ELSEVIER

# Soybean weed community composition and richness between 1995 and 2003 in the Rolling Pampas (Argentina)

E.B. de la Fuente [a,*], S.A. Suárez [b], C.M. Ghersa [c]

[a] *Department of Vegetal Production, Faculty of Agronomy, University of Buenos Aires, Av. San Martin 4453, (1417) Buenos Aires, Argentina*
[b] *Department of Natural Sciences, National University of Río Cuarto, Ruta 8 y 36 km 603, (5800) Río Cuarto, Argentina*
[c] *Department of Natural Resources and Environment-IFEVA, Faculty of Agronomy, University of Buenos Aires,*
*Av. San Martin 4453, (1417) Buenos Aires, Argentina*

## Abstract

The introduction of new agricultural practices (no tillage cropping and soybean transgenic cultivars resistant to glyphosate) to Argentina, together with market factors, have resulted in an increase in the area cropped with soybean and generated a new environment in the Rolling Pampas agroecosystem. During the summers of 1995, 1998, 1999, 2001 and 2003, a total of 120 soybean fields were surveyed, to evaluate the changes in the weed communities of the central Rolling Pampas through the period during which the adoption of these new technologies was increasing exponentially. Floristic structure was analyzed in terms of species composition, and functional structure in terms of morphotypes and physiotypes. Data were summarized by calculating species constancy, and alpha, beta, gamma diversity and functional richness. Alpha (local) diversity and functional richness were linearly related with gamma (regional) diversity and after an initial increase from 1995 to 1998, decreased over time, this being associated with the adoption of the new technologies. Beta diversity was not related to soybean regional pool of weed species, thus it was probably related to the availability of refuges provided by the landscape's habitat. Tillage system and cultivars were the main agronomic variable affecting the occurrence of weeds.
© 2006 Elsevier B.V. All rights reserved.

*Keywords:* Soybean; Weed community; Richness; Temporal changes; Transgenic cultivars

## 1. Introduction

Agriculture is considered one of the largest contributors to the loss of species richness (McLaughlin and Mineau, 1995; Benton et al., 2003) or, at least, of several functional groups (Burel et al., 1998), such as morphotypes and physiotypes. The loss of species richness, in addition to loss of genetic resources, of productivity and of ecosystem buffering against perturbation, may also alter the services that ecosystems provide (Tilman and Downing, 1994; Naeem et al., 1994; Luck et al., 2003).

In the Rolling Pampas ecosystem, structural and functional changes have occurred during the last century.

Since 1970, agricultural land-use was intensified. The mixed annual cropping–grazing system disappeared as wheat (*Triticum aestivum* L.)–soybean [*Glycine max* (L.) Merr.] double cropping was expanded throughout the region, increasing soil cultivation and degradation, and generating a soil heterogeneous environment associated with the cropping histories of the fields (Michelena et al., 1989; Maddonni et al., 1999).

At the end of the 20th century, no tillage cropping system was adopted because it improved water use by the crop and reduced cropping labor time. In a little more than a decade, almost all of the cropped soil in the Rolling Pampas was under permanent no tillage cropping and using soybean transgenic cultivars resistant to glyphosate.

The objective of this work was to study soybean weed community richness, composition and function in the

* Corresponding author. Tel.: +54 11 4902 9914; fax: +54 11 4514 8737.
*E-mail address:* fuente@agro.uba.ar (E.B. de la Fuente).

Rolling Pampas, Argentina between 1995 and 2003 and their relationships with management.

## 2. Materials and methods

The Rolling Pampas is a sub-region of the grassland of Río de la Plata in Argentina (between 34° and 36°S and 58° and 62°W). The climate is mild and humid with hot summers. The annual average rainfall is 950 mm, the annual average temperature is 17 °C (Hall et al., 1992).

Agricultural practices in soybean crop are very similar across this region. Main activities included in the rotation are as follows: soybean, wheat–soybean and in a lower extent corn and pasture. Soybean fields are not fertilized nor irrigated. In no tillage fields, weed control included grass and broadleaf herbicides at the beginning of this study and glyphosate during the last period. The same chemical weed control complemented with mechanical control is used in conventional tillage fields.

A total of 120 soybean fields were surveyed in 1995, 1998, 1999, 2001 and 2003. A surface of approximately $5 \times 10^4$ ha was covered in each year. Fields were selected randomly on highlands of typical Argiudol soils (INTA, 1974) located in the central Rolling Pampas. In all cases, surveys were made between 15th January and 15th February. This time interval was chosen based on three criteria: (1) both, spring-summer and autumn-winter weed communities were present, (2) weed chemical control had already been applied, and (3) crops had achieved maximum ground-cover.

The entire surface of each field was surveyed, fields averaged 50 ha. Sampled fields fulfilled the following requirements (Mueller-Dombois and Ellenberg, 1974): (1) they were large enough to contain all species belonging to the plant community (minimum 25–100 m$^2$ for agricultural weed communities), (2) the habitat was uniform within the field area, and (3) plant cover was homogeneous, without large openings or different dominant species at different parts of the field. Field margins and depressions were avoided, because they may represent different habitats (e.g. different soil conditions). Furthermore, surveys were also restricted to those field areas which had homogeneous crop cover. Surveys were performed by two or more trained persons that walked across each field for at least 30 min, recording all species observed until no more new species were found. Cover abundance of each species was estimated adapting Braun Blanquet cover abundance method (Mueller-Dombois and Ellenberg, 1974). It considers the percentage of ground cover, with the following scale intervals: 0–1, 1–5, 5–10, 10–25, 25–50, 50–75, 75–100%.

Each year, once the crop cycle had finished, farmers from each field were interviewed to acquire information concerning the following agronomic variables: number of annual cropping cycles, sowing dates, tillage system, yield, previous crops and cultivars.

## 3. Data analyses

Vegetation structure was analyzed in terms of species and functional groups composition. Since plant traits instead of species are adapted to a particular environment, arranging weed species in functional groups may give a better understanding of how weed communities assembled than species lists (Ghersa and León, 1999; Booth and Swanton, 2002). Each species was classified in functional groups by its life cycle: annual, biennial, perennial; production of secondary metabolites: alkaloids, tannins, aromatic amino acids, saponins, heterosides, terpenoids, flavonoids; morphotype: dicotyledonous monocotyledonous; and origin/distribution: native, exotic, cosmopolitan.

Data were summarized by calculating species constancy (proportion of fields in which a given species is present), and alpha, beta and gamma diversity (Whittaker, 1975). Alpha or local diversity, also called species richness, is the average number of species occurring in each year. Beta diversity [(gamma diversity/average alpha diversity) − 1] is the rate of change of species richness across years. Gamma or regional diversity is the total number of species occurring in each year (Whittaker, 1975; Magurran, 1988).

Data was subjected to Multi-Response Permutation Procedures (MRPP) (Mielke, 1984) and canonical correspondence analysis (CCA) (ter Braak, 1987a,b). Analyses were made only using species with constancy greater than 5% because species with lower constancy were considered occasional (Mueller-Dombois and Ellenberg, 1974). Distance measure was Sorensen modified by Bray Curtis. A weighting factor was applied to the items in each group using $n/\text{sum}(n)$, $n$ is the number of items in group. CCA constructs those linear combinations (axes) of agronomic variables along which the distribution of the species are maximally separated. Axis scores were centered and standardized to unit variance, and were scaled to compromise representation of species and surveys. The agronomic variables used were yield, sowing date (early or late), previous crop (soybean, wheat, corn or pasture), tillage system (conventional or no tillage), number of years with cropping and cultivar (conventional or transgenic). To determine association between data and agronomic variables, a biplot from CCA was obtained by overlaying a vector diagram based on coefficients from the canonical functions describing each canonical axis.

## 4. Results

A total of 66 weeds with constancy values higher than 5% were recorded in the 120 soybean surveys carried out in total through the five years of study. According to MRPP, floristic composition differed among years ($P < 0.01$). There were more annuals (35 species) than perennials (23 species), while annuals–biennials (two species) and annuals–perennials (one species) were rare. According to morphotype,

there were more dicotyledonous (53 species) than mono-cotyledonous (13 species). According to species origin almost the same quantities of native (27 species) and exotic (30 species) were present. Four species, *Chenopodium album* L., *Chenopodium ambrosioides* L., *Cyperus rotundus* L. and *Sida rhombifolia* L., were cosmopolitan (Table 1).

Among those species that presented high constancy values in the past (de la Fuente et al., 1999; Suárez et al., 2001), only a few, *Anoda cristata* (L.) Schelcht, *Digitaria sanguinalis* (L.) Scopoli, *Portulaca oleracea* L., and *Euphorbia lasciocarpa* Klotzsch, maintained their constancy across this period. These species dominated weed

Table 1
Functional structure in terms of life cycle, Cy (A: annual, B: biennial, P: perennial); morphotype, Mo (M: monocotyledonous, D: dicotyledonous); origin, O (N: native, E: exotic, C: cosmopolitan) and weed species of soybean crops in the central Rolling Pampas, Argentina, by descreasing mean constancy values

| Species | Cy | Mo | O | Code | Species constancy (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1995 | 1998 | 1999 | 2001 | 2003 |
| *Anoda cristata* (L.) Schelcht. | A | D | N | ANOCR | 100 | 90 | 90 | 72 | 100 |
| *Digitaria sanguinalis* (L.) Scopoli | A | M | E | DIGSA | 80 | 80 | 80 | 83 | 95 |
| *Portulaca oleracea* L. | A | D | E | POROL | 78 | 50 | 55 | 78 | 76 |
| *Sorghum halepense* (L.) Pers. | P | M | E | SORHA | 78 | 80 | 70 | 56 | 48 |
| *Euphorbia lasciocarpa* Klotzsch | A | D | N | EUPLA | 53 | 65 | 75 | 67 | 67 |
| *Chenopodium album* L. | A | D | C | CHEAL | 80 | 65 | 65 | 28 | 14 |
| *Stellaria media* (L.) Vill. | A | D | E | STEME | 40 | 55 | 55 | 17 | 33 |
| *Tagetes minuta* L. | A | D | N | TAGMI | 58 | 45 | 50 | 17 | 19 |
| *Oxalis chrysantha* (Kunth.) Prog. | P | D | N | OXACR | 20 | 60 | 45 | 28 | 24 |
| *Amaranthus quitensis* H.B.K. | A | D | N | AMAQU | 60 | 55 | 30 | 17 | 14 |
| *Taraxacum officinale* Weber in Wiggers | P | D | E | TAROF | 18 | 55 | 55 | 11 | 14 |
| *Echinochloa crus-galli* (L.) Beauvois | A | M | E | ECHCR | 68 | 50 | 10 | 6 | 19 |
| *Triticum aestivum* L. | A | M | E | TRIAE | 33 | | | 22 | 33 |
| *Bidens subalternans* De Candolle | A | D | N | BIDSU | 20 | 55 | 30 | 11 | 24 |
| *Cynodon dactylon* (L.) Pers. | P | M | E | CYNDA | 23 | 55 | 10 | 33 | 19 |
| *Veronica persica* Poir. | A | D | E | VERPE | 23 | 50 | 30 | 17 | 14 |
| *Trifolium repens* L. | P | D | E | TRIRE | 8 | 45 | 25 | 17 | 33 |
| *Cyperus* sp. | | M | | CYPSP | 8 | 15 | 10 | 22 | 19 |
| *Datura ferox* L. | A | D | E | DATFE | 88 | 40 | 30 | 11 | |
| *Carduus acanthoides* L. | A | D | E | CARAC | 33 | 45 | 45 | 6 | |
| *Sonchus oleraceus* L. | A | D | E | SONOL | 20 | 45 | 40 | 17 | |
| *Physalis viscosa* L. | P | D | N | PHYVI | 18 | 20 | 15 | 11 | |
| *Polygonum aviculare* L. | A | D | E | POLAV | 13 | 10 | | 11 | |
| *Convolvulus arvensis* L. | P | D | E | CONAR | 8 | | | 6 | |
| *Galinsoga parviflora* Cavanilles | A | D | N | GALPA | 20 | 20 | 15 | | |
| *Rumex crispus* L. | P | D | E | RUMCR | 23 | 20 | 10 | | |
| *Medicago sativa* L. | P | D | E | MEDSA | 23 | 10 | 10 | | |
| *Eragrostis cilianensis* (All.) E. Mosher | | M | | ERACI | 8 | 10 | 20 | | |
| *Lamium amplexicaule* L. | A | D | E | LAMAM | 8 | 15 | 10 | | |
| *Echinochloa colonum* (L.) Link. | A | M | E | ECHCO | 25 | 10 | | | |
| *Brassica rapa* L. | A | D | E | BRARA | 13 | 10 | | | |
| *Cucurbita andreana* Naudin | A | D | N | CUCAN | 8 | 10 | | | |
| *Althernanthera philoxeroides* (Mart.) Griseb. | P | D | N | ALTPH | 15 | | | | |
| *Polygonum convolvulus* L. | A | D | E | POLCO | 15 | | | | |
| *Setaria parviflora* (Poir.) Kerguelen | P | M | N | SETGE | 13 | | | | |
| *Jaborosa integrifolia* Lam. | P | D | N | JABIN | 10 | | | | |
| *Zea mays* L. | A | M | N | ZEAMA | | 10 | 30 | 17 | 29 |
| *Cyperus rotundus* L. | P | M | C | CYPRO | | 25 | 20 | | 19 |
| *Sida rhombifolia* L. | P | D | C | SIDRH | | 40 | 10 | 11 | 14 |
| *Eleusine indica* (L.) Gaertner | A | M | E | ELEIN | | 20 | 10 | | 14 |
| *Gleditsia triachanthos* L. | P | D | E | GLETR | | 20 | 10 | | 10 |
| *Solanum chenopodioides* Lam. | A | D | N | SOLCE | | 15 | 10 | | |
| *Cirsium vulgare* (Savi)Tenore | A | D | E | CIRVU | | 15 | | 11 | |
| *Artemisia annua* L. | A | D | E | ARTAN | | 25 | | 6 | |
| *Xanthium cavanilliesi* Schouw. | A | D | N | XANCA | | 10 | | 6 | |
| *Coronopus dydimus* (L.) Smith | A–B | D | N | CORDY | | 30 | | | |
| *Conyza bonariensis* (L.) Cronquist | A | D | N | CONBO | | 30 | | | |
| *Solidago chilensis* Meyer | P | D | N | SOLCH | | 20 | | | |
| *Bowlesia incana* Ruiz et Pav. | A | D | N | BOWIN | | 20 | | | |
| *Solanum sisymbrifolium* Lam. | P | D | N | SOLSY | | 15 | | | |
| *Gamochaeta* sp. | | <u>D</u> | | GAMSP | | 15 | | | |
| *Chenopodium ambrosioides* L. | P | D | C | CHEAM | | 15 | | | |

Table 1 (Continued)

| Species | Cy | Mo | O | Code | Species constancy (%) | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1995 | 1998 | 1999 | 2001 | 2003 |
| *Euphorbia hirta* L. | A–P | D | N | EUPHI | | 10 | | | |
| *Verbena gracilescens* (Cham.) Hert. | P | D | E | VERGR | | 10 | | | |
| *Paspalum* sp. | | M | | PASSP | | 10 | | | |
| *Xanthium spinosum* L. | A | D | N | XANSP | | 10 | | | |
| *Sonchus asper* (L.) Hill. | A | D | E | SONAS | | 10 | | | |
| *Hypochoeris* sp. | | D | | HYPSP | | 10 | | | |
| *Facelis retusa* (Lam.) Schultz Bip. | A | D | N | FACRE | | 10 | | | |
| *Conyza blakei* (Cabr.) Cabr. | A | D | N | CONBL | | | 20 | | |
| *Dichondra microcalyx* (Hallier.) Fabris. | P | D | N | DICMI | | | 10 | | |
| *Aster squamatus* (Spreng.) Hiernymus | P | D | N | ASTSQ | | | 10 | | |
| *Euphorbia peplus* L. | A | D | E | EUPPE | | | | 17 | |
| *Melilotus albus* Medikus | A–B | D | E | MELAL | | | | 11 | |
| *Fraxinus americana* L. | P | D | E | FRAAM | | | | 6 | |
| *Commelina erecta* L. | P | D | N | COMER | | | | | 14 |
| Number of surveys | | | | | 41 | 20 | 20 | 18 | 21 |

community over time (1995–2003), indicating that they were well adapted to the different environments of the center of the Rolling Pampas. The rest of species that presented high constancy values in the past, such as *Sorghum halepensis* (L.) Pers., *C. album* L., *Tagetes minuta* L., *Amaranthus quitensis* H.B.K., *Echinochloa crus-galli* (L.) Beauvois, and *Datura ferox* L. dominated weed community only at the beginning and decreased their constancy in the last years (Table 1).

*Althernanthera philoxeroides* (Mart.) Griseb., *Polygonum convolvulus* L., *Setaria parviflora* (Poir.) Kerguelen, and *Jaborosa integrifolia* Lam., that were present in the soybean weed communities previous to 1998, were not observed in the more recent surveys, in which *S. rhombifolia*, *C. rotundus*, *Eleusine indica* (L.) Gaertner and *Gleditsia triachantos* L. appeared as new components. *Melilotus albus* Medikus, *Fraxinus americana* L., and *Euphorbia peplus* L. were found for the first time in 2001 and *Commelina erecta* L. was surveyed for the first time in 2003.

Alpha (local) diversity and gamma (regional) diversity were linearly related ($P < 0.01$), while beta (differentiation) diversity was not related to gamma diversity (Fig. 1). The richness of all the functions was positively related to gamma diversity, except for monocotyledonous. There was no relationship between monocotyledonous and gamma diversity (Fig. 2).
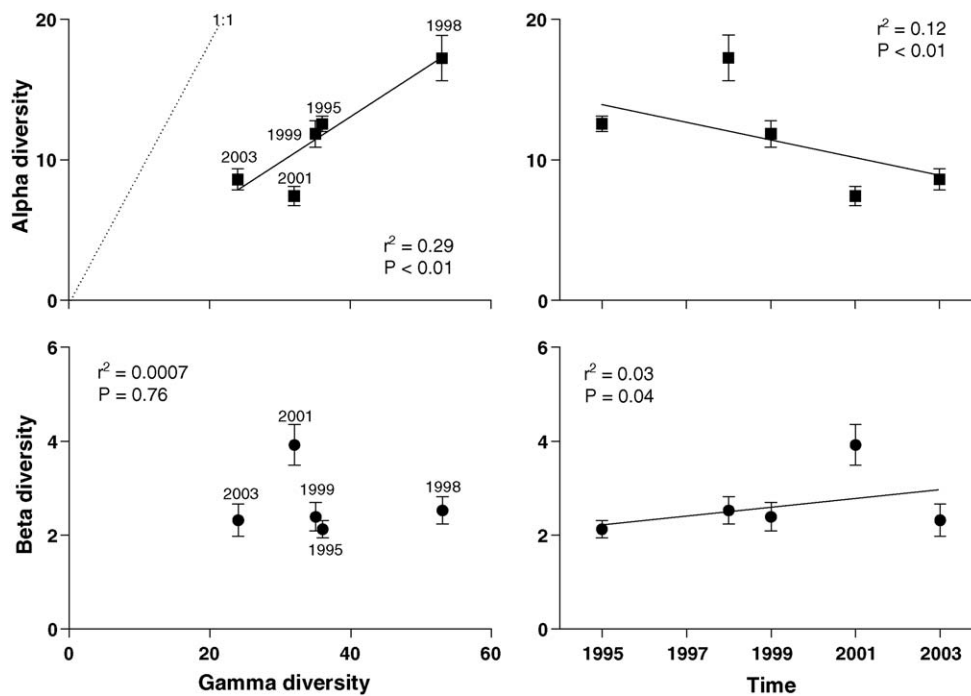


Fig. 1. Relationship between (■) alpha, (●) beta diversities and gamma diversity (left) and between (■) alpha, (●) beta diversities and time (right). Symbols represent mean values and bars represent S.E.M.
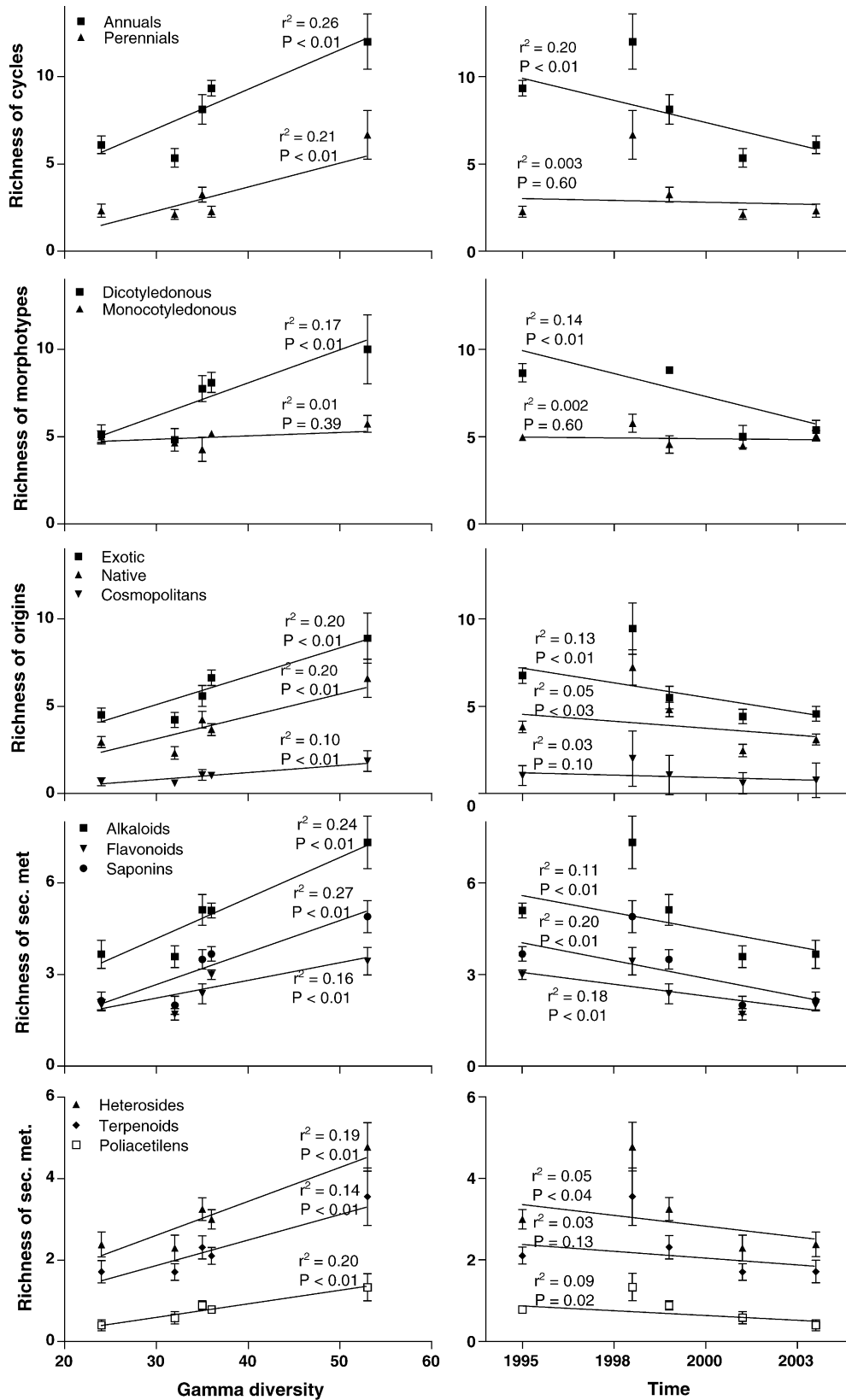
Fig. 2. Richness of functional types, life cycles, morphotypes, origins/distribution and secondary metabolites related to gamma diversity and time. Symbols represent mean values and bars represent S.E.M.

Fig. 3. Ordination diagram of weeds (code three first letters gene, two last letters species) and plots (□, conventional tillage and cultivars; △, no tillage and conventional cultivars; ■, no tillage and transgenic cultivars; ▲, conventional tillage and transgenic cultivars) in the two principal axes of CCA. Eigenvalue given for each axis represented the variance in the data matrix attributed to that axis. Vectors represent cultivar and tillage system.

Alpha diversity decreased over time ($P < 0.01$) (Fig. 1), probably accompanying the increase of soybean and no tillage area and the widely adoption of transgenic crops resistant to glyphosate herbicide between 1998 and 2003.

The alpha diversity of perennials, monocotyledonous and cosmopolitan species remained constant over time, while annuals, dicotyledonous, exotics and native species decreased ($P < 0.01$). The richness of secondary metabolites also decreased over time ($P < 0.01$), except for terpenoids (Fig. 2).

CCA was carried out on the five years of data for the 92 fields where management information was complete. *A. cristata*, *D. sanguinalis*, *P. oleracea*, *S. halepensis*, *E. lasciocarpa*, *C. album*, *Stellaria media* (L.) Vill., *T. minuta*, *Oxalis chrysantha* (Kunth.) Prog., *A. quitensis* and *Taraxacum officinale* Weber in Wiggers, the most constant species (Table 1), were located near the origin of the ordination diagram (Fig. 3). Tillage and cultivar were the main agronomic variables related to axis 1, as indicated by long vectors (Fig. 3) and by high inter-set correlation with the axis ($-0.74$ and $-0.63$, respectively). The first axis represented a

contrast between two groups of variables, conventional tillage system and non transgenic cultivars, belonging to 1995 survey (right side of the ordination diagram) and no tillage and transgenic cultivars, belonging mainly to 1998 and 2003 survey (left side of the ordination diagram). *Echinochloa colonum* (L.) Link., *Brassica rapa* L., *Cucurbita andreana* Naudin, *A. philoxeroides*, *P. convolvulus* and *J. integrifolia* were the species related to the first group of variables. *Verbena gracilescens* (Cham.) Hert., *Paspalum* sp., *Xanthium spinosum* L., *Sonchus asper* (L.) Hill., *Hypochoeris* sp., *E. peplus*, *M. albus*, *F. americana* and *C. erecta* were the species related to the second group of variables.

## 5. Discussion

From 1995 to 2003, some species that dominated soybean weed community in the past maintained their constancy values; others increased or decreased them at different rates. Other woody species, such as *F. americana*, *G. triacanthos*

and *S. rhombifolia*, that were only observed in waste and non arable lands in the past, became new components of cropland communities. Permanent no tillage favored the establishment of these species, which may avoid herbicide damage or may recover from its effects.

Each sampled field can be considered as a patch due to its homogeneous cultural management and biotic interactions that are especially driven by cultural practices (Ghersa and León, 1999). Taking this into account, the number of species present in each field is an estimator of patch or local diversity. Local (alpha) diversity and regional (gamma) diversity, resulting from all the species present in the mosaic, were linearly related. This relationship was interpreted by Cornell and Lawton (1992) as an indication of strong regional influence and weak influence of interactions within local communities, and the importance of dispersal as one of the main processes responsible of weed species assembly. Mainly if, as in this study, local sampling area was considerably stable and smaller (50 ha on average) than regional area ($5 \times 10^4$ ha) and body size of organisms was big enough (herbs) to prevent biases.

Both gamma and alpha diversity decreased over time. New technologies reduced differences among patches conforming the agricultural mosaic, and thus, homogenized the environment at regional-landscape levels. Habitat heterogeneity is associated with biodiversity at landscape level, thus a mosaic of different fields connected by non cropped habitats that can provide for a diversity of needs (such as refuges and dispersal corridors) is expected to aid species persistence and richness (Benton et al., 2003; Crawley, 1986; de la Fuente et al., 1999; Swift and Anderson, 1993).

In the present study, alpha diversity increased initially, between 1995 and 1998. When the first floristic surveys were carried out (1995), the continuous use of no tillage was rare since cropping was carried either with a continuous conventional cropping system or with a particular rotation of conventional and no tillage cropping systems (de la Fuente et al., 1999). In 1998, different cropping systems coexisted, the conventional ones the new ones and a blend of both. This spatial and temporal heterogeneity of habitats as well as the "biological inertia" related to the existence of a weed seed bank, may explain the high number of species recorded at that time. As the intensification of farming associated with a narrow range of techniques used in soybean crop expanded over the region, the species community changed to a set of species adapted to the new environment and conventional tilling habitat became nearly extinct.

Beta diversity was not related to soybean regional pool of weed species, thus it was probably related to the availability of refuges, which is linked to the heterogeneity of habitats in the landscape. The data of the 2001 season support this hypothesis, because it was an extraordinary dry season which would intensify the differences among fields resulting from their land-use history. Subtle soil differences among fields related to different cropping histories become apparent during dry seasons (Maddonni et al., 1999; Suárez et al., 2001), augmenting the differences among soil environments that filter annual weed recruitment, and also beta diversity.

Not only alpha diversity decreased but also species abundance decreased in the last years (1999–2003) (data not shown). Recruitment is an important process determining alpha diversity, influenced by organisms and habitat characteristics. The decrease of species abundance could be accompanied with a decrease in propagule density, because propagule density does not only affect the colonization of local communities, but also the internal interactions within these communities (Hillebrand and Blenckner, 2002).

In this work, functional richness was related to gamma diversity and decreased with time, except for monocotyledonous.

At the beginning of this study (1995) when mechanical and chemical techniques were combined to control weeds, recruitment occurred mainly from the seed bank thus favoring dicotyledonous species (Ghersa and Martinez-Ghersa, 2000).

Many species presented similar functionality. Rather than a superfluous repetition, redundancy is an insurance policy against the lost of function in the event that species were lost. The larger the number of functionally similar species in a community, the greater the probability that at least some of these species will survive changes in the environment and maintain the properties of the agroecosystem (Díaz and Cabido, 2001). Nevertheless, if cultural practices continue the ongoing homogenization of the environment at the landscape level, species richness will continue decreasing and functions that may be crucial for sustaining wildlife, such as pollinators or birds, may become extinct (Gerowitt et al., 2003).

## Acknowledgements

## References

Benton, T.G., Vickery, J.A., Wilson, J.D., 2003. Farmland biodiversity: is habitat heterogeneity the key? Trends Ecol. Evol. 18 (4), 182–188.

Booth, B.D., Swanton, C.J., 2002. Assembly theory applied to weed communities. Weed Sci. 50, 2–13.

Burel, F., Baudry, J., Butet, A., Clergeau, P., Delettre, Y., Le Coeur, D., Dubs, F., Morvan, N., Paillat, G., Petit, S., Thenait, C., Brunel, E., Lefeuvre, J.C., 1998. Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecol. 19 (1), 49–60.

Cornell, H.V., Lawton, J.H., 1992. Species interaction, local and regional processes, and limits to the richness of ecological communities: a theoretical perspective. J. Anim. Ecol. 61, 1–12.

Crawley, M.J., 1986. The structures of plant communities. In: Crawley, M.J. (Ed.), Plant Ecology. Blackwell Scientific Publications, Cambridge, MA, pp. 1–50.

de la Fuente, E.B., Suárez, S.A., Ghersa, C.M., León, R.J.C., 1999. Soybean weed community: relationship with cultural history and crop yield. Agron. J. 91, 234–241.

Díaz, S., Cabido, M., 2001. Vive la différence: plant functional diversity matters to ecosystem processes. Trends Ecol. Evol. 16 (11), 646–655.

Gerowitt, B., Bertke, E., Hespelt, S.K., Tute, C., 2003. Towards multi-functional agriculture-weeds as ecological goods? Weed Res. 43, 227–235.

Ghersa, C.M., Martinez-Ghersa, M.A., 2000. Ecological correlates of weed seed size and persistence in the soil under different tilling systems: implications for weed management. Field Crops Res. 67, 141–148.

Ghersa, C.M., León, R.J.C., 1999. Successional changes in agroecosystems of the rolling pampas. In: Walker, L.R. (Ed.), Ecosystems of Disturbed Ground. Ecosystems of the World, vol. 16. Elsevier, New York, pp. 487–502.

Hall, A.J., Rebella, C.M., Ghersa, C.M., Culot, J.Ph., 1992. Field–crop systems of the Pampas. In: Pearson, C.J. (Ed.), Field Crop Ecosystems. Ecosystems of the World, vol. 19. Elsevier, Amsterdam, The Netherlands, pp. 413–449.

Hillebrand, H., Blenckner, T., 2002. Regional and local impact on species diversity—from pattern to processes. Oecologia 132, 479–491.

Instituto Nacional de Tecnología Agropecuaria (INTA), 1974. Carta de suelos de la República Argentina. Hojas 3560-2, Rojas, 3560-3 Salto. ISAG, Buenos Aires, Argentina.

Luck, G.W., Daily, G.C., Erlich, P.R., 2003. Population diversity and ecosystem services. Trends Ecol. Evol. 18 (7), 331–336.

Magurran, A.E., 1988. A variety of diversities. In: Magurran, A.E. (Ed.), Ecological Diversity and its Measurement. Princeton Univ. Press, Princeton, NJ, pp. 81–99.

Maddonni, G.A., Urricariet, S., Ghersa, C.M., Lavado, R., 1999. Assessing soil quality in the Rolling Pampa using soil properties and maize characteristics. Agron. J. 91, 280–287.

McLaughlin, A., Mineau, P., 1995. The impact of agricultural practices on biodiversity. Agric. Ecosyst. Environ. 55, 201–212.

Michelena, R.O., Irurtia, C.B., Vavruska, F.A., Mon, R., Pittaluga, A., 1989. Degradación de suelos en el Norte de la Región Pampeana. INTA Pub. Tecn. 6.0. Centros Regionales de Buenos Aires Norte, Córdoba, Entre Ríos y Santa Fé. Proyecto de Agricultura Conservacionista.

Mielke Jr., P.W., 1984. Meteorological applications of permutation techniques 16 based on distance functions. In: Krishnaiah, P.R., Sen, P.K. (Eds.), Handbook of Statistics, vol. 4. Elsevier, pp. 813–830.

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

Naeem, S., Thompson, L.J., Lawler, S.P., Lawton, J.H., Woodfln, R.M., 1994. Declining biodiversity can alter the performance of ecosystems. Nature 368, 734–737.

Suárez, S.A., de la Fuente, E.B., Ghersa, C.M., León, R.J.C., 2001. Weed community as an indicator of summer crop yield and site quality. Agron. J. 93, 524–530.

Swift, M.J., Anderson, J.M., 1993. Biodiversity and ecosystem function in agricultural systems. In: Schulze, E.-D., Mooney, H.A. (Eds.), Biodiversity and Ecosystem Function. Springer-Verlag, Berlin, pp. 15–66.

ter Braak, C.J.F., 1987a. The analysis of vegetation–environment relationships by canonical correspondence analysis. Vegetatio 69, 69–77.

ter Braak, C.J.F., 1987b. Ordination. In: Jongman, R.H.G., ter Braak, C.J.F., van Tongeren, O.F.R. (Eds.), Data Analysis in Community and Landscape Ecology. 1st ed. Pudoc, Wageningen, The Netherlands, pp. 91–173.

Tilman, D., Downing, J.A., 1994. Biodiversity and stability in grasslands. Nature 367, 363–365.

Whittaker, R.H., 1975. Communities and Ecosystems. MacMillan Publishing, New York.