DOI: 10.1111/j.1365-3180.2010.00785.x

Weed communities of transgenic glyphosate-tolerant soyabean crops in ex-pasture land in the southern Mesopotamic Pampas of Argentina

M T MAS*, A M C VERDÚ*, B C KRUK†, D DE ABELLEYRA†,
A C GUGLIELMINI† & E H SATORRE†
*Escola Superior d'Agricultura de Barcelona, Departament d'Enginyeria Agroalimentària i Biotecnologia-UPC, Castelldefels, Barcelona, Spain, and †Cátedra de Cerealicultura, Departamento De Producción Vegetal, Facultad de Agronomía-UBA, Ciudad Autónoma de Buenos Aires, Argentina

Received 10 July 2009
Revised version accepted 18 January 2010

Summary

Weed surveys were performed in commercial no-till glyphosate-tolerant soyabean crops in southern Entre Ríos province (Mesopotamic Pampas of Argentina) in 2005 and 2007, during the soyabean grain filling to maturity growth stages. The objectives were to describe the weed communities in fields recently introduced to crop production and to analyse the effect of the new cropping patterns on assemblages. The fields surveyed varied in the length of the no-till period (1–11 years), the previous crop and the soil productivity rating. Weed communities were described in terms of composition, constancy, life forms, morphotypes and (only during 2007) frequency. *Tragia geraniifolia*, *Bidens subalternans*, *Sida spinosa*, and *Eryngium horridum* were species associated with fields with more than 5 years of no-till glyphosate-tolerant crops. These fields had a significantly higher relative abundance of perennials (52% versus 32%) and of dicotyledons (66% versus 39%) than fields with less than 5 years of no-till. Previous crop and soil productivity affected weed community structure. Six species, five of them annuals, were associated with fields that had high yields and maize as the previous crop. In contrast, perennials and dicotyledons had the highest relative abundance when wheat–soyabean double cropping was the previous crop. The results show that changes in cropping systems acted as filters on functional traits, modifying the previous weed community assemblage. The information may be used to develop integrated crop–weed management strategies, leading to a reduction in the assemblage of highly competitive weed communities.

Keywords: glyphosate, no-tillage, crop rotation, genetically modified soyabean.

MAS MT, VERDÚ AMC, KRUK BC, DE ABELLEYRA D, GUGLIELMINI AC & SATORRE EH (2010). Weed communities of transgenic glyphosate-tolerant soyabean crops in ex-pasture land in the southern Mesopotamic Pampas of Argentina. *Weed Research* **50**, 320–330.

Introduction

It is known that native plant communities are highly modified when cropping is introduced into new areas (Ghersa *et al.*, 1996; Booth & Swanton, 2002). Once cropping systems are introduced, weed communities tend to change in response to the inherent disturbance factors of the cropping systems, usually forcing weed populations to change and adjust to the introduced technologies (Mortensen *et al.*, 1998). Therefore, the floristic composition of weed communities may result not only from seasonal variation, agricultural cycles, or

---

Correspondence: Maria Teresa Mas Serra, Escola Superior d'Agricultura de Barcelona, Departament d'Enginyeria Agroalimentària i Biotecnologia, Universitat Politècnica de Catalunya, Av. del Canal Olímpic 15, 08860 Castelldefels, Barcelona, Spain. Tel: +34 935 521 231; Fax: +34 935 521 001; E-mail: maite.mas@upc.edu

soil degradation under agriculture (Ghersa *et al.*, 1996; Ghersa & León, 1999; Smith & Gross, 2007), but also from any frequent agronomic factor associated with crop production (McLaughlin & Mineau, 1995; Légère *et al.*, 2005). Herbicide resistant weeds are evidence of such transforming forces (Mortimer & Maxwell, 1994; Martínez-Ghersa *et al.*, 2000). Moreover, assembly theory applied to weed communities has recently provided a framework to understand disturbance in cropping systems as filters and constraints. In this context, the crop sequence, the soil characteristics and the herbicide applications could act as environmental constraints that would filter some vegetative and/or reproductive traits in the weed community (Booth & Swanton, 2002; Booth *et al.*, 2003), leading to new assemblages in weed communities.

In the Pampas region of Argentina, agriculture has undergone huge transformations in the past two decades. First, the soyabean crop area under no-tillage cultivation systems has expanded (Satorre, 2001). Transgenic glyphosate-tolerant soyabean varieties were released and soon covered more than 95% of the area sown with this crop (Satorre, 2001, 2005). At present, transgenic soyabean is sown in almost 65% of Argentinean arable land and its associated agricultural practices (i.e. no-till cropping, glyphosate herbicide and crop growth periods: single-crop or double-crop soyabean) have strongly modified previous agronomic disturbances and resource availability patterns for arable weed species. Such agricultural transformation mostly occurred in areas that, for decades, had previously been sown with grain crops, and changes in its weed communities have been reported (Vitta *et al.*, 2004; Puricelli & Tuesca, 2005; de la Fuente *et al.*, 2006). In contrast, little information is available on the effect of transgenic soyabean crop technologies on areas that were previously managed as pastures for extensive cattle raising. Exploring what is occurring in new areas, recently introduced to arable farming, may help to understand how these new technologies affect weed communities.

Ellenberg (1950), León and Suero (1962) and Holzner (1982), among others, have recognised the importance of environmental and anthropogenic factors on the structuring and functioning of weed communities. The assembly of weed communities in different cropping systems has been described in many productive areas of the world. For example, in eastern Canada, species richness and community composition changes were found in relation to weed management intensity (Légère *et al.*, 2005; Swanton *et al.*, 2006). In Michigan (USA), community composition changes were related to tillage timing (Smith, 2006) and species richness was affected by crop rotation (Smith & Gross, 2007). Particularly, in the Rolling Pampa, one of the most productive arable areas in Argentina, the relationship between summer weed community structure and cropping history of fields has also been studied. Ghersa and León (1999) found decreases in species number at the beginning of agricultural grain production in the early 20th century, but afterwards increases were registered as the soil became degraded by continuous cultivation. Community composition was also related to different crop production levels (Suárez *et al.*, 2001). De la Fuente *et al.* (2006) studied community composition changes in soyabean crops during the period of expansion of transgenic no-till production systems (1995–2003). They found decreases in overall species richness over time, due to decreases in the number of annual species and dicotyledon species, but this was linked to increases in the percentage of perennials.

Weed community changes in areas previously considered marginal for grain production, such as the Mesopotamic Pampa (Hall *et al.*, 1992), have received no attention. In this region, transgenic glyphosate-tolerant soyabean has recently become a dominant crop and the new grain crop production system, which includes no-tillage and continuous glyphosate applications, has been strongly favoured. From the results of previous works, reductions in weed diversity are expected with the establishment of arable systems in previously extensively grazed areas (Ghersa *et al.*, 1996). However, species richness can increase with time of cropping, although decreases in number of dicotyledon species and increases in number of perennial species are expected, particularly under no-till production systems (de la Fuente *et al.*, 2006). Nevertheless, such predictions have seldom been evaluated in real production systems. For this reason, the objectives of this work were: (i) to describe weed community structure in commercial fields recently introduced to arable farming with transgenic glyphosate-tolerant soyabean crops under a no-tillage cultivation system; (ii) to analyse the effect of time of continuous cropping and some agronomic variables on the southern Mesopotamic Pampa's soyabean weed communities.

Materials and methods

On-farm weed surveys were performed in the southern Mesopotamic Pampas of Entre Ríos province in Argentina (Hall *et al.*, 1992; Soriano *et al.*, 1992). The fields were located on a 27 000 ha farm (Estancia Centella) close to the city of Gualeguaychú (32°41′48′S, 58°23′25′W). This farm was previously under an extensive mixed grain – cattle raising system, but 10 years ago started to increase grain cropping, mostly soyabean, production. Information concerning crop management and crop performance (i.e. field history, weed control strategy and crop grain yield) is properly recorded on the farm.

Study region

This research focuses on transgenic glyphosate-tolerant soyabean production systems. In particular, we focus on the southern area of the 'Mesopotamic' sub-region of the Pampas, which has experienced recent transformations from a dominant cattle raising system to mainly grain crop production methods. The Mesopotamic Pampas grain production area grew from almost 0.1 million hectares in 1993 to 1.2 million hectares in 2003 (Bernaudo, 2003). This growth replaced traditional extensive cattle raising production systems with modern grain crop production systems. The recent history of its crop production makes this study region an interesting research case. In addition to single soyabean crops, which represent more than 65% of the cropped area, important crops in the region include maize and wheat–soyabean double crop. The soyabean varieties used are transgenic glyphosate-tolerant, also called Roundup Ready (RR), and they are sown mostly under no-tillage rainfed systems. The predominant soils are vertisols and vertic argiudols (*c*. 40%). Soils tend to show high deficiencies in available phosphorous; all crops, with the exception of double cropped soyabean, are fertilised with phosphorous fertiliser at sowing (average rate used is 10 kg P ha^{-1} and crop) but only wheat and maize are fertilised with nitrogen sources (average rate used is 70 kg N ha^{-1}), usually before crop sowing. Mean annual precipitation in the area is about 1150 mm, with maximums in autumn and late spring-summer. Annual precipitation was 970 mm in 2005 and 1539 mm in 2007, when the fields were surveyed.

With respect to rangeland farming, the expansion of grain cropping has tended to reduce the percentage of the ground covered by vegetation and has led to an increase in the use of fertilisers and herbicides. Most land is at present cultivated with at least a single soyabean crop per year, within individual fields that may vary greatly in the region, from 10 to 400 ha, with an average field size of around 66 ha. Glyphosate-tolerant varieties were rapidly adopted, as most annual and perennial weeds were easily controlled with this technology (Satorre, 2005).

Until 1995, none of the surveyed fields at Estancia Centella were under grain crop production; natural grassland such as '*pastizales de flechilla*' *sensu* León (1991) or pastures were usually grazed. From 1995 onwards, the majority of Estancia Centella's 116 fields were progressively sown with annual crops and kept in continuous grain crops production. Before 1995, only a few fields were arable and produced grain for animal feed.

Surveys and determinations

In total, 24 fields were surveyed; 12 of the soyabean fields were surveyed in 2005 and the rest in 2007. Fields were selected to provide a descriptive gradient of the most frequent cropping histories, determined through land use on the farm. At the time of the first survey, in 2005, the fields' agricultural history ranged from 1 to 9 years under annual grain crop production, while the agricultural history of the fields surveyed during 2007 ranged from 4 to 11 years. In all the surveyed fields, weed management included chemical control with glyphosate prior to crop sowing (late October and early November) and after crop emergence. Usually two applications of glyphosate were performed at rates ranging from 360 to 883 g a.e. ha^{-1} per application, depending on the weed species and weed abundance. Glyphosate-tolerant soyabean fields were surveyed between the reproductive growth stages R6 and R8 (Fehr *et al.*, 1971); i.e. between the grain filling into developed pods and the seed-maturing growth stages. The species surveyed were mostly flowering and/or fruiting; thus, weed plants had grown together with the soyabean crops and had shown the ability to spread seeds or asexual propagules before harvest or at harvest time, despite the fact that herbicides had been applied.

The survey method differed slightly between years. During 2005, twelve glyphosate-tolerant soyabean fields were surveyed between 11 March and 20 April. Within a field of known agricultural history, surveys were performed by trained persons who walked over the homogeneous ground of the soyabean crop recording all species observed until no more species were found (Mueller-Dombois & Ellenberg, 1974). The surveyed area varied depending on the field, ranging from 2000 to 5000 m^2 and did not include field margins in any case. In each survey, all species were carefully identified. The main objective of the 2005 surveys was to obtain the floristic structure of each field in terms of species composition.

During 2007, twelve fields were surveyed between 19 March and 21 March. In each field, surveys were performed by walking along four imaginary radial transects, starting at a geo-referenced field midpoint. Each transect was 30 m long, and presence or absence of each weed species was recorded every 2 m in a 1 m^2 sample quadrat. Therefore, for each field, 60 positions were sampled to determine the frequency of each species within an 11 300 m^2 sample area. In this case, attention was focused not on determining the highest number of species, but on the frequency of each of the weed species within their weed communities.

In all surveys, species were determined according to Burkart (1969–1979), Burkart and Bacigalupo (2005) and Burkart *et al.* (1987). Community floristic composition, community richness (total number of weed species in a field) and species constancy (the proportion of fields in which a given species was present) were obtained. Afterwards, functional structure was characterised using Raunkiaer life forms (therophytes, geophytes, hemicryptophytes, chamaephytes, phanerophytes), morphotypes (monocotyledons, dicotyledons) and phenology (flowering and fruiting, vegetative, seedling). Arranging weed species in functional groups may give a better understanding of how weed communities are assembled than just using species lists (Ghersa & León, 1999; Booth & Swanton, 2002).

Data analyses

The weed communities surveyed during 2005 were described in terms of floristic and functional structure. Differences between the floristic compositions of the surveyed fields were checked by means of a multi-response permutation procedure (MRPP; Zimmerman *et al.*, 1985) using the number of years under a no-tillage glyphosate-tolerant cropping system as a categorical variable. Three categories were considered: 1 year, 2–4 years, and more than 4 years.

The relative frequency of: (i) therophytes, (ii) geophytes, (iii) chamaephytes, (iv) perennials and (v) dicotyledons, as well as relative frequency of each species obtained in 2007, were also subjected to three different one-factor analyses of variance. The standard errors of the differences (SED) were computed to give comparisons of mean values of the variables concerning functional structure. The SAS GLM procedure (SAS Institute Inc, 1999) was used for the analyses; type III sums of squares were computed, and variables were arcsine transformed in order to homogenise variances (Gomez & Gomez, 1984). We considered one source of variation for each analysis: (i) the number of years under the no-till glyphosate-tolerant cropping system, with two levels (as a result of the effect of crop rotation on soyabean position, in the 2007 surveys the categories defined in 2005 were modified to 3–5 years, and more than 5 years), (ii) the previous crop, with two levels (wheat–soyabean double crop, maize), and (iii) the soil productivity rating, considering three levels (high, medium, low). The landscape of the southern Mesopotamic Pampa is gently undulating due to the erosive activity of the rain water. The fields located at the bottom of the valleys had the most fertile soils (high productivity rating), the fields located on the hilltops are undergoing erosion and had the least fertile soils (low productivity rating). The fields located on the hillsides had soils that support crops with intermediate levels of production (medium productivity rating).

The influence of some environmental and agronomic factors on weed species composition was explored by a canonical correspondence analysis (CCA; ter Braak, 1986). It was performed using a PC-ORD program (McCune & Mefford, 1999) with data obtained in 2007, considering only those species with frequency $>1\%$. This ordination method seeks to represent the dominant patterns in community composition that can be best explained by the environmental or agronomic variables. The variables used in the analysis were both quantitative and categorical. Quantitative variables included were: previous soyabean yield (REND) and number of years under no-tillage agriculture (ASD). Categorical variables included were: previous crop (MANT, maize or wheat–soyabean double crop) and soil productivity rating (high, medium or low).

Results and discussion

During the 2005 survey, a total of 72 species were identified, belonging to 25 botanical families (Table 1). Fifteen of these species were monocotyledons but only two of them had constancy $>50\%$. However, *Digitaria sanguinalis* (L.) Scopoli appeared as one of the two most constant species. Despite the large number of species found, individual field weed species richness ranged from 4 to 29.

At the time of the 2005 survey, 72% of the species listed were at the flowering and fruiting stage and 24% of the species were at an advanced vegetative stage. Only 23 species were annuals, so the majority of the species were perennials. Within the perennial species surveyed, 34 species were geophytes, 9 species were hemicryptophytes, 5 species were chamaephytes and *Acacia caven* Mol. was the only phanerophyte found. When species constancy is considered, the Raunkiaer life form distribution was 53.5% geophytes, 27% therophytes, 8.8% hemicryptophytes, 9.3% chamaephytes and 1.4% phanerophytes.

The floristic composition of the fields surveyed in 2005 was not significantly different, as tested by MRPP analysis, when the number of years under a no-tillage glyphosate-tolerant cropping system was used as the categorical variable ($P > 0.10$), suggesting that floristic composition was largely influenced by environmental factors rather than by time under continuous agriculture.

The total number of species recorded during the 2007 surveys was lower than that obtained in 2005, as can be expected considering the differences in the methodology. Thus, 42 species belonging to 17 botanical families were observed (Table 2). Only two of the listed species were

Table 1 Species names, family names, morphotype, Raunkiaer life forms, observed phenology, and constancy for weeds recorded in 12 soyabean fields surveyed at Estancia Centella between 11 March and 20 April 2005

Species	Family*	Raunkiaer life form	Phenology	Constancy (%)
Digitaria sanguinalis (L.) Scopoli	Poaceae^M	Th	FF	91.7
Tragia geraniifolia Klotzsch.	Euphorbiaceae	Ge	FF	91.7
Solanum sisymbriifolium Lamarck	Solanaceae	Ge	FF	83.3
Eryngium horridum Malme	Apiaceae	Ge	FF	75.0
Pfaffia gnaphaloides (L. f.) Mart.	Amaranthaceae	Ge	FF	75.0
Sida spinosa L.	Malvaceae	Ch	FF	75.0
Sida rhombifolia L.	Malvaceae	Ch	FF	66.7
Echinochloa colonum (L.) Link	Poaceae^M	Th	FF	58.3
Hybanthus parviflorus (Mutt.) Baill.	Violaceae	Ge	FF	50.0
Chrysanthemum leucanthemum L.	Asteraceae	Ge	FF	41.7
Lotus tenuis Waldst. et Kit	Fabaceae	Ge	V	41.7
Solanum chacoense Bitter	Solanaceae	Ge	FF	41.7
Commelina erecta L.	Commelinaceae^M	Ge	FF	33.3
Convolvulus arvensis L.	Convolvulaceae	Ge	FF	33.3
Dichondra repens Forst. et Forst.	Convolvulaceae	Ge	V	33.3
Ipomoea indivisa (Vell.) Hallier	Convolvulaceae	Th	FF	33.3
Oenothera parodiana Munz.	Onagraceae	He	FF	33.3
Solidago chilensis Meyen.	Asteraceae	Ge	FF	33.3
Vernonia incana Less.	Asteraceae	Ge	FF	33.3
Acacia caven Mol.	Fabaceae	Ph	V	25.0
Aster squamatus (Spreng.) Hieronymus	Asteraceae	Ge	FF	25.0
Cynodon dactylon (L.) Persoon	Poaceae^M	Ge	FF	25.0
Cyperus sp.	Cyperaceae^M	Ge	V	25.0
Juncus bufonius L.	Juncaceae^M	Th	FF	25.0
Oxalis crysantha Prog.	Oxalidaceae	Th	FF	25.0
Picris echioides L.	Asteraceae	Th	V	25.0
Portulaca oleracea L.	Portulacaceae	Th	FF	25.0
Setaria geniculata (L.) Pal. Beauvois	Poaceae^M	Ge	FF	25.0
Solanum sublobatum Willdenow	Solanaceae	He	V	25.0
Spermacoceodes glabrum (Michx.) O.K.	Rubiaceae	Ge	FF	25.0
Zea mays L.	Poaceae^M	Th	S	25.0
Bidens subalternans De Candolle	Asteraceae	Th	FF	16.7
Echinochloa crus-galli (L.) Pal. de Beauvois	Poaceae^M	Th	FF	16.7
Eleusine tristachya (Lam.) Lamarck	Poaceae^M	He	FF	16.7
Eragrostis bahiensis (Schrad. et Schult.) Schult.	Poaceae^M	He	FF	16.7
Euphorbia serpens H.B.K.	Euphorbiaceae	Th	FF	16.7
Evolvulus sericeus Swartz	Convolvulaceae	Ge	FF	16.7
Gamochaeta pensylvanica (Willd.) Cabrera	Asteraceae	He	FF	16.7
Ibicella lutea (Lindley) Van Eseltine	Martiniacaceae	Th	FF	16.7
Jaborosa integrifolia Lamarck	Solanaceae	Ge	FF	16.7
Panicum bergii Arechavaleta	Poaceae^M	He	FF	16.7
Physalis pubescens L.	Solanaceae	Th	FF	16.7
Richardia stellaris (Cham. Et Schecht.) Steud.	Rubiaceae	He	FF	16.7
Stemodia verticillata (Mill.) Hassler	Scrophulariaceae	Th	FF	16.7
Verbena intermedia Gill et Hook.	Verbenaceae	Ge	FF	16.7
Unknown 1	Verbenaceae	Ge	V	16.7
Ambrosia tenuifolia Sprengel	Asteraceae	Ge	V	8.3
Amaranthus quitensis H.B.K.	Amaranthaceae	Th	FF	8.3
Ammi majus L.	Apiaceae	Th	S	8.3
Arenaria serpyllifolia L.	Caryophyllaceae	Th	FF	8.3
Baccharis trimera (Less.) DC.	Asteraceae	Ch	FF	8.3
Bidens pilosa (Bl.) Sherff.	Asteraceae	Th	FF	8.3
Bowlesia incana Ruiz et Pav.	Apiaceae	Th	S	8.3
Conyza bonariensis (L.) Cronquist	Asteraceae	Th	V	8.3
Coronopus didymus (L.) Smith	Brassicaceae	He	V	8.3
Eclipta prostrata L.	Asteraceae	Th	FF	8.3
Gomphrena celosioides Mart.	Amaranthaceae	Ge	FF	8.3
Iresine diffusa Humb. et Bonpl.	Amaranthaceae	Ch	FF	8.3
Medicago sativa L.	Fabaceae	Ch	V	8.3

Table 1 (Continued)

Species	Family*	Raunkiaer life form	Phenology	Constancy (%)
Mollugo verticillata L.	Aizoaceae	Th	V	8.3
Nothoscordum bonariense (Pers.) Beauv.	Liliaceae^{M}	Ge	FF	8.3
Oxalis corymbosa DC.	Oxalidaceae	Ge	FF	8.3
Paspalum dilatatum Poiret	Poaceae^{M}	He	FF	8.3
Rhynchosia diversifolia Micheli	Fabaceae	Ge	V	8.3
Rhynchosia senna Gillies	Fabaceae	Ge	FF	8.3
Sida flavescens Cav.	Malvaceae	Ge	FF	8.3
Sisyrinchium junceum E. Mey	Iridaceae^{M}	Ge	FF	8.3
Spilanthes decumbens (Smith) A.H. Moore	Asteraceae	Ge	FF	8.3
Stellaria media (L.) Villars	Caryophyllaceae	Th	V	8.3
Trifolium sp.	Fabaceae	Ge	V	8.3
Unknown 2	Unknown	Ge	V	8.3
Unknown 3	Unknown	Ge	V	8.3

*Morphotype: ^{M}: monocotyledon, without ^{M}: dicotyledon.

Ph, phanerophyte; Ch, chamaephyte; He, hemicryptophyte; Ge, geophyte; Th, therophyte; FF, flowering and fruiting; V, vegetative; S, seedling.

not found in 2005. Field community richness ranged from 7 to 23 species. As in the surveys performed during 2005, most of the species listed (81%) were at the flowering and fruiting stage at soyabean grain filling time and the majority were also perennials (69%). *Digitaria sanguinalis* and *Tragia geraniifolia* Klotzsch. were ubiquitous species and were followed in constancy by *Euphorbia serpens* H.B.K. and *Sida rhombifolia* L.

Mean relative abundance of geophytes, as well as of total perennials, was greater in the fields that had more than 5 years under a no-till glyphosate-tolerant cropping system (Table 3). Its value was still greater if fields had wheat–soyabean double crop as a preceding crop and if it was a field with a medium productivity rating. The differences in functional structure of species assemblages between wheat–soyabean double crop and maize are consistent with weed management techniques and with the influence of each crop on summer weed species. The influence of wheat on summer weed communities is marginal, since it is a winter-spring crop species in the region; however, wheat–soyabean double crops may represent, for those weeds that are poorly controlled in the previous soyabean, an opportunity to increase their abundance in such a situation. This may explain why dicotyledon and geophyte species are relatively more abundant in soyabean after wheat–soyabean double crop than after maize. Similarly, relatively poorly controlled perennial weeds increased and better controlled therophytes diminished in soyabean crops after wheat–soyabean double crop (Table 3). Maize, as a previous summer crop, greatly differed from soyabean in the herbicides used, and herbicides are important filters determining weed community composition; the maize crop herbicides help to reduce dicotyledons due to the better control efficacy of these species, but they also serve to increase the relative abundance of therophytes (or annuals). Considering that *c.* 70% of perennials were dicotyledons (Table 2), it seems that the technology used in the maize crop had filtered perennial dicotyledon plant species; i.e. dicotyledon species successfully surviving herbicide applications in maize tended to be perennials. Some species appeared to be more sensitive to this factor: *T. geraniifolia*, followed by *S. rhombifolia*, was the most abundant perennial dicotyledon. *Digitaria sanguinalis* and *Echinochloa colonum* (L.) Link were the species with the highest contribution to the annual monocotyledon category. Moreover, the annual dicotyledons *E. serpens* and *Ipomoea indivisa* (Vell.) Hallier had high levels of constancy and frequency (Table 2), possibly because *E. serpens* may also be a biannual and *Ipomoea* species establish after herbicides have been applied in the maize season, usually in late spring (Marzocca *et al.*, 1979).

Weed shifts promoting an increase in the mean frequency of perennials, particularly geophytes (Table 3), have been associated with no-till practices in many agroecosystems of the Pampas region (Tuesca *et al.*, 2001; Ghersa *et al.*, 2002; de la Fuente *et al.*, 2006). A decrease in the proportion of dicotyledon species has been associated with no-till production systems (de la Fuente *et al.*, 2006), but in our work overall increases in frequency of individuals belonging to the dicotyledon morphotype were observed in fields that had more than 5 years under no-till agriculture. Considering the frequency values of each species, the only species that showed significant variation attributable to years of no-tillage glyphosate-tolerant agriculture was *T. geraniifolia*; its mean frequency was 21.2% in fields under 3–5 years of no-till, and 59% in fields that had been under no-till for five or more years ($P = 0.015$).

Table 2 Species names, family names, morphotype, Raunkiaer life forms, observed phenology, constancy, and mean frequency for weeds recorded in 12 soyabean fields surveyed at Estancia Centella during March 2007

Species	Family*	Raunkiaer life form	Phenology	Constancy (%)	Frequency (%)
Tragia geraniifolia Klotzsch.	Euphorbiaceae	Ge	FF	100.0	36.9
Digitaria sanguinalis (L.) Scopoli	Poaceae^{M}	Th	FF	100.0	30.7
Euphorbia serpens H.B.K.	Euphorbiaceae	Th	FF	91.7	29.2
Echinochloa colonum (L.) Link	Poaceae^{M}	Th	FF	83.3	20.8
Sida rhombifolia L.	Malvaceae	Ch	FF	91.7	19.0
Eragrostis airoides Nees	Poaceae^{M}	Ge	FF	41.7	7.5
Ipomoea indivisa (Vell.) Hallier	Convolvulaceae	Th	FF	41.7	6.0
Dichondra repens Forst. et Forst.	Convolvulaceae	Ge	V	75.0	5.8
Sida spinosa L.	Malvaceae	Ch	FF	50.0	4.6
Paspalum inaequivalve Raddi	Poaceae^{M}	Ge	FF	25.0	4.6
Bidens subalternans De Candolle	Asteraceae	Th	FF	25.0	4.2
Triticum aestivum L.	Poaceae^{M}	Th	V	58.3	3.8
Setaria geniculata (L.) Pal. Beauvois	Poaceae^{M}	Ge	FF	25.0	3.2
Pfaffia gnaphaloides (L. f.) Mart.	Amaranthaceae	Ge	FF	50.0	2.9
Solanum sisymbriifolium Lamarck	Solanaceae	Ge	FF	33.3	2.9
Solanum chacoense Bitter	Solanaceae	Ge	FF	58.3	2.6
Portulaca oleracea L.	Portulacaceae	Th	FF	16.7	2.5
Oxalis corymbosa DC.	Oxalidaceae	Ge	FF	8.3	2.1
Hybanthus parviflorus (Mutt.) Baill.	Violaceae	Ge	FF	33.3	1.8
Cyperus sp.	Cyperaceae^{M}	Ge	V	25.0	1.5
Physalis pubescens L.	Solanaceae	Th	FF	8.3	1.0
Acacia caven Mol.	Fabaceae	Ph	V	16.7	0.7
Xanthium cavanillesii Schouw	Asteraceae	Th	FF	16.7	0.7
Convolvulus arvensis L.	Convolvulaceae	Ge	FF	33.3	0.6
Aster squamatus (Spreng.) Hieronymus	Asteraceae	Ge	FF	25.0	0.6
Amaranthus quitensis H.B.K.	Amaranthaceae	Th	FF	16.7	0.6
Cynodon dactylon (L.) Persoon	Poaceae^{M}	Ge	FF	16.7	0.6
Rhynchosia diversifolia Micheli	Fabaceae	Ge	FF	8.3	0.6
Eryngium horridum Malme	Apiaceae	Ge	FF	16.7	0.4
Paspalum plicatulum Michaux	Poaceae^{M}	He	FF	8.3	0.4
Bowlesia incana Ruiz et Pav.	Apiaceae	Th	S	16.7	0.3
Anoda cristata (L.) Schltdl.	Malvaceae	Th	FF	8.3	0.3
Chrysanthemum leucanthemum L.	Asteraceae	Ge	FF	8.3	0.1
Commelina erecta L.	Commelinaceae^{M}	Ge	FF	8.3	0.1
Eragrostis bahiensis (Schrad. et Schult.) Schult.	Poaceae^{M}	He	FF	8.3	0.1
Iresine diffusa Humb. et Bonpl.	Amaranthaceae	Ch	FF	8.3	0.1
Jaborosa integrifolia Lamarck	Solanaceae	Ge	FF	8.3	0.1
Verbena intermedia Gill et Hook.	Verbenaceae	Ge	FF	8.3	0.1
Sonchus oleraceus L.	Asteraceae	Th	FF	8.3	0.1
Unknown 1	Asteraceae	–	V	8.3	0.1
Unknown 2	Asclepiadaceae	–	V	8.3	0.1
Unknown 3	Liliaceae^{M}	Ge	V	8.3	0.1

*Morphotype: ^{M}: monocotyledon, without ^{M}: dicotyledon.
Ph, phanerophyte; Ch, chamaephyte; He, hemicryptophyte; Ge, geophyte; Th, therophyte; FF, flowering and fruiting; V, vegetative; S, seedling.

This species is a dicotyledon with thin rhizomes and erect or vine-like aboveground stems; the aerial parts are irritating because they are armed with prickles; the axillary pistillate flowers develop capsules bearing three large seeds (Burkart & Bacigalupo, 2005).

The 2007 results also show that, with an increase in the length of the no-till period, the most notable changes in the functional structure of the weed communities occurred in fields with medium productivity soils (Table 3). This was expected, since low and high productivity soils have strong organising factors – low availability of soil resources and crop competition respectively – that may reduce the influence of crop management on weed structuring (Ghersa *et al*., 1996; Guglielmini *et al*., 2000; Martínez-Ghersa *et al*., 2000).

The ordination diagram (Fig. 1) provides a good representation of the pattern of weed distribution with respect to environmental and agronomic variables

Table 3 Mean relative abundance (percentage) and number of observations (in parentheses) of functional groups analysed using three-one-factor ANOVAs for weeds recorded in 12 soyabean fields surveyed at Estancia Centella during March 2007. The significance of each source of variation is given in each analysis and each column; degrees of freedom and standard error of difference (SED) of the transformed data means (arcsine of the proportion) are also shown

	Functional groups				
	Therophytes	Geophytes	Chamaephytes	Perennials	Dicotyledons
Years under no-till glyphosate-tolerant soyabean crops					
Significance	<0.0001	<0.0001	0.2626	<0.0001	<0.0001
3–5 years	47.0 (419)	24.4 (419)	7.2 (419)	31.7 (419)	38.5 (420)
>5 years	36.8 (299)	43.0 (299)	8.7 (299)	52.1 (299)	66.3 (300)
d.f.	716	716	716	716	718
SED	0.045	0.040	NS	0.041	0.042
Previous crop					
Significance	<0.0001	<0.0001	0.0220	<0.0001	<0.0001
Maize	58.9 (299)	20.5 (299)	9.7 (299)	30.4 (299)	40.7 (300)
Wheat–soyabean double crop	31.3 (419)	40.4 (419)	6.5 (419)	47.2 (419)	56.8 (420)
d.f.	716	716	716	716	718
SED	0.043	0.039	0.015	0.041	0.043
Soil productivity rating					
Significance	0.0014	0.0011	0.0361	0.0164	0.0537
High	38.1 (119)	25.9 (119)	11.5 (119)	38.4 (119)	44.2 (120)
Medium	48.7 (299)	38.1 (299)	6.6 (299)	45.0 (299)	54.3 (300)
Low	38.8 (300)	28.6 (300)	7.5 (300)	36.2 (300)	48.2 (300)
d.f.	715	715	715	715	717
SED	0.059	0.054	0.020	0.056	0.059

according to the CCA analysis performed. The two axes explain 32.6% of the variance in the species data. The first axis (eigenvalue = 0.36) is strongly correlated with variables REND (0.805) and MANT (0.779), while the second axis (eigenvalue = 0.187) is correlated with variable ASD (−0.727). Another aspect to note in Fig. 1 is the differential length of the soil productivity rating lines. The longer line for MEDIUMPROD with respect to HIGHPROD represents the greater importance of the first variable in the distribution of species.

Species associated with high yield plots were *E. colonum*, *Portulaca oleracea* L., *Xanthium cavanillesii* Schouw, *Amaranthus quitensis* H.B.K. and *I. indivisa*, whereas *Paspalum inaequivalve* Raddi, *Pfaffia gnaphaloides* (L. f.) Mart., *Hybanthus parviflorus* (Mutt.) Baill., and *T. geraniifolia* were found in low yield plots. It is known that species differ in total soil resource use and use efficiency; for example, *E. colonum* and *P. oleracea* were among a group of five weed species that take up the largest amounts of nutrients in a soyabean field trial in India (Singh & Sharma, 1989) and the *A. quitensis* seedbank and seedling emergence was greater in N-fertilised soyabean plots than in unfertilised ones (Pace *et al*., 1991). Weed community assemblage in high and low yield plots may possibly have reflected differences in the response of species to soil fertility requirements (Guglielmini *et al*., 2000).

Ordered by mean frequency, species associated with a large number of years under a no-till glyphosate-tolerant soyabean cropping system were *T. geraniifolia*, *Sida spinosa* L., *Bidens subalternans* De Candolle and *Eryngium horridum* Malme. *Hybanthus parviflorus* also belongs to this group, but only when the soil productivity rating is low. In contrast, *Eragrostis airoides* Nees, *Setaria geniculata* (L.) Pal. Beauvois and *A. caven* were found in plots with few years of no-till cropping. There were six species, five of them annuals, which clearly appeared to be associated with fields that had a high crop yield and maize as the previous crop: *A. quitensis*, *E. colonum*, *I. indivisa*, *P. oleracea*, *S. geniculata* and *X. cavanillesii*. In contrast, when wheat–soyabean double crop was the previous crop, perennial species (mainly geophytes) and dicotyledons had higher relative abundance than annuals and/or monocotyledons.

Moreover, weed communities after five or more years of no-till glyphosate-tolerant soyabean cropping systems had: (i) higher relative abundance of perennials (52.1% versus 31.7%), and (ii) higher relative abundance of dicotyledons (66.3% versus 38.5%) than the weed communities of fields with < 5 years of no-till. Among the perennial species, those that had subterranean storage organs were particularly abundant. This vegetative trait would seem to be an important feature that may characterise the weed species assemblage of no-till glyphosate-tolerant soyabean crops.

There was one group of species with high constancy that appeared to be unaffected by any of the variables considered in this study. They were cosmopolitan species

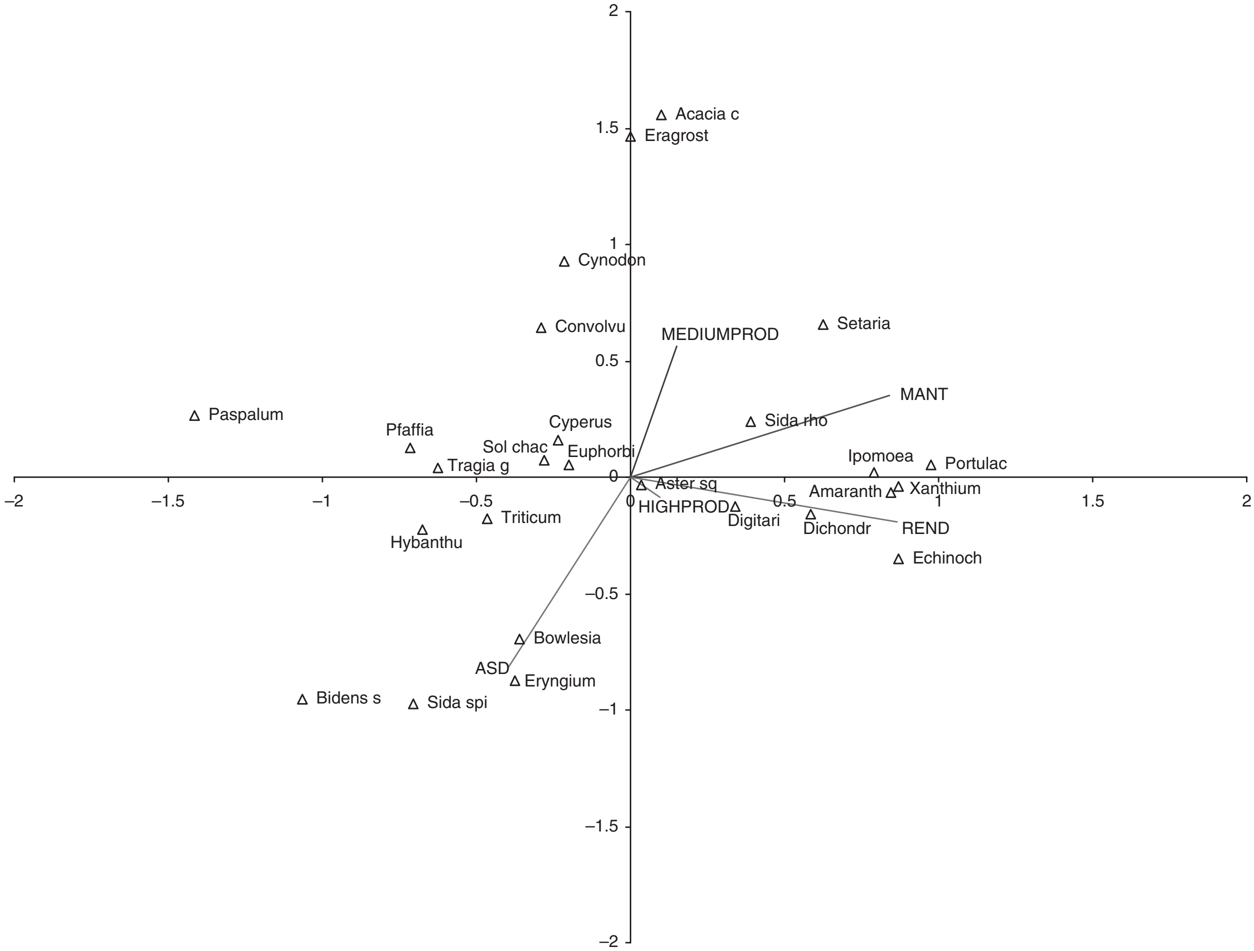

Fig. 1 Canonical correspondence analysis diagram with plant species (Δ) and environmental and anthropogenic variables (lines); the first axis is horizontal, the second axis is vertical. Plant species shown are: Acacia c = *Acacia caven*, Amaranth = *Amaranthus quitensis*, Aster sq = *Aster squamatus*, Bidens s = *Bidens subalternans*, Bowlesia = *Bowlesia incana*, Convolvu = *Convolvulus arvensis*, Cynodon = *Cynodon dactylon*, Cyperus = *Cyperus* sp., Dichondr = *Dichondra repens*, Digitari = *Digitaria sanguinalis*, Echinoch = *Echinochloa colonum*, Eragrost = *Eragrostis airoides*, Eryngium = *Eryngium horridum*, Euphorbi = *Euphorbia serpens*, Hybanthu = *Hybanthus parviflorus*, Ipomoea = *Ipomoea indivisa*, Paspalum = *Paspalum inaequivalve*, Pfaffia = *Pfaffia gnaphaloides*, Portulac = *Portulaca oleracea*, Setaria = *Setaria geniculata*, Sida rho = *Sida rhombifolia*, Sida spi = *Sida spinosa*, Sol chac = *Solanum chacoense*, Sol sisy = *Solanum sisymbriifolium*, Tragia g = *Tragia geraniifolia*, Triticum = *Triticum aestivum*, Xanthium = *Xanthium cavanillesii*. The environmental and anthropogenic variables are: REND = soyabean yield in 2006–2007, ASD = number of years under no-tillage agriculture, MANT = maize and wheat–soyabean double crop, MEDIUMPROD and HIGHPROD are variables related to soil productivity rating.

that are recognised as weeds in many other crop systems of the world (Holm *et al.*, 1977); they were *D. sanguinalis*, *Solanum sisymbriifolium* Lamarck, and *Convolvulus arvensis* L. Among them, there was no single species that can be considered as indicative of glyphosate-tolerant crops, although they could be considered weeds of no-till glyphosate-tolerant soyabean. It is known that weed control efficacy depends on various factors (herbicide rate, weed developmental stage, environmental conditions, weed establishment time relative to weed control, etc.), but no single mechanism determining weed success can be identify from this study. However, all three of these species have been reported as important weeds in glyphosate-tolerant summer crops in arable areas of Argentina (Oreja & de la Fuente, 2005; Puricelli & Tuesca, 2005; Arregui *et al.*, 2006).

General models have been proposed to explain weed community changes in agricultural systems (e.g. Ghersa *et al.*, 2000; Guglielmini *et al.*, 2007). Nevertheless, little work has been done to evaluate the influence of new technologies in areas recently incorporated into arable land. It has been recognised that herbicide and glyphosate-tolerant crops are strong organising factors (Satorre & Snaydon, 1992; Martínez-Ghersa *et al.*, 2000; Puricelli & Tuesca, 2005; Graef *et al.*, 2007). However, to understand the interactions between herbicide and crop competition, functional approaches may be relevant, as Booth *et al.* (2003) pointed out. For example, Mithila *et al.* (2008), studying three weed species, explained the reduced glyphosate efficacy detected under low soil nitrogen conditions using a physiological approach.

Weed community performance depends on the influence of factors that are directly related to the structure of the crop (e.g. crop growth rate, light interception), agronomic factors such as herbicide dose and number of applications and environmental conditions (e.g. water and nutrient availability, soil structure). Moreover, variations in the diversity of crops within a cropping system (rotation) can have significant crop-specific impacts on weed communities (Smith & Gross, 2007). More data is still needed and research has to be done to elucidate the effects of various factors at on-farm field scale; however, cases such as the one described here in the southern Mesopotamic Pampas may help to hypothesise how some cropping practices may act as changing forces on weed communities. For example, the inclusion of imidazolinone resistant maize varieties may improve the control of mono- and dicotyledonous weeds and the reduction of the distance between rows in soyabean, by increasing early crop competitive ability, may help to reduce the abundance of some highly abundant and competitive weeds in the community assemblage. It therefore appears that crop planning may be carefully considered in the studied area to manage weed community assemblages to minimise those conditions that are favourable to an increase in the abundance of some highly competitive weed species.

Acknowledgements

This work has been financially supported by the Agencia Española de Cooperación Internacional of the Spanish government (A/6759/06), the University of Buenos Aires, Argentina (UBACyT AG-090) and Secyt, Argentina (PICT 25432). The authors wish to thank Ing. Agr. Andrés Blaquier and Ing. Agr. Roberto Becker from La Biznaga S.A. for allowing us to survey fields at Estancia Centella. We also thank Dr. Santiago Poggio for his help during the 2005 surveys and Ing. Agr. Silvia Burkart for lending us her father's books when we needed to recognise weed species. E.H.S. is a member of CONICET, the Research Council of Argentina.

References

Arregui MC, Scotta R & Sánchez D (2006) Improved weed control with broadleaved herbicides in glyphosate-tolerant soyabean (*Glycine max*). *Crop Protection* **25,** 653–656.

Bernaudo G (2003) El papel de la soja en los planteos de producción zonales: Zona Litoral. In: *El libro de la soja* (ed. EH Satorre), 189–197. Servicios y Marketing Agropecuario, Buenos Aires, Argentina.

Booth BD & Swanton CJ (2002) Assembly theory applied to weed communities. *Weed Science* **50,** 2–13.

Booth BD, Murphy SD & Swanton CJ (2003) *Weed Ecology in Natural and Agricultural Systems*. CABI Publishing, Wallingford, UK.

ter Braak CJF (1986) Canonical correspondence analysis: a new eigenvector technique for multivariate direct gradient analysis. *Ecology* **67,** 1167–1179.

Burkart A (ed.) (1969–1979) *Flora Ilustrada de Entre Ríos, partes 2, 5 y 6*. Colección Científica INTA, Buenos Aires, Argentina.

Burkart A & Bacigalupo NM (eds) (2005) *Flora Ilustrada de Entre Ríos, Parte 4*. Colección Científica INTA, Buenos Aires, Argentina.

Burkart A, Troncoso NS & Bacigalupo NM (eds) (1987) *Flora Ilustrada de Entre Ríos, Parte 3*. Colección Científica INTA, Buenos Aires, Argentina.

Ellenberg H (1950) *Landwirtschaftliche Pflanzensoziologie, Bd. I: Unkrautgemeinschaften als Zeiger für Klima und Boden*. Ulmer, Stuttgart, Germany.

Fehr WR, Caviness CE, Burmood DT & Pennington JS (1971) Stage of development descriptions for soyabeans, *Glycine max* (L.) Merrill. *Crop Science* **11,** 929–931.

de la Fuente EB, Suárez SA & Ghersa CM (2006) Soyabean weed community composition and richness between 1995 and 2003 in the Rolling Pampas (Argentina). *Agriculture, Ecosystems and Environment* **115,** 229–236.

Ghersa CM & León RJC (1999) Successional changes in agroecosystems of the Rolling Pampa. In: *Ecosystems of the World 16: Ecosystems of Disturbed Ground* (ed. LR Walker), 487–502. Elsevier, New York, USA.

Ghersa CM, Martínez-Ghersa MA & Suárez SA (1996) Spatial and temporal patterns of weed invasions: implications for weed management and crop yield. Proceedings of the Second International Weed Control Congress, Copenhagen, Denmark, 41–47.

Ghersa CM, Benech-Arnold RL, Satorre EH & Martínez-Ghersa MA (2000) Advances in weed management strategies. *Field Crops Research* **67,** 95–104.

Ghersa CM, de la Fuente EB, Suarez S & León RJC (2002) Woody species invasion in the Rolling Pampa grasslands, Argentina. *Agriculture, Ecosystems and Environment* **88,** 271–278.

Gomez KA & Gomez AA (1984) *Statistical Procedures for Agricultural Research*. 2nd edn. Wiley, New York.

Graef F, Stachow U, Werner A & Schütte G (2007) Agricultural practice changes with cultivating genetically modified herbicide-tolerant oilseed rape. *Agricultural Systems* **94,** 111–118.

Guglielmini AC, Satorre EH, Varela F & Miguens D (2000) Nitrogen fertilizer application and competitive balance between spring wheat (*Triticum aestivum* L.) and volunteer oilseed rape (*Brassica napus* L.). *Ecología Austral* **10,** 133–142.

Guglielmini AC, Ghersa CM & Satorre EH (2007) Co-evolution of domesticated crops and associated weeds. *Ecología Austral* **17,** 167–178.

Hall AJ, Rebella CM, Ghersa CM & Culot JP (1992) Field crop systems of the Pampas. In: *Ecosystems of the World 18:*

Field Crop Ecosystems (ed. CJ Pearson), 413–449. Elsevier, New York, USA.

Holm LG, Plucknett DL, Pancho JV & Herbeger JP (1977) *The World*'s Worst Weeds: Distribution and Biology. University Press of Hawaii, Honolulu, Hawaii, USA.

Holzner W (1982) Weeds as indicators. In: *Biology and Ecology of Weeds* (eds W Holzner & M Numata), 187–190. Dr. W. Junk Publishers, The Hague, the Netherlands.

Légère A, Stevenson FC & Benoit DL (2005) Diversity and assembly of weed communities: contrasting responses across cropping systems. *Weed Research* **45,** 303–315.

León RJC (1991) Geographic limits of the region, Geomorphology and geology, Regional subdivisions, Floristic aspects, Description of the vegetation. In: *Natural Grasslands, Introduction and Western Hemisphere* (ed. RT Coupland), 369–387. Elsevier, Amsterdam, the Netherlands.

León RJC & Suero A (1962) Las comunidades de malezas de los maizales y su valor indicador. *Revista Argentina de Agronomía* **29,** 23–28.

Martínez-Ghersa MA, Ghersa CM & Satorre EH (2000) Coevolution of agricultural systems and their weed companions: implications for research. *Field Crops Research* **67,** 181–190.

Marzocca A., Marsico OJ & Del Puerto O (1979) *Manual de Malezas*, ed. Hemisferio Sur, Buenos Aires, Argentina.

McCune B & Mefford MJ (1999) *PC-ORD Multivariate Analysis of Ecological Data. Version 4.0*. MjM Software, Gleneden Beach, OR, USA.

McLaughlin A & Mineau P (1995) The impact of agricultural practices on biodiversity. *Agriculture, Ecosystems and Environment* **55,** 201–212.

Mithila J, Swanton CJ, Blackshaw RE, Cathcart RJ & Hall JC (2008) Physiological basis for reduced glyphosate efficacy on weeds grown under low soil nitrogen. *Weed Science* **56,** 2–17.

Mortensen DA, Dielemann JA & Johnson GA (1998) Weed spatial variation and weed management. In: *Integrated Weed and Soil Management* (eds JL Hatfield, DD Buhler & BA Stewart), 293. Ann Arbor Press, Chelsa, MI, USA.

Mortimer AM & Maxwell BD (1994) Selection for herbicide resistance. In: *Herbicide Resistance in Plants: Biology and Biochemistry* (eds SB Powles & Hotum JAM), 1–25. CRC Press, Boca Raton, FL, USA.

Mueller-Dombois D & Ellenberg H (1974) Causal analytical inquiries into the origin of plant communities. In: *Aims and Methods of Vegetation Ecology* (eds D Mueller-Dombois & H Ellenberg), 335–370. John Wiley & Sons, New York, USA.

Oreja FH & de la Fuente EB (2005) Dinámica poblacional del pasto cuaresma (*Digitaria sanguinalis* (L.) Scop.) en cultivos de soja de la Pampa Ondulada. In: Proceedings XVII Congreso de la Asociación Latinoamericana de Malezas (ALAM), Varadero, Matanzas, Cuba, 8–11 November 2005, 767–771.

Pace A, di Fernandez ON, Requesens E & Nuciari MC (1991) Effects of crop sequence and nitrogen fertilization on the structure of a weed community. Proceedings of the 12th Argentine meeting on weeds and their control, Mar del Plata, Argentina, 9–11 October 1991, Vol. 1, 31–44.

Puricelli E & Tuesca D (2005) Weed density and diversity under glyphosate-resistant crop sequences. *Crop Protection* **24,** 533–542.

SAS Institute Inc. (1999) *SAS Online Doc*®, Version 8. SAS Institute Inc., Cary, NC, USA.

Satorre EH (2001) Production systems in the Argentine Pampas and their ecological impact. In: *Globalization and the Rural Environment* (eds OT Solbrig, R Paalberg & F di Castri), 79–102. Harvard University Press, Cambridge, MA, USA.

Satorre EH (2005) Cambios tecnológicos en la agricultura argentina actual. *Ciencia Hoy* **15,** 24–30.

Satorre EH & Snaydon RW (1992) A comparison of root and shoot competition between spring cereals and *Avena fatua* L. *Weed Research* **32,** 45–55.

Singh D & Sharma KC (1989) Influence of row spacing and weed management on the nutrient uptake by soyabean (*Glycine max* L.). *Indian Journal of Weed Science* **21,** 3–4.

Smith RG (2006) Timing of tillage is an important filter on the assembly of weed communities. *Weed Science* **54,** 705–712.

Smith RG & Gross KL (2007) Assembly of weed communities along a crop diversity gradient. *Journal of Applied Ecology* **44,** 1046–1056.

Soriano A, León RJC & Sala OE (1992) Río de la Plata grasslands. In: *Ecosystems of the World 8A: Natural Grasslands. Introduction and Western Hemisphere* (ed. RT Coupland), 367–407. Elsevier, New York, USA.

Suárez SA, de la Fuente EB, Ghersa CM & León RJC (2001) Weed community as an indicator of summer crop yield and site quality. *Agronomy Journal* **93,** 524–530.

Swanton CJ, Booth BD, Chandler K, Clements DR & Shrestha A (2006) Management in a modified no-tillage corn-soyabean-wheat rotation influences weed population and community dynamics. *Weed Science* **54,** 47–58.

Tuesca D, Puricelli E & Papa JC (2001) A long-term study on weed flora shifts in different tillage systems. *Weed Research* **41,** 369–382.

Vitta J, Tuesca D & Puricelli E (2004) Widespread use of glyphosate-tolerant soyabean and weed community richness in Argentina. *Agriculture, Ecosystems and Environment* **103,** 621–624.

Zimmerman GM, Goetz H & Mielke PW Jr (1985) Use of an improved statistical method for group comparisons to study effects of prairie fire. *Ecology* **66,** 606–611.