D	N	16.67	10.34	0.62	0.38
Borreria verticillata (L.) G. Mey.	Shrubby false buttonweed	Rubiaceae	Zoochory	Perennial	D	N		10.34	0	1
Bromus catharticus Vahl.	Rescuegrass	Poaceae	Zoochory	Annual	M	N		3.45	0	1
Cenchrus pauciflorus Benth.	Coastal sandbur	Poaceae	Zoochory	Annual	M	N	45.83	82.76	0.15	0.85
Chenopodium album L.	Lambsquarters	Chenopodiaceae	Zoochory	Annual	D	C	37.5	41.38	0.30	0.70
Citrullus colocynthis (L.) Schrad.	Colocynth	Cucurbitaceae	Zoochory	Perennial	D	NN	8.33	13.79	0.38	0.62
Clematis montevidensis Spreng.	Traveler's joy	Ranunculaceae	Anemochory	Perennial	D	N	4.17	13.79	0.23	0.77
Commelina erecta L.	Whitemouth dayflower	Commelinaceae	Nonspecialized	Perennial	M	N		10.34		1
Condalia microphyllia Cav.	Snakewood	Rhamnaceae	Zoochory	Perennial	D	N	4.17	6.9	0.37	0.63
Conyza blakei (Cabrera) Cabrera	Fleabane	Asteraceae	Anemochory	Annual	D	N		3.45		1
Conyza bonariensis (L.) Cronq.	Hairy fleabane	Asteraceae	Anemochory	Annual	D	N	62.5	44.83	0.51	0.49
Cucumis anguria L.	Burgherkin	Cucurbitaceae	Zoochory	Annual	D	N	45.83	51.72	0.35	0.65
Cynodon dactylon (L.) Pers	Bermudagrass	Poaceae	Nonspecialized	Perennial	M	NN	29.17	31.03	0.05	0.95
Cynodon hirsutus Stent	Hairy couchgrass	Poaceae	Anemochory	Perennial	M	N	8.33	6.9	0.29	0.71
Datura ferox L.	Chinese thorn-apple	Solanaceae	Nonspecialized	Annual	D	N	4.17	10.35	0.29	0.71
Descurainia erodiifolia (Phil.) Prantl ex Reiche	Mustard	Brassicaceae	Nonspecialized	Biennial	D	N		3.45		1
Dichondra sericea Sw.	Silverleaf ponysfoot	Convolvulaceae	Nonspecialized	Perennial	D	N		3.45		1
Digitaria californica (Benth.) Henr.	Arizona cottontop	Poaceae	Anemochory	Perennial	M	N		3.45		1
Digitaria sanguinalis (L.) Scop.	Large crabgrass	Poaceae	Anemochory	Annual	M	NN	29.17	48.27	0.5	0.5
Dysphania pumilio (R. Br.) Monsyakin & Clemants	Clammy goosefoot	Chenopodiaceae	Zoochory	Annual	D	NN	12.5	6.9	0.80	0.20
Eleusine indica (L.) Gaertn.	Goosegrass	Poaceae	Zoochory	Annual	M	C	4.17	6.9	0.38	0.62
Eragrostis cilianensis (All.) Vignolo ex Janchen	Stinkgrass	Poaceae	Anemochory	Annual	M	NN		13.79		1
Eragrostis curvula (Schrader) Nees	Weeping lovegrass	Poaceae	Anemochory	Perennial	M	NN		3.45		1

Table 1. *(Continued)*

							Frequency		Relative abundance	
Species	Common name	Family	Dispersion	Life cycle	Morphotype	Origin	Soybean	Corn	Soybean	Soybean
Eragrostis lugens Nees	Mourning lovegrass	Poaceae	Anemochory	Perennial	M	N		3.45		1
Eragrostis mexicana (Hornem.) Link	Mexican lovegrass	Poaceae	Anemochory	Annual	M	N	4.17	3.45	0.55	0.45
Euphorbia dentata Michx.	Toothed spurge	Euphorbiaceae	Nonspecialized	Annual	D	N		3.45		1
Euphorbia serpens Kunth	Creeping spurge	Euphorbiaceae	Nonspecialized	Perennial	D	N		24.14		1
Eustachys retusa (Lag.) Kunth	Argentine fingergrass	Poaceae	Zoochory	Perennial	M	N	8.33	6.9	0.55	0.45
Gaya parviflora (Phil.) Krapov.	Unknown	Malvaceae	Nonspecialized	Perennial	D	N	8.33	51.72	0.11	0.89
Geoffroea decorticans (Gillies ex Hook. & Arn.) Burkart	Chañar	Fabaceae	Zoochory	Perennial	D	N	4.17	3.45	0.55	0.45
Glandularia parodii Covas & Schnack	Mock vervain	Verbenaceae	Nonspecialized	Perennial	D	N		3.45		1
Hypochaeris chilensis (Kunth) Hieron.	South American catsear	Asteraceae	Anemochory	Perennial	D	N		3.45		1
Ibicella lutea (Lindl.) Van Eselt.	Yellow devil’s claw	Martyniacea	Nonspecialized	Annual	D	N		3.45		1
Ipomoea purpurea (L.) Roth	Tall morningglory	Convolvulaceae	Nonspecialized	Annual	D	N	8.33	10.35	0.45	0.55
Ipomoea rubriflora O’Donell	Scarlet morningglory	Convolvulaceae	Nonspecialized	Annual	D	N	8.33	3.45	0.71	0.29
Jodina rhombifolia (Hook. & Arn.) Reissek	Loose quebracho	Santalaceae	Zoochory	Perennial	D	N		6.9		1
Lucilia acutifolia (Poir.) Cass.	Unknown	Asteraceae	Anemochory	Perennial	D	N	4.17		1	
Lycium ferocissimum Miers	Boxthorn	Solanaceae	Zoochory	Perennial	D	N	4.17		1	
Mollugo verticillata L.	Carpetweed	Molluginaceae	Zoochory	Annual	D	N	8.33	6.9	0.55	0.45
Nassella tenuis (Phil.) Barkworth	Needlegrass	Poaceae	Zoochory	Perennial	M	N		3.45		1
Nassella tenuissima (Trin.) Barkworth	Finestem needlegrass	Poaceae	Zoochory	Perennial	M	N		6.9		1
Oxalis corniculata L.	Creeping woodsorrel	Oxalidaceae	Zoochory	Perennial	D	C		6.9		1
Pappophorum pappiferum (Lam.) Kuntze	Limestone pappusgrass	Poaceae	Anemochory	Perennial	M	N	16.67	10.35	0.62	0.38
Physalis viscosa L.	Grape groundcherry	Solanaceae	Zoochory	Perennial	D	N	12.5		1	
Piptochaetium napostaense (Speg.) Hack.	Speargrass	Poaceae	Zoochory	Perennial	M	N		10.35		1
Plantago patagonica Jacq.	Woolly plantain	Plantaginaceae	Zoochory	Annual	D	N		3.45		1
Portulaca grandiflora Hook.	Rose moss	Portulacaceae	Nonspecialized	Annual	D	N	12.5	27.59	0.31	0.69
Portulaca oleracea L.	Common purslane	Portulacaceae	Nonspecialized	Annual	D	C	45.83	48.28	0.64	0.36
Prosopis caldenia Burkart	Calden/mesquite	Fabaceae	Zoochory	Perennial	D	N	12.5	20.69	0.38	0.62
Pseudognaphalium gaudichaudianum (DC.) Anderb.	Weedy cudweed	Asteraceae	Anemochory	Annual	D	N	8.33	17.24	0.33	0.67

Table 1. (*Continued*)

							Frequency		Relative abundance	
Species	Common name	Family	Dispersion	Life cycle	Morphotype	Origin	Soybean	Corn	Soybean	Soybean
Rhynchosia senna Gillies ex Hook.	Texas snoutbean	Fabaceae	Zoochory	Perennial	D	N		3.45		1
Salpichroa origanifolia (Lam.) Baill.	Lily-of-the-valley vine	Solanaceae	Zoochory	Perennial	D	N		3.45		1
Salsola kali L.	Common saltwort	Chenopodiaceae	Anemochory	Annual	D	C	58.33	68.97	0.26	0.74
Salvia reflexa Hornem.	Lanceleaf sage	Lamiaceae	Zoochory	Perennial	D	NN		3.45		1
Schinus fasciculatus (Griseb.) I. M. Johnst.	Peppertree	Anacardiaceae	Anemochory	Perennial	D	N		3.45	0.38	0.62
Schkuhria pinnata (Lam.) Kuntze ex Thell.	Pinnate false threadleaf	Asteraceae	Anemochory	Annual	D	N	4.17	3.45	0.55	0.45
Secale cereale L.	Cereal rye	Poaceae	Zoochory	Annual	D	NN	4.17		1	
Senecio ceratophylloides Griseb.	Narrow-leaved groundsel	Asteraceae	Anemochory	Perennial	D	N		20.69		1
Setaria leucopila (Scribn. & Merr.) K. Schum.	Streambed bristlegrass	Poaceae	Zoochory	Perennial	M	N	4.17		1	
Sida rhombifolia L.	Arrowleaf sida	Malvaceae	Zoochory	Annual	D	N		3.45		1
Sida spinosa L.	Prickly sida	Malvaceae	Zoochory	Perennial	D	N	4.17	3.45	0.55	0.45
Solanum elaeagnifolium Cav.	Silverleaf nightshade	Solanaceae	Zoochory	Perennial	D	N	4.17	3.45	0.55	0.45
Sorghum halepense (L.) Pers.	Johnsongrass	Poaceae	Zoochory	Perennial	M	NN	29.17	27.59	0.51	0.49
Sphaeralcea bonariensis (Cav.) Griseb.	Latin globemallow	Malvaceae	Zoochory	Perennial	D	N	29.17	20.69	0.59	0.41
Sporobolus cryptandrus (Torr.) Gray	Sand dropseed	Poaceae	Anemochory	Perennial	M	NN	4.17	3.45	0.55	0.45
Tagetes minuta L.	Wild marigold	Asteraceae	Zoochory	Annual	D	N		3.45		1
Taraxacum officinale G. H. Weber ex Wiggers	Dandelion	Asteraceae	Anemochory	Perennial	D	NN		3.45		1
Tragus berteronianus Schult.	Spiked bur grass	Poaceae	Zoochory	Annual	D	N		3.45		1
Tribulus terrestris L.	Puncturevine	Zigophyllaceae	Zoochory	Annual	D	C	8.33	20.69	0.19	0.81
Trichloris pluriflora Fourn.	Multiflower false Rhodes grass	Poaceae	Anemochory	Perennial	M	N		3.45		1
Verbascum thapsus L.	Common mullein	Scrophulariaceae	Zoochory	Biennal	D	NN		3.45		1
Xanthium spinosum L.	Spiny cocklebur	Asteraceae	Zoochory	Annual	D	N	3.45			1

[a] Abbreviations: D, dicotyledons; M, monocotyledons; N, native; NN, nonnative (exotics and cosmopolitans).

species, we carried out a binomial generalized linear model, using the *logit link* function and compared by chi-square test. For mean cover analyses, we carried out a generalized linear mixed model, using Poisson distribution and *log link* function and compared by Fisher's LSD. The analysis was performed with R v. 3.0.3 (R Development Core Team 2014).

Canonical correspondence analysis (CCA) was carried out to analyze the associations between floristic composition and agronomic variables ('vegan' package in R; Oksanen et al. 2015). The analysis was performed considering species present in more than 10% of the surveyed fields. Species present in less than 10% of fields were considered of rare occurrence (Perelman et al. 2001). Agronomic variables used were time of continuous cropping (years), sowing date (Julian days), previous crop type, fertilization (nutrient and dose in kg ha^{-1}), herbicide use, and grain yield expressed as energetic units (Penning de Vries et al. 1983). Due to the different energetic content in seeds of corn and soybean, grain yield was standardized by dividing each data by the mean yield of each crop of the data set.

Results and Discussion

Floristic Comparison

Eighty-six weed species were recorded in the fields grown with corn and soybean crops surveyed in the Espinal region. Sixty species had frequencies lower than 10%, which included 32 species that were found only at a single site. This high proportion of rare species, mostly native annuals, suggests a strong presence of the original vegetation in these recently cultivated systems (Table 1). Twenty-six botanical families were represented in the 77 species that were taxonomically determined (7 rare species remained unidentified due to their nonreproductive phenological stage, while 2 were volunteer crops). Poaceae (24 species) and Asteraceae (13 species) families comprised the largest numbers of species of monocotyledons and dicotyledons, respectively (Table 1).

The weed community in cornfields was more species rich than that of soybean at both local (field) and regional scales. Mean alpha diversity at field scale (species richness) was greater in corn (10.0 species) than in soybean (7.6 species; Kruskal-Wallis, P = 0.023). Total number of species surveyed in the study region (gamma diversity) was also greater in corn (80 species) than in soybean (46 species). Greater diversity in corn was due to the presence of more rare species, which were mostly native (Tables 1 and 2). Moreover, most species listed in cornfields had a greater frequency of occurrence at the regional level than in soybean fields (Figure 2). Our findings concur with previous observations at both field and regional scales in the Rolling Pampa of Argentina, where weed communities were more species rich in cornfields than in soybean fields (Poggio et al. 2013). In the same region, weed communities harbor more species in field pea (*Pisum sativum* L.) crops than in wheat (*Triticum aestivum* L.) crops (Poggio et al. 2004).

Species composition of weed communities was also more variable in corn than soybean. Similarity between soybean fields was higher (low d_{BC}) than between either cornfields or fields of both crops (Figure 3), whereas species abundance was almost equal between fields ($d_{\mathrm{BC\text{-}grad}}$). In addition, distributions of dissimilarity measures for cornfields or between fields of both crops were highly similar in terms of median, quantiles, and range values (Figure 3). In the cropping environments prevailing in the semiarid Espinal, our findings indicate that weed communities are less variable among soybean crops (i.e., low beta diversity) than among corn crops (i.e., high beta diversity).

Our results provide further indication that contrasting crop types, such as cereals and legumes, can impose different filtering effects on companion weed communities, which will consequently result in the occurrence of a different number of species.

Table 2. Binomial generalized linear model to compare the frequency of functional groups in corn and soybean crops.[a]

Functional classification	Categories	Corn	Soybean	Parameters[b]
Morphotype	Dicotyledonous	65.7 a	70.8 a	Crop: NS
	Monocotyledonous	34.3 b	29.2 b	Morphotype: $\chi^2 = 158.5$, df = 1, $P < 0.0001$
Photosynthetic pathway	C_3	40.5 b	42.3 b	Crop: NS
	C_4	53.6 a	53.9 a	Photosynt: $\chi^2 = 4.57$, df = 1, $P = 0.03251$
Origin	Natives	65.7 a	70.8 a	Crop: NS
	Nonnatives	34.3 b	29.2 b	Status: $\chi^2 = 176.6$, df = 1, $P < 0.0001$
Life cycle	Annuals	62.3 a	69.3 a	
	Perennials	37.7 b	30.7 b	Crop × cycle : $\chi^2 = 6.358$, df = 1, $P = 0.01169$
Dispersal strategy	Anemochory	28.4 b	32.5b	
	Zoochory	54.4 a	56.0 a	
	Nonspecialized	17.2 bc*	11.6 c	Crop × dispersal : $\chi^2 = 4.8434$, df = 2, $P = 0.08877$
Plant height	Short	8.4 c	9.8 c	Crop: NS
	Medium	60.4 a	56.4 a	Height: $\chi^2 = 282.75$, df = 2, $P < 0.0001$
	Tall	25.3 b	30.2 b	

[a] Different lowercase letters indicate significant differences within each functional classification group, according to chi-square test.

[b] Abbreviation: NS, not significant; photosynt, photosynthetic pathway.

*$P < 0.1$.

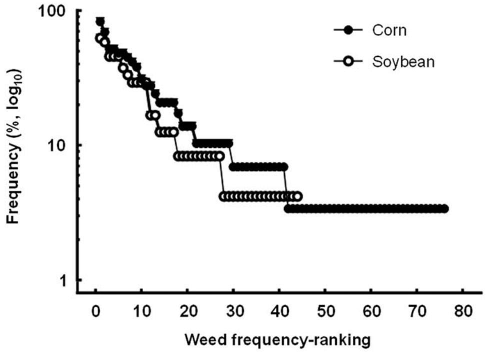

Figure 2. Percent frequency of weed species (log 10) as a function of the frequency ranking in the communities of corn and soybean crops.

An experiment carried out in Oklahoma, USA, evaluated the species diversity of weed communities occurring in contrasting crop species and showed that corn monocultures had the highest weed richness, while soybean monocultures presented the most weed species–poor communities (Palmer and Maurer 1997).

Differences in crop identity that differ starkly in their canopy and rhizosphere structures may create different microenvironmental heterogeneity above- and belowground (Gao et al. 2010; Gitelson et al. 2014), which potentially allows for the occurrence of some weed species adapted to the specific crop environment, while other species are filtered out (Booth and Swanton 2002; Swanton et al. 1993). Corn canopies rarely reach complete ground cover, so radiation interception is rarely maximum in productive conditions (Maddonni et al. 2001). Conversely, soybean canopies often eventually reach full ground cover, which consequently restricts the proportion of sunlight reaching the ground, reducing available light for weed development (Pengelly et al. 1999). In addition, corn crops are usually sown with lower seeding rates and wider row spacing than soybean crops (3 and 18 plants m^{-2}, respectively, in the Espinal region [JA Garay, personal communication]). This difference in density and spatial arrangement of crop plants may also result in more open canopies in corn than soybean crops. Contrasting crop species may differentially modulate the species diversity of weed communities by restricting the sunlight and modifying the light quality and thermal environments of the canopy understory (Poggio and Ghersa 2011). However, canopy structure effects may have greater impact on weed richness in small areas (e.g., 1 to 100 m^2), where competition is important, while other factors, such as spatial heterogeneity in soil and climate, would have greater influence on weed richness at landscape and regional scales (100 ha to 1,000 km^2) Thus, contrasting crop types may also have different effects on the variation in weed species composition between fields in a region.

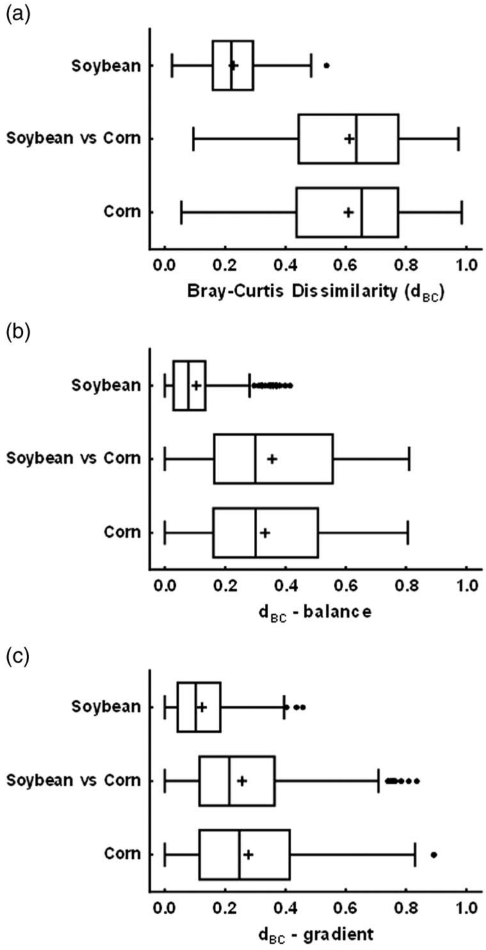

Figure 3. Box plots of the abundance-based Bray-Curtis dissimilarity (d_{BC}) and its additive partition into the balance ($d_{BC\text{-bal}}$) and gradient ($d_{BC\text{-grad}}$) components. The three dissimilarity measures were calculated to compare the species composition within corn and soybean and between both crops. Crosses within boxes are mean values.

Our observations in the Espinal are in agreement with previous research in the more humid conditions prevailing in the Rolling Pampa, where weed species composition was less variable between soybean fields than between cornfields (Poggio et al. 2013). Most of the variation in weed species composition at farmland scale was related to the interactions between crop types and management differences among neighboring farmers in the landscape (Hyvönen et al. 2005). In an extensive cross-regional weed survey carried out in France, crop type also had a significant influence on species composition, particularly between crops sown in different seasons; thus, winter cereals had greater beta diversity (low similarity) compared with spring cereals or sugar beet (*Beta vulgaris* L.) (Fried et al. 2008). Although different weed communities were also identified in cereals and oilseed crops in Sweden, crop type was less influential than other environmental variables with greater impact on weeds, such as crop sowing season, geographical region, and soil type (Hallgren et al. 1999). In the present study, differences in species composition between corn and soybean crops would have become evident because weed surveys were carried out in a relatively homogeneous region in terms of soil types, climate, and land use. Our findings thus provide evidence supporting the concept that factors explaining the variation in species composition of weed communities are scale dependent (Hyvönen et al. 2005). Hence, weed communities can be mostly modulated by factors defining landscape complexity at the regional level, while structure of local communities in small patches is mainly determined by interactions and habitat heterogeneity, which may result from soil fertility and microdisturbances (Poggio 2012).

Functional Composition Was Similar between Corn and Soybean

The frequency of functional groups was quite similar between both crops (Table 2), except for a higher frequency of species with nonspecialized dispersion strategies, but with marginal significance. The absence of differences in frequency of functional groups between crops indicates that the functional composition of the weed community may be principally determined by macroclimatic conditions rather than local biotic mechanisms (Poggio 2012). The higher frequency of annual, dicotyledonous, and native species (Table 2) likely resulted from the relatively recent inception of row-crop agriculture in the semiarid Espinal (Froud-Williams 1986). Evidence indicates that annuals and dicotyledons decrease as time of continuous no-tillage management increases (de la Fuente et al. 1999, 2006; Mas et al. 2010). In addition, medium-height species could have been favored by intermediate light interception conditions in comparison with the more shaded, short species and the rarer, shorter native species (Anderson et al. 1970). Some native perennial woody species were also present, and the higher cover of tall species reflects their presence. Croplands in central Argentina come from the conversion of forest (González-Roglich et al. 2015), where no-tillage technologies were adopted immediately. These conditions favor woody species expansion, and the system will probably result in an increase in their abundance through time (Ghersa et al. 2002).

There are differences in the cover of species among functional groups of weed communities in the Espinal region, where weed communities differed between corn and soybean (Table 3). There is evidence that crops limit weed abundance through competition, principally for light (Mhlanga et al. 2016), and although we have not demonstrated this, our results agree with this idea. Many of the rare species present, principally in corn, are perennial (probably due to the early successional stage of these agricultural soils) and are associated with no-tillage practices (de la Fuente et al. 1999). Differential crop competitive effects of corn and soybean on the accompanying weeds may be the main driver of the different weed community structures observed between these crops, which concurs with previous research (Poggio et al. 2004).

Table 3. Generalized linear mixed model for cover data, with Poisson distribution and log link function.[a]

Functional classification	Categories	Corn	Soybean
Morphotype	Dicotyledonous	0.9 ± 0.14 c	1.1 ± 0.27 c
	Monocotyledonous	5.2 ± 2.23 a	1.8 ± 0.85 b
Life cycle	Annuals	2.2 ± 0.65 a	1.6 ± 0.43 a
	Perennials	1.7 ± 1.16 a	0.4 ± 0.05 a
Origin	Natives	1. 7 ± 0.42 ab	1.2 ± 0.28 b
	Nonnatives	2.4 ± 1.30 a	1.5 ± 0.79 b
Dispersal strategy	Anemochory	1.5 ± 0.63 bc	1. 7 ± 0.54 b
	Zoochory	2.5 ± 0.84 a	0.8 ± 0.16 de
	Nonassisted	0.5 ± 0.10 e	1.0 ± 0.72 cd
Metabolism	C_3	1.2 ± 0.29 bc	0.9 ± 0.21 c
	C_4	3. 5 ± 1.33 a	1.8 ± 0.79 b
Height	Short	0.7 ± 0.19 bc	1.0 ± 0.72 b
	Medium	1.0 ± 0.2 b	0.6 ± 0.08 c
	Tall	2.3 ± 0.32 a	1.8 ± 0.24 a

[a] Comparisons were made within each functional classification. Lowercase letters indicate differences at $P < 0.05$ by Fisher's LSD test.

Weed Community Structure Was Related to Crop Management

Floristic and functional composition was also affected by the different agronomic management in corn and soybean crops (Table 4; Figures 2 and 3). Our results are also in agreement with previous research (Pyšek and Leps 1991), in which fertilizers were found to have a significant effect on the species composition of weed communities. While mean sowing dates were similar between crops, corn was sown during a more extended range of dates (i.e., from early to late dates). This longer period provides more opportunities for the establishment of species, especially those with several cohorts per season, like coastal sandbur (*Cenchrus pauciflorus* Benth.) (Lemes et al. 1993), which was the most frequent species in corn (Table 1). There was high variability in amounts of fertilizer added among fields (coefficient of variation varied between 37% and 88%, evaluated by nutrient and crop). No differences were seen in sulfur use between crops, whereas corn received higher doses of nitrogen and phosphorous than soybean crops. Sulfur and nitrogen were important factors in determining floristic composition (Figure 4). In almost all soybean fields, fallow was followed by application of broadleaf and broadleaf–grass herbicides, whereas PRE herbicides were more

Table 4. Agronomic variables of corn and soybean crops in 38 sampling sites.[a]

Agronomic variables	Corn	Soybean
Grain yield (kg ha^{-1})	4775.95 ± 500.71	2784.41 ± 233.70
Glucose yield (GJ/ha)	107.0 ± 10.4 a	85.5 ± 8.2 a
Mean sowing date (range between earliest and latest sowing dates)	November 19, 2013 (October 5 and December 30)	November 18, 2013 (November 1 and December 20)
No-tillage	100%	100%
Previous crop (% of fields)		
Soybean	76.2	10
Corn	14.3	90
Sorghum	9.5	—
Fertilization rates (kg ha^{-1})[b]		
Nitrogen	26.8 a (88)	7.6 b (13)
Phosphorus	34.6 a (71)	9.8 b (40)
Sulfur	5.1 (29)	6.8 (33)
Herbicides (% of fields)[c]		
Fallow	89.5	100
POST	100	93.3
PRE/early POST	85	20
Broadleaf	79	100
Grass	5.3	13.3
Broadleaf–grass	100	93.3

[a] Lowercase letters indicate differences among crops.

[b] Kruskal-Wallis test, $P < 0.05$. Numbers in parentheses for fertilization rates indicate the percentage of fields treated.

[c] Herbicides: glyphosate (mean dose: 1.68 L ha^{-1}); dicamba (mean dose: 0.1 L ha^{-1}); atrazine (mean dose: 1.37 kg ha^{-1}); 2,4-D (mean dose: 0.6 L ha^{-1}); haloxyfop (0.11 L ha^{-1}); chlorimuron (0.04 kg ha^{-1}). Applied herbicides with no dosage data: diclosulam; imazethapyr; clethodim; imazapic + imazapyr; sulfentrazone.

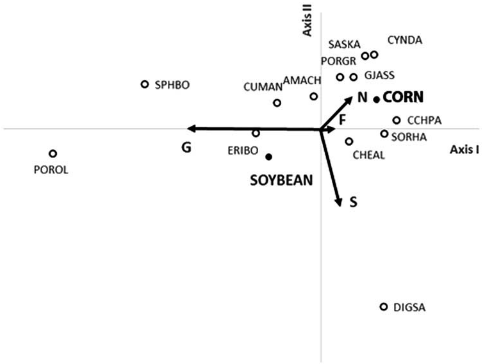

Figure 4. Ordination diagram from canonical correspondence analysis. Abbreviations: AMACH, *Amaranthus hybridus*; CCHPA, *Cenchrus pauciflorus*; CHEAL, *Chenopodium album*; CORN, corn crop; CUMAN, *Cucumis anguria*; CYNDA, *Cynodon dactylon*; DIGSA, *Digitaria sanguinalis*; ERIBO, *Conyza bonariensis*; F, fertilization; G, grass herbicide; GJASS, *Gaya parviflora*; N, nitrogen fertilization; PORGR, *Portulaca grandiflora*; POROL, *Portulaca oleracea*; S, sulfur fertilization; SASKA, *Salsola kali*; SORHA, *Sorghum halepense*; SOYBEAN, soybean crop; SPHBO, *Sphaeralcea bonariensis*. Eigenvalues: axis 1: 0.397; axis 2: 0.312. Proportion explained by axes: axis 1: 0.2335; axis 2: 0.1833.

frequent in corn. Grass herbicides were applied in fewer fields. There is a strong association between grass herbicide application and axis 1 of the CCA ordination, with most monocotyledonous species located on the opposite side of the axis (Figure 4). Finally, yields were similar between crops when they were expressed in energetic units, and no-tillage was the common practice in all fields.

Our results suggest that in the semiarid Espinal, the floristic and functional composition of weed communities could be modulated by a combination of several strategies—crop rotation, competitive crop varieties, fertilization, and herbicide application—leading to a synergistic improvement in weed control (Derksen et al. 2002). Planned sequences of crop rotation, combined with selective fertilization and herbicide use, could be an important tool in the management of weed communities (Liebman and Dyck 1993). However, as crop cover was not a manipulated variable in this study, the effect of crop competition over weed community should be considered as correlation only (Pyšek and Leps 1991).

Our evaluation suggests that the original vegetation of the semiarid Espinal had a high representation in the floristic composition in weed communities, due to the high proportion of annual, dicotyledonous, and native species, which reflected the recent transformation of these croplands (de la Fuente et al. 1999, 2006; Froud-Williams 1986; Mas et al. 2010). Overall weed cover was very low in this dry region, which is marginal for agriculture, indicating that the high herbicide doses associated with no-tillage technologies were effective, possibly due to local relative absence of resistant biotypes in the original vegetation. Therefore, this system represents an opportunity for the design of integrated management strategies that could help reduce the use of chemicals and, consequently, the appearance of resistant variants.

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Supplementary material. To view supplementary material for this article, please visit http://dx.doi.org/10.1017/wsc.2017.76

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