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Glyphosate management strategies, weed diversity and soybean yield in Argentina

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ABSTRACT

From their introduction in 1996, glyphosate resistant (GR) soybean cultivars have been rapidly adopted by farmers in Argentina and in other countries in the world. The high rate of adoption of this technology seems to be based on the simplicity of use provided by a single herbicide (glyphosate), its high efficacy to control many weeds and, the low costs of the technology relative to that used in conventional crops. During 2001–2002, 2002–2003 and 2003–2004 soybean growing seasons, field surveys and field experiments were performed with the aim of studying the effect of different glyphosate management strategies on the diversity of soybean weed communities, weed control, individual survival, fecundity and crop yield. In addition, the emergence pattern of three important weeds, *Digitaria sanguinalis*, *Cyperus rotundus* and *Anoda cristata*, was also studied. Both field surveys and field experiments were carried out on no-till soybean crops sown immediately after wheat or barley harvest (double cropped system). Experiments were set up in commercial soybean crops and consisted of different times of a single glyphosate application, two glyphosate applications and also the application of glyphosate plus a residual herbicide imazethapyr. *A. cristata*, *D. sanguinalis*, *Stellaria media*, *Chenopodium album* and *Cyperus* sp. were the most prevalent weeds recorded at pre-harvest of the soybean crops, showing regional constancy higher than 80% in both years. In three out of four field experiments, crop yield was not increased when glyphosate was applied twice compared with a single application of the herbicide. In addition there was a lower negative effect on weed species richness when glyphosate was applied once during the crop cycle than with two applications of glyphosate or glyphosate plus imazethapyr. *D. sanguinalis* escaped the glyphosate early treatment because of the long weed emergence period, while *A. cristata* and *C. rotundus* survived treatments due to their high individual tolerance. The results suggest that it is possible to manage glyphosate application to get high crop yield with a low impact on weed diversity, depending on the weed species and their abundance.

1. Introduction

Glyphosate resistant (GR) soybean is the most important transgenic crop and globally by 2009 was planted on 52% of the area sown with transgenic crops (James, 2009). The high rate of adoption of this technology seems to be based on the simplicity provided by the use a single herbicide (glyphosate), its high efficacy on many weeds and the lower cost than weed control used in conventional crop cultivars (Kudsk and Streibig, 2003; Vitta et al., 2004).

Soybean is the major crop in Argentina and the use of transgenic cultivars resistant to glyphosate has increased dramatically during the last decade (SAGPYA, 2010). By 2010 the area planted to soybean in Argentina had reached 18,000,000 M ha and a high proportion was under a no-tillage cropping system with glyphosate resistant varieties (SAGPYA, 2010). Interestingly, weed control costs decreased approximately four times under the no-till GR soybean system compared to production of non-transgenic cultivars with conventional tillage no-RR technology.

In spite of the advantages of GR crops, questions have been raised on the risk of losing biodiversity in agroecosystems. The rationale of this opposition is that the use of a single herbicide with high efficacy may reduce the food resources provided by weeds to other organisms (Watkinson et al., 2000; Conner et al., 2003).

Agriculture expansion may be one of the largest contributors to biodiversity losses or at least of several functional groups such as morphotypes and physiotypes (Benton et al. 2003, cited in De la Fuente et al., 2006). Most agronomic practices tend to reduce

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plant diversity in favor of a single crop species (Legere et al., 2005). Although weed diversity is commonly measured by the number of species (species richness), community studies also take into account both the number of species and their relative abundance. Synthetic diversity indices are used to characterize communities integrating both, species richness and also relative contribution of each species on the community (Magurran, 1988). Moreover, different authors evaluated the effect of different agronomic practices on weed community using those indices (Derksen et al., 1995; Stevenson et al., 1997; Legere et al., 2005; Sosnoskie et al., 2006; Gulden et al., 2009). Shannon diversity index (H') integrates both, richness and abundance in a single value and effective species richness ($e^{H'}$) is equivalent to the number of species required to produce the value of H' (Magurran, 1988).

Although glyphosate efficacy has been documented in various studies, few of them were focused on the effects of herbicide application on different demographic processes and on weed diversity. In this context, during 2002 and 2003, field surveys were carried out with the aim of studying weed community composition and diversity at pre-harvest of commercial RR soybean crops treated with glyphosate. In addition, four field experiments were also performed during 2002–2003 and 2003–2004 with the objective of study the effect of different glyphosate management strategies on weed community, individual survival, fecundity and crop yield and its components.

2. Materials and methods

2.1. Survey and experimental area

Field surveys and experiments were carried out at Alberti, Buenos Aires province, located at 35°2′S and 60°16′W on the rolling pampas of Argentina, with annual average rainfall of 950 mm and average temperature of 17 °C (Hall et al., 1992).

2.2. Weed survey

Fifty-four commercial soybean fields were surveyed in both growing seasons (2001–2002 and 2002–2003). All the fields had been sown immediately after wheat harvest and surveys were carried out during March and April before the soybean harvest. Average individual field area surveyed was 70 ha; field margins and depressions in fields were not sampled. In each field the number of species (species richness) was registered and the constancy of each one was calculated as the proportion of fields with presence of that species (Eq. (1)).

$$\text{Constancy}(\text{Ci})(\%) = \frac{\text{Number of fields with presence of species}(i)}{\text{Total field surveyed}} \times 100 \quad (1)$$

For each weed, frequency (2) and cover (3) were assessed. Within each field, thirty 1 m^2 quadrats were sampled and in each one of them, weeds species were identified and ground cover for each one was estimated visually.

Frequency for each species was calculated as:

$$\text{Frequency}(\text{Fi})(\%) = \frac{\text{Number of quadrats with the}(i)\text{species}}{\text{Total number of quadrats}} \times 100 \quad (2)$$

Weed cover was calculated as:

$$\text{Cover}(\text{Ci})(\%) = \frac{\sum \text{Average cover for each species in each field}}{\text{Total number of field surveyed}} \quad (3)$$

2.3. Field experiments

During 2002–2003 and 2003–2004 growing seasons, four on-farm experiments were carried out in commercial soybean fields. Soybean sowing was in a no-till system between 1 and 20 December at 0.52 m between rows with a seeding rate aimed to achieve 42 plants m^{-2}. Soils at the experimental fields were typical argiudols with 3.5% organic matter.

In 2002–2003 the glyphosate treatments consisted of one or two applications of herbicide, and in 2003–2004 glyphosate plus a residual herbicide was also included (Table 1). Each treatment was replicated four times and the experiment design was a randomised complete block. All experiments also included a weedy check plot. Experimental plots were 2.5 m wide × 7.0 m long and herbicides were applied with a CO_2-pressurized backpack sprayer delivering 130 l ha^{-1} at 50 lb pg^{-2} in normal air temperature and soil moisture conditions.

2.4. Data collection

2.4.1. Ground cover

Ground cover of weeds was measured four times during the crop cycle beginning before herbicide application ending prior to crop harvest. Herbicide effectiveness was evaluated during the crop cycle and pre-harvest regarding weed cover related to the check plots. Five sub-samples of 0.2 m^2 in each plot were established and number of species and soil cover for each one was assessed.

2.4.2. Individual survival and fecundity

Seedlings of *Anoda cristata* L. and *Euphorbia hirta* L. were identified with colour cable rings in each treatment before the herbicide application. At crop maturity, those individuals were classified as live or dead plants and individual survival rate was calculated as the proportion of live plants for each species related to the whole seedling population.

For *A. cristata*, mature plants were harvested by hand so that fruits and the number of seeds per fruit could be counted. Plant biomass was determined after drying at 70 °C for 48 h.

2.4.3. Weed emergence

For *Digitaria sanguinalis* L., *Cyperus rotundus* L. and *A. cristata*, emergence during the crop cycle was assessed identifying individuals with different colour cable rings from 10 days after crop emergence until crop maturity.

2.4.4. Weed community composition and diversity

Prior to harvest the number of species and individuals and cover were recorded and different indices were calculated (Magurran, 1988; Doucet et al., 1999):

$$\text{Shannon's diversity index} = H' = -\sum P_i \ln P_i \quad (4)$$

$$\text{Shannon's evenness}(E) = H'(\ln S)^{-1} \quad (5)$$

Table 1
Experimental treatments in 2002–2003 and 2003–2004.

	Description	Rate l f ha^{-1}	Phenological stage at application[a]
2002–2003			
T1	Weedy check		
T2	Gllyphosate (48%)	2.5	V3
T3	Glyphostae (48%)	2.5 + 2.5	V3–V5
2003–2004			
T1	Weedy check		
T2	Glyphosate 24% + Imazethapyr 2%	3	V3
T3	Glyphosate 48%	2.5	V3
T4	Glyphosate 48%	2.5 + 2.5	V3–V5
T5	Glyphosate 48%	2.5	V5

[a] Fehr and Caviness (1977) developmental scale.

$$\text{Effective species richness } e^H \text{ where } e = 2.72 \tag{6}$$

P_i: proportion of individuals of i species.
S, number of species by plot.

2.4.5. Crop yield and its components

At crop maturity, all plants from a 1.5 m length of the three central rows of each plot were harvested by hand. Pods per plant, seeds per pod and 1000 grain weight were assessed.

2.5. Data analysis

All the variables studied were analysed by ANOVA. Previously, data of cover were transformed in arcsine (x). When P value was significant ($P < 0.05$) means from different treatments were analysed by LSD test (Least Significant Difference) corrected by Fisher.

3. Results

3.1. Fields surveys

The total number of weed species (gamma diversity) observed regarding both years (2002 and 2003) was 48 (Table 2), 40 and 35 species in 2002 and 2003, respectively. Average field species richness was 13.6 (S.E. 1.42) in 2002 and 11.3 (S.E. 1.21) in 2003. *A. cristata*, *D. sanguinalis*, *Stellaria media* L., *Chenopodium album* L. and *Cyperus* sp. L. were recorded in more than 80% of the fields. Although most of species were spring summer annuals, there was also high constancy of *S. media* (autumn–winter). Moreover, there were 20 annual winter species observed in both years (Table 2). Regarding weed cover, *D. sanguinalis*, *A. cristata*, *S. media* and *Portulaca oleracea* L. showed cover higher than 0.4 (S.E. 0.05)% in 2002. In 2003, *A. cristata*, *D. sanguinalis*, *S. media*, *Cyperus* sp. and *Sida rhombifolia* L. showed the highest cover.

3.2. Field experiments 2002–2003

3.2.1. Glyphosate effectiveness and weed community composition

In the first experiment, before herbicide application, average weed cover and weed density was 26 (S.E. 2.8)% and 68 (S.E. 8.4) plants m^{-2} in the experimental area. Barley (*Hordeum vulgare* L.) had been the previous crop and was the dominant “weed” species with 50 (S.E. 6) plants m^{-2}. Other weeds registered were *D. sanguinalis*, *A. cristata*, *Sorghum halepense* L. Pers., *Euphorbia* sp. L., and with lower abundance *Polygonum* sp. and *P. oleracea*.

Regarding weed cover and density, glyphosate effectiveness forty days after the last application and at pre-harvest was not significantly different between herbicide treatments ($P > 0.05$) (data not shown).

Table 2
Averaged constancy (%) of weeds at pre-harvest in Alberti (2002 and 2003). Origin: exotic-cosmopolite-native. Class: monocotyledonous and dicotyledonous. Cycle: annual, biennial, perennial. Emergence: Au.W (autumn–winter) Sp.S (spring–summer).

Weed species	Averaged constancy	O C C/E
Anoda cristata L.	95.85	N D A Sp.S
Digitaria sanguinalis L.	90.25	E M A Sp.S
Stellaria media L.	86.65	E D A Au.W
Chenopodium album L.	85.25	C D A Sp.S
Cyperus sp. L.	81.65	C M P Sp.S
Portulaca oleracea L.	79.35	E D A Sp.S
Tagetes minuta L.	66.85	N D A Sp.S
Euphorbia sp. L.	65.4	D A Sp.S
Sida rhombifolia L.	57.65	C D P Sp.S
Sorghum halepense L. PERS.	53.6	E M P Sp.S
Oxalis chysantha = (Kunth) Prog	41	N D P Sp.S
Carduus sp. L.	38.15	D A Au.W
Sonchus oleraceus L.	30.65	E D A Au.W
Solanum sp. L.	26.5	N D Sp.S
Triticum aestivum L.	26	E M A Au.W
Amaranthus quitensis L.	26	N D A Sp.S
Datura ferox L.	22.5	E D A Sp.S
Cynodon dactylon (L.) PERS.	22.1	E M P Sp.S
Lamium amplexicaule L.	22.1	E D A Au.W
Bidens subalternans D.C.	19.85	N D A Sp.S
Verbena gracilescens (Cham.) Hert	18.75	E D P Sp.S
Viola arvensis MURR	16.9	E D A B Au.W
Anagallis arvensis L.	13.6	E D A Au.W
Trifolium repens L.	12.5	E M P Au.W
Echinocloa cruss galli P. BEAUV	12.1	E M A Sp.S
Dichondra repens J.R. & G. FORST	10.65	N D P Sp.S
Alternanthera philoxeroides (MART.) GRISEB	8.6	N D P Au.W
Anthemos cotula L.	6.5	E D A Au.W
Solanum sysimbrifolium LAM.	5.65	N D A Sp.S
Eleusine indica L. GAERTN.	5.6	E M A Sp.S
Poa annua L.	4.15	E M A Au.W
Molugo verticilata L.	4.15	E D A Sp.S
Brassica campestris L.	4.15	E D A Ot. W
Melilotus albus Medicus.	4.15	E D P Au.W
Convolvulus arvensis L.	3.5	E D P Au.W
Physallis viscosa L.	3.5	N D P Sp.S
Polygonum convolvulus L.	3.5	E D A Au.W
Vicia sativa L.	3.5	E D A Au.W
Conyza bonariensis L. CRONQ	3.5	N D A Sp.S
Veronica arvensis L.	3.5	E D A Au.W
Ammi visnaga L. (LAM.)	3.5	E D A Au.W
Setaria sp. BEAUV.	2.1	M A Sp.S
Gleditisia triancanthos L.	2.1	E D P Sp.S
Silene gallica L.	1.5	N D A Au.W
Gamochaeta spicata (LAM.) CABR.	1.5	N D A Au.W
Zea mays L.	1.5	E M A Sp.S
Bowlesia incana RUIZ & PAV.	1.5	N D A Au.W
Panicum sp. L.	1.5	E M A Sp.S

In the second experiment, weed species observed in all plots before herbicide application were *Triticum aestivum* L., *E. hirta*, *C. rotundus*, *A. cristata* and *Polygonum* sp. and total weed cover and density was 31 (S.E. 2.8)% and 107 (S.E. 11.2) plants m^{-2}. As in experiment 1, the herbicide effectiveness was not significantly different between treatments. Weed cover was 83% and 91% ($P > 0.05$) for the treatments with one and two glyphosate applications, respectively.

Species richness decreased with high intensity use of glyphosate, $e^{H'}$ was affected by herbicide application regardless of the glyphosate treatment and Evenness was not affected by herbicide application (Table 3). *A. cristata*, *C. rotundus*, *E. hirta*, *P. oleracea*, *C. album*, *S. rhombifolia*, *S. media*, *Carduus* sp. L. and *Sonchus oleraceus*, were recorded in glyphosate treatments.

Table 3
Species richness, effective species richness ($e^{H'}$) and evenness in all experiments. Means followed by different letters in each column are significantly different ($P < 0.05$).

	Species richness		$e^{H'}$		Evenness		Yield	
	Exp1	Exp2	Exp 1	Exp 2	Exp 1	Exp 2	Exp 1	Exp 2
2002–2003								
Weedy check	15a	13a	3.9a	4.1a	0.5	0.55	878b	2061b
Glyphosate V3	9b	8b	2b	3b	0.3	0.55	2145a	2845a
Glyphosate V3-V5	6c	4c	1.9b	2b	0.35	0.55	2174a	2525a
2003–2004								
Weedy check	6a	9a	2.4	2.5a	0.5	0.4 bc	903d	1021b
Glyphosate V3	4ab	6b	2	1.7ab	0.5	0.3 c	1964c	2021a
Glyphosate V5	4ab	5bc	2.5	2.5a	0.65	0.6 a	2082c	1956a
Glyphosate V3-V5	5ab	3bc	2.6	1.6b	0.6	0.5ab	3016a	2105a
Glyph + Imaz.(V3)	3b	3c	2.4	1.5b	0.8	0.5ab	2579b	2075a

3.2.2. *Weed survival and fecundity*

In the average of both glyphosate treatments individual weed survival was 10 (S.E. 1.2)% and 20 (S.E. 1.8)% for *E. hirta* and *A. cristata*, respectively. In the case of *A. cristata*, individual mean biomass was 5 (S.E. 0.5) g and 19.8 (S.E. 1.8) g ($P < 0.05$) treated and check plots respectively, and fecundity was 135 and 540 seeds, respectively in treated and check plots.

3.2.3. *Crop yield*

In 2002–2003, glyphosate application increased crop yield (Table 3). In both experiments the number of pods by square meter were also significantly higher with glyphosate application than in the weedy check ($P < 0.05$). In the average of both experiments these figures were 544 (S.E. 56), 797 (S.E. 81) and 856 (S.E. 84) pods by square meter on weedy check, one glyphosate and two glyphosate applications treatments, respectively.

3.3. *Field experiments 2003–2004*

3.3.1. *Glyphosate effectiveness and weed community composition*

In the first experiment seven weed species were registered before the herbicide application and *D. sanguinalis* and *C. rotundus* were dominant with initial cover and density of 27% and 308 plants m^{-2} and 4% and 63 plants m^{-2}, respectively. *A. cristata*, *P. oleracea*, *Cynodon dactylon* L., *T. aestivum* and *Carduus* sp., were also registered but with low abundance.

The cover of *D. sanguinalis*, during the crop cycle was significantly different ($P < 0.05$) between treatments. Glyphosate applied at V3 and V5 and glyphosate applied with imazethapyr had low cover during the crop cycle and provided the most effective control the weed. Glyphosate applied at V5 increased the weed control effectiveness at crop maturity (Table 4) and weed cover was similar to that with two glyphosate applications and glyphosate with imazethapyr. On the other hand, when glyphosate was applied at V3 weed cover was higher than with the other treatments ($P < 0.05$) diminishing weed control effectiveness at crop maturity (Table 4).

Regarding the effect on weed community at pre-harvest, species richness showed significant differences between treatments but these differences were not reflected on diversity indices (Table 3).

In the second experiment, 13 species were recorded before herbicide application and total weed cover was 13%. In addition, weed density was 97 plants m^{-2} and the most abundant was barley. However, from the beginning of January there was an increase of emergence of *D. sanguinalis*, and *C. rotundus*

During the crop cycle imazethapyr + glyphosate and glyphosate applied twice were significantly ($P < 0.05$) more effective than one glyphosate application. These figures were 92 (S.E. 0.8)% and 89.4 (S.E. 0.82)% with imazethapyr + glyphosate and glyphosate applied twice, respectively. On the other hand with one glyphosate applications the effectiveness was not higher that 85% (S.E. 0.92). There were significantly differences ($P < 0.05$) between treatments in weed species richness and in weed diversity indices. Species richness and $e^{H'}$ decreased with the increase of herbicides application. On the other hand, species evenness tended to be lower in the weedy check and when glyphosate was applied early compared to all other treatments (Table 3). Regarding both experiments *D. sanguinalis*, *C. rotundus*, *A. cristata* and *H. vulgare* were registered in all the treatments.

3.3.2. *Weed emergence*

Weed emergence patterns of *D. sanguinalis* and *C. rotundus* reflected that almost 65% of the whole population had emerged during ten days from crop emergence and continued until crop maturity with the same emergence pattern (Fig. 1). On the other hand, the emergence of *A. cristata* was later than that of *D. sanguinalis* and only 15% of the whole population emerged during the first ten days from the crop emergence (Fig. 1). At the beginning of crop flowering more than 85% of *A. cristata*, *D. sanguinalis* and *Cyperus* sp. plants had emerged.

3.3.3. *Weed survival*

The effectiveness of *C. rotundus* control was lower than for *D. sanguinalis* (Table 4). Individual survival in *C. rotundus* was significantly ($P < 0.05$) different between treatments. Survival with glyphosate applied twice and glyphosate plus imazethapyr was 1 and 5%, respectively but when glyphosate was applied once individual survival was higher than 40%.

Table 4
Effectiveness (%) in *Digitaria sanguinalis* and *Cyperus rotundus*. control 12 days after first application (24-1), 25 days after the second application (19-2) and at pre-harvest (24-04). Means followed by different letters in each column are significantly different ($P < 0.05$).

Herbicide treatments	*Digitaria sanguinalis* control %			*Cyperus* sp. control %	
	24-01	19-02	24-04	24-01	24-04
Glyphosate V3	86 b	69 b	31 c	42 a	30 b
Glyphosate V5		56 c	81 b		30 b
Glyphosate V3-V5	83 b	98 a	88 b	48 a	80 a
Imaz.+Glyp.(v3)	96 a	97 a	97 a	46 a	82 a

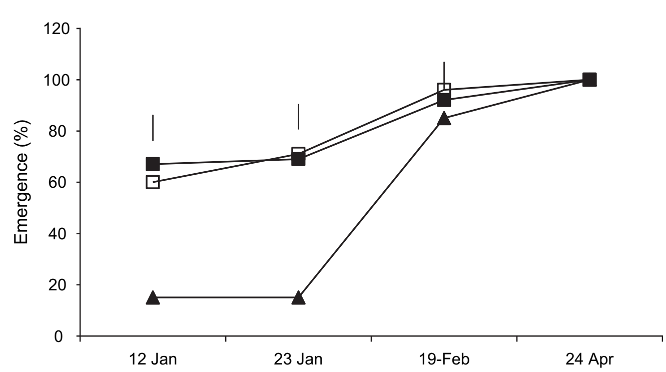

Fig. 1. Emergence pattern for *Digitaria sanguinalis* (■), *Cyperus* sp. (□) and *Anoda cristata* (▲) on weedy check plots in 2003–2004. Bars represent LSD ($P < 0.05$) between treatments.

3.3.4. Crop yield

In 2003–2004, there were significant differences between herbicide treatments only in the first experiment (Table 3). Crop yield was positive and significantly related with variations in grain number and, grain number was explained by the number of pods per plant. On the other hand, grain weight and the number of grains per pod were not significantly affected by the herbicide treatment (data not shown).

4. Discussion

The regional diversity registered in this study was 40 species in 2003 and 35 in 2004. In surveys performed by De la Fuente et al. (2006) in the same farming area, 24 species were registered in 2003, whereas in 1995, prior to the adoption of transgenic soybean, 36 species were recorded. Weed richness reduction was explained by the authors regarding the widespread adoption of glyphosate resistant soybean as well as no-till farming systems causing an important reduction of the agricultural landscape heterogeneity and, consequently, of biodiversity (De la Fuente et al., 2006). However, our studies do not show evidence of a decrease in regional diversity. Likewise, our results agree with Puricelli and Tuesca (2005) surveys in studies of continuous glyphosate applications in different rotation systems, in Argentina that reported an increase of the specific richness at crop pre-harvest with prevalence of late emergence weeds that escaped treatments.

The present survey was performed in glyphosate resistant no-till double cropped (wheat-soybean) at soybean pre-harvest, 50 days later than was carried out by De la Fuente et al. (2006). The length of the field emergence time of different species can explain the differences observed between both studies. *Cyperus* sp. that have an extended emergence period (Vitta et al., 1999) was reported in almost 25% of the fields by De la Fuente et al. (2006) but in more than 80% of the fields in the present survey. However, *A. cristata*, *D. sanguinalis* and *P. oleracea*, were reported with high constancy in both studies. The increase of annual grasses such as *D. sanguinalis*, *Setaria* sp. as well as wind-dispersed species such as *Sonchus oleraceus*, *Taraxacum officinale* and *Carduus acanthoides* in no-till farming systems has already been documented by other authors (Tuesca et al., 2001; Sosnoskie et al., 2009).

In the present work, different glyphosate management strategies reduced the specific richness, reducing the number of species, when the herbicide treatment intensity increases (two applications of glyphosate or glyphosate in combination with a pre-emergence herbicide). In terms of diversity indices, herbicides application reduced the Effective Species Richness ($e^{H'}$) in 2002–2003 and differences between treatments were only registered in one of the 2003–2004 experiments. In most of the treatments evenness was between 0.4 and 0.6 suggesting little evidence of truly dominant species (Derksen et al., 1995; Legere et al., 2005). Diversity indices were similar to other previously reported for other cropping systems (Puricelli and Tuesca, 2005; Scursoni et al., 2006). Although weedy checks have the highest weed abundance this does not imply highest diversity. Diversity indices can reflect part of the complexity of weed communities and allow evaluation of the impact of different management practices. Other effects of weed management such as species shift cannot be captured by a single index. Changes in dominant species have more implication for weed management that changes on the diversity of weed community (Legere et al., 2005) Moreover, rank abundance curves reveal more information about weed community structure than diversity indices (Gulden et al., 2009).

The results in weed control efficacy showed significant differences between species, particularly in the case of *C. rotundus*. Several authors have reported the variability in *Cyperus* sp. control with glyphosate, since herbicide application time dose or weed growth stage influence control efficacy (Nelson et al., 2002). Regarding *D. sanguinalis*, our results agree with those published by Arnold et al. (1997) who reported low weed control levels with a single application due to the emergence of late weed cohorts that escaped the herbicide application. In this respect, it is important to be aware of species that escape management practices and become the pre-dominant weeds in the fields. Understanding weed emergence patterns and determining when to target a weed are important aspects to be consider in Integrated Weed Management System (Hilgenfeld et al., 2004).

Herbicides affected growth and individual weed fecundity. The results obtained with *A. cristata* agree with those published by Puricelli et al. (2002) who reported an individual fecundity of 70–87 seeds/plant. Interestingly, from 8% to 14% of the buried seeds up to 15 cm deep can emerge in the following cropping year (Puricelli et al., 2002). Thus, regarding a 100% seed dispersal and plant densities of 0.6 plants m^{-2} before crop harvest, as was recorded in the survey, and fecundity of 50 seeds/plant, 3 plants m^{-2} could be generated in the following cropping year.

The results suggest that it is possible to regulate glyphosate effects upon the structure of weed communities by modifying its use intensity, depending on target species and its abundance. In three out of four experiments, crop yield with a single application of glyphosate was not lower than the obtained with two applications of glyphosate. Nevertheless, in experiment 1 of 2003–2004, with high abundance of *D. sanguinalis*, it was necessary to apply twice or to include a residual herbicide.

Crop yield obtained with treatments which maintained the least weed cover from V3 crop stage presented the highest grain number and consequently the highest yields, suggesting that the critical period for late control would be around V3 crop stage. Nevertheless, it must be pointed out that critical period for control may vary due to different environmental factors as well as for weed species and density (Moiser and Oliver, 1995; Dalley et al., 2004), row width (Knezevic et al., 2003), cropping system (Mulugeta and Boerboom, 1996) and weed location, either in rows or inter-rows (Bedmar et al., 2000).

The decision regarding glyphosate management strategy should consider not only the crop but also weed species, its abundance and phenology as well as the impact on biodiversity. A more intensive herbicide use, i.e. more than one application during the crop cycle, do not always increase crop yields. Therefore, it will be possible to increase herbicide use efficiency and sustainability in the use of inputs and resources, increasing the availability of growth limiting factors and minimizing those that reduce crop yield while maintaining weed community indices within reasonable agricultural values.

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