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PHYTOSOCIOLOGICAL CHARACTERIZATION OF WEEDS AS A FUNCTION OF RESIDUAL HERBICIDES APPLIED TO RICE GROWN UNDER SPRINKLER IRRIGATION

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SUMMARY

We aimed to characterize the weed community in sprinkler irrigated rice, previously applied with residual herbicides for two years, as well as to infer about sustainability of the management applied to the fields based on an ecological approach. The experiment was conducted during the cropping seasons 2013/14 and 2014/15, under sprinkler irrigation. Rice was planted in the second-half of October, using the cultivar PUITA INTA CL. Herbicides were applied in pre- and post-emergence (sequential application) of crop and weeds. Ryegrass (*Lolium multiflorum*) was planted in winter. In May 2015, soil samples were collected for the soil seed bank study. Phytosociological characterization of weeds emerged from the seed bank was conducted from May 2015 to January 2016, until soil seed bank depletion. *Echinochloa crusgalli*, *Fimbristyllis* sp., *Cyperus esculentus* and *Killinga brevifolia* were the weeds to which most concern should be directed when growing rice under sprinkler irrigation in lowland areas of Southern Brazil. Their competition strategies are based on density. Herbicides used should be efficient in controlling at least these four weed species. A selecting action of herbicides on weed species was botanically characterized, as the weed species reported after two cropping seasons depended on the herbicide treatment applied.

INTRODUCTION

Rice is a staple food for nearly half the world's population, being cultivated in 112 countries. The demand for water in paddy rice is considerably high, reaching as much as 8000–10,000 m^3 of water per hectare to supplement rainfall, in an irrigation period of 80–100 days (SOSBAI, 2014). Sprinkler irrigation is being tested for rice cultivation in Brazil, claiming for 50% water savings when sprinkler irrigated rice is compared to paddy rice (Parfitt *et al.*, 2011). This water surplus may be used either to increase rice acreage or to irrigate crops on additional fields with great potential to be applied in rice growing areas with low water availability. In the rice fields of Southern Brazil, several plant species may be planted during winter, but ryegrass (*Lolium multiflorum*) is usually adopted. This plant serves as pasture for beef or milk cattle, as well as sheep feeding, allowing crop-livestock succession in lowland areas where only rice is planted in summer (Agostinetto and Vargas, 2014). Thus, traditional rice fields in Southern Brazil usually succeed ryegrass, and the adoption of the sprinkler irrigation in rice would favour the success of the crop (rice)/livestock (cattle/ryegrass) succession.

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In rice crop, one of the factors that most influence the decrease in yield and final product quality is the presence of weeds, which compete with rice for physical space, light and nutrients. These species occur in great diversity, presenting high capacity to compete, which makes their control difficult even with all the technology and management practices known for the production of rice in Brazil (SOSBAI, 2014). One of the main management practices used in an attempt to increase weed control, associated with the winter crop for mulching or grazing, is the application of pre- or post-emergence herbicides (Oliveira, 2011). Vanlieshout and Loux (2000) conducted trials to evaluate the efficacy of residual selective herbicides in soybean associated with glyphosate and verified higher than 85% control by the end of crop cycle. However, this procedure is not applicable if succeeding crop is susceptible to the residual herbicide previously applied, resulting in damages to crop development or yields (Mancuso et al., 2011).

Due to its high efficiency, fast action and attractive cost, chemical weed control has been irrationally misused, causing problems such as the appearance of resistant species to herbicides, phytotoxicity in areas that are not grown with herbicide tolerant cultivars or that are grown with crop species susceptible to herbicide drift and, as mentioned above, phytotoxicity caused by residual effect in soil (Agostinetto and Vargas, 2014). In fact, herbicides should not be used as the single weed management strategy in a crop field and they should be associated with other management practices aiming to suppress weed species (Jastrzebska *et al.*, 2013). Some cover crops also present allelopathy, being able to inhibit the development of other plants (Barbour *et al.*, 1998), including weed species. In this context, the phytosociological survey, which is a group of ecological assessment methods that aims to determine the composition of the plant community and the distribution of species within the community, was used to understand the dynamics of species within the ecosystem formed into a sprinkler irrigated rice crop, where residual herbicides for weed control were used. The phytosociological analysis can assist in weed management strategies and adaptation of management practices (Concenço, 2015). In this sense, we aimed with this study to characterize the weed community before planting in sprinkler irrigated rice field, where distinct residual herbicides were previously applied for two years, as well as to infer about sustainability of the management applied to the fields based on an ecological approach.

MATERIAL AND METHODS

The experiment was carried out in a rice field in Capão do Leão RS, Brazil (Lat: −31.8209; Lon: −52.4588°), during the cropping seasons 2013/14 and 2014/15, under sprinkler irrigation, in soil classified as Planosol (Planossolo in the Brazilian Soil Classification System) (Olendzki *et al.*, 2009). The experimental design was in completely randomized blocks with four replications.

Rice was planted in the second half of October, by using 100 kg ha^{-1} of rice (*Oryza sativa*) seeds of the cultivar PUITA INTA CL (Clearfield® variety). Fertilization and other agricultural practices were done according to the official Brazilian

Table 1. Description of the treatments and herbicides used in 2013/14 and 2014/15 cropping seasons.

Treat.	Herbicides applied in pre-emergence	Dose (g ha^{-1})	Herbicides applied in post-emergence	Dose (g ha^{-1})
T1	Control (no application)		Control (no application)	
T2	Clomazone	360	Cyhalofop-butyl	180
T3	Clomazone	450	Cyhalofop-butyl	180
T4	Penoxsulam	48	Cyhalofop-butyl	180
T5	Penoxsulam	36	Cyhalofop-butyl	180
T6	Imazethapyr+Imazapic	75+25	Cyhalofop-butyl	180
T7	Imazethapyr+Imazapic	56.2+18.7	Imazethapyr+Imazapic	56.2+18.7
T8	Imazapyr+Imazapic	73.5+3.5	Cyhalofop-butyl	180

recommendation for rice (SOSBAI, 2014). Herbicides tested in the present study were chosen because they represent about 90–95% of the herbicides regularly used in rice fields of Southern Brazil, both in paddy and sprinkler irrigated rice (Table 1), being the treatments defined as: T1 – control treatment (no application); T2 to T5 – clomazone or penoxsulam followed by cyhalofop-butyl; T6 – commercial mixture of imazethapyr+imazapic followed by cyhalofop-butyl; T7 – two sequential applications of the commercial mixture of imazethapyr+imazapic; T8 – commercial mixture of imazapyr+imazapic followed by cyhalofop-butyl. The first set of applications was accomplished at post-planting, in pre-emergence of both crop and weeds; the sequential applications, with cyhalofop-butyl or imazethapyr+imazapic, were done in early post-emergence of both crop and weeds (Table 1). Herbicide applications were accomplished by using a backpack CO_2-propelled sprayer at 40 psi (2.81 kgf cm^2), connected to a bar equipped with four 110.02 nozzles, spaced in 0.50 m, spraying 125 L ha^{-1} of herbicide solution.

Between cropping seasons, after rice was harvested, ryegrass (*L. multiflorum*) was planted for soil mulching in winter. This simulates the traditional winter management by rice farmers in Southern Brazil. The dry mass of ryegrass at the flowering stage averaged 1750 kg ha^{-1} for all herbicide treatments, being burned down with glyphosate (1080 g a.i. ha^{-1}) 20 days prior to planting rice in the second cropping season.

In May 2015, intact soil samples with 15 cm × 10 cm × 5 cm (length × width × depth) were collected in the experimental units, being placed in trays. For eight months, favourable conditions were provided for the emergence of weeds under greenhouse, with average temperature of 25±4 °C and soil moisture near to field capacity. Phytosociological characterization of weeds emerged from the seed bank was done from May 2015 to January 2016, until soil seed bank depletion. Every 20 days, all emerged seedlings and plants were identified, collected and stored by species, being dried in an oven with forced air circulation at 60 °C for subsequent determination of dry mass. Soil samples were then revolved, deposited back to the trays, being subjected to a new emergence cycle of 20 days. Sampling precision based on density (Pr.De) and dominance (Pr.Do) was obtained as follows (Barbour *et al.*, 1998):

$$\text{Pr.De} = \frac{1}{s^2\,(\text{De})} \tag{1}$$

$$\text{Pr.Do} = \frac{1}{s^2\,(\text{Do})} \tag{2}$$

where s^2 (De) = sampling variance based on Density; and s^2 (Do) = sampling variance based on Dominance.

The number of plants (units m^{-2}) and total dry mass (g m^{-2}) of the weed community (absolute infestation) were presented in histograms with their standard errors, being also compared by Scott-Knott at 5%. Dataset of absolute infestation was tested for normality by Shapiro–Wilk, and when needed, transformation by $\sqrt{(x)}$ was done. Density (number of individuals), frequency (spatial distribution of species) and dominance (ability to accumulate mass) were estimated, which were used to obtain the importance value for each species in each area, according to Pandeya *et al.* (1968) and Barbour *et al.* (1998), as follows:

$$de = \frac{I}{TI} * 100 \tag{3}$$

$$fr = \frac{Q}{TQ} * 100 \tag{4}$$

$$do = \frac{DM}{TDM} * 100 \tag{5}$$

$$iv = \frac{de + fr + do}{3} \tag{6}$$

where de = relative density (%); fr = relative frequency (%); do = relative dominance (%); iv = importance value (%); I = number of individuals of species x in area r; TI = total number of individuals in area r; Q = number of samples evaluated in area r where species x is present; TQ = total number of samples in area r; DM = dry mass of individuals of species x in area r; TDM = total dry mass of weeds in area r.

The importance value (iv) locates each weed species within the community, depending on its ability to cause damage (severity of occurrence), based on the three parameters previously mentioned. Areas were also intra-analyzed for species diversity by Simpson's (D) and Shannon-Weiner's (H′) indices (Barbour *et al.*, 1998), and the SEP (Shannon-Weiner Evenness Proportion) sustainability coefficient was determined according to McManus and Pauly (1990), being as follows:

$$D = 1 - \frac{\sum ni * (ni - 1)}{N * (N - 1)} \tag{7}$$

$$H' = \sum \left(pi * \ln\left(pi\right)\right) \tag{8}$$

$$\text{SEP} = \frac{Hd'}{H'} \tag{9}$$

where D = Simpson's diversity index; H' = Shannon-Weiner's diversity index (based on density); ni = number of individuals of species 'i'; N = total number of individuals

Table 2. Sampling precision based on the density and dominance of weed species in rice fields, as function of herbicide residue and cover crops. Embrapa Temperate Agriculture, Pelotas-RS, 2014.

Treat.	PrDe*	PrDo
1	1.86	1.65
2	5.76	4.53
3	8.90	6.44
4	15.81	66.72
5	11.16	6.40
6	12.94	19.42
7	5.79	2.16
8	8.44	3.90

*PrDe = sampling precision based on weed density.
PrDo = sampling precision based on weed dry mass.

in the sample; pi = proportion of individuals in the sample belonging to species 'i'; SEP = Shannon-Weiner Evenness Proportion; and Hd' = Shannon-Weiner's diversity index (based on dominance).

Subsequently, areas were compared by the binary asymmetric similarity coefficient of Jaccard. Based on Jaccard's coefficients, the similarity matrix was prepared, and from this one the dissimilarity matrix was obtained (1-similarity), as follows:

$$\mathcal{J} = \frac{c}{a + b - c} \tag{10}$$

$$Di = 1 - \mathcal{J} \tag{11}$$

where $\mathcal{J}$ = Jaccard's similarity coefficient; a = number of species in area 'a'; b = number of species in area 'b'; c = number of species common to areas 'a' and 'b'; and Di = dissimilarity.

Multivariate analysis of hierarchical clustering was performed from the dissimilarity matrix, by the UPGMA (Unweighted Pair Group Method with Arithmetic Mean) hierarchical clustering method (Sneath and Sokal, 1973). The critical level for separation of groups in the cluster analysis was based on the arithmetic mean of similarities in the original matrix of similarity (Barbour *et al.*, 1998), disregarding crossing points between the same areas in the matrix. Group validation was accomplished by the cophenetic correlation coefficient (Sokal and Rohlf, 1962), obtained by Pearson's linear correlation between the original matrix of dissimilarity and its respective cophenetic matrix. Diversity and similarity coefficients and cluster analysis were obtained in the R statistical environment (R Development, 2015). All equations and procedures, both for area sampling and community description with species clustering, followed recommendations by Barbour *et al.* (1998) for synecological analyses.

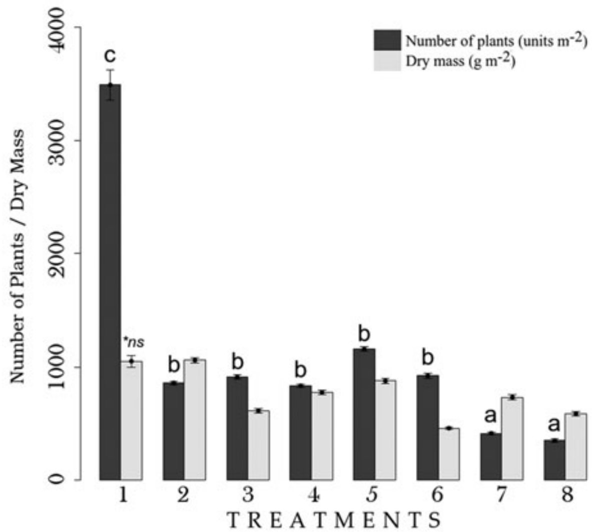

Figure 1. Density and dry mass of weeds in rice fields as affected by herbicides. For treatments 1–8, see Table 1.

RESULTS AND DISCUSSION

Sampling precision proved that all areas were reliably sampled (Table 2), according to the described by Bordeau (1953) and Goldsmith and Harrison (1976), who established that the variance of sample means increases in the reverse order to the number of sites sampled per area. Barbour *et al.* (1998) have consolidated sampling precision in defining that the inverse of the variance (Equation 1) should be used as a precision indicator. In this study, data was standardized previously to this analysis according to Concenço (2015), and '1' was considered as the minimum precision value for a reliable sampling.

Number of weeds per square meter (Figure 1) indicated high infestation in all treatments, with about 600–1200 individuals per square meter. Treatment 1 was an exception, presenting 3490 weed individuals per square meter. After the proper dataset transformation for reaching normality, three groups were formed by Skott-Knott (at 5%), regarding the number of weed individuals per treatment: (i) treatment 1, (ii) treatments 2– 6, and (iii) treatments 7 and 8. Considering dry mass accumulation by these individuals (Figure 1), there was no difference among treatments according to the F-test (at 5%) with an overall average of 770 g m^{-2} of weed dry mass.

Herbicides affected the number of weeds established in rice field, being treatments 7 (imazethapyr + imazapic) and 8 (imazapyr + imazapic) superior to the other herbicide treatments in efficiency (Figure 1). Such difference was not observed for dry mass, indicating that most weed species could be most efficient in producing seeds compared to their respective ability to occupy the area. This is important for crop management, as weed species whose survival strategy is based on numerous offspring (density) are supposed to be controlled at pre-emergence; those investing on dry mass and area occupation (dominant) and at the same time presenting low frequency are usually most efficiently controlled at post-emergence, and infrequent species may require a localized herbicide application, opposite to a broadcast herbicide application (Aldrich, 1984; Barbour *et al.*, 1998).

When treatments are compared in terms of composition of infestation (Table 3), barnyardgrass (*Echinochloa crusgalli*) was responsible for 22.6% of the importance value of infestation, with 51.7% of the dominance in the area. This means that supposing this weed species is removed from the system, about 22% of the problems with weeds will be eliminated until another species takes advantage of physical space made available by *E. crusgalli* control. This weed was followed by *Cyperus esculentus*, *Cynodon dactylon*, and *Fimbristylis* sp., with 12.9%, 11.1% and 9.6% of the dominance, respectively (Table 3). Herbicides to be adopted in such field are supposed to be efficient on these weed species. In fact, all herbicides were efficient in controlling barnyardgrass as IV for this weed was reduced to 15.8%, 5.2%, 4.9%, 5.4%, 8.6%, 0% and 8.6%, respectively, for herbicide treatments 2–8, while it was 22.6% for the control (Table 3). In none of these treatments there was a single weed able to take the place of barnyardgrass in infestation when it was chemically controlled. However, *C. esculentus* had its importance value (*iv*) increased under application of low dose of clomazone (T2), any dose of penoxsulam (T4 and T5), and any dose or mixture of imazethapyr, imazapyr or imazapic (T6 to T8). The same species were highly dominant at T4, but with low frequency (Table 3). The other species of *Cyperus* were not important in those treatments.

Barnyardgrass is supposed to be efficiently controlled by pre-emergence applications of the ALS-inhibiting herbicides. Lack of control of *C. esculentus* in this study was attributed to a difference in susceptibility of this species to the herbicides compared to other *Cyperus* species, which could result in distinct control levels as residual effect is reduced with degradation of the herbicide in soil. In addition, one should remember that the complimentary effect of the water layer in flooded (paddy) rice fields is necessary for allowing high weed control levels with use of ALS-inhibiting herbicides, which was preponderant for the high infestation reported for T4 and T5 where these herbicides were applied. *C. dactylon* was among the most impacting weeds in the treatments with imazethapyr, imazapyr and imazapic (Table 3).

Although herbicides were able to reduce the overall infestation – mainly in terms of number of individuals (Figure 1), there was no significant shift in the number of weed species among treatments (Table 3), being reported 9, 12, 9, 11, 13, 9, 8 and 10 weed species, respectively, for treatments 1–8. This is an initial indicative that herbicide treatments alone are not efficient in properly suppressing the weed community in the following years, supposing the same treatments are always applied to the same area. Diversity is an ecological concept that considers the balance of plant communities in a given area; for agriculture, it is usually a consequence of good management (Pandeya *et al.*, 1968). Simpson's diversity index (D) quantifies, in an ultimate simplification, the probability of two individuals randomly collected in the same area to belong to the same species. The Shannon-Weiner diversity index (H′), on the other hand, is derived from the Information Theory and confuses diversity with species richness, being mostly influenced by rare species (Barbour *et al.*, 1998). Simpson's coefficient

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Table 3. Density (de), frequency (fr), dominance (do) and importance value (iv) of weed species in rice fields, as function of herbicide residue and cover crops. Pelotas RS, Brazil, 2014.

	T1				T2				T3				T4			
Weed species	de[1]	fr	do	iv	de	fr	do	iv	de	fr	do	iv	de	fr	do	iv
Aeschynomene denticulata				*0*				*0*				*0*				*0*
Alternathera filoxera				*0*				*0*	4.2	5.26	9.02	*6.16*				*0*
Brachiaria sp.				*0*	0.74	3.85	0.14	*1.58*				*0*				*0*
Conyza canadensis				*0*				*0*				*0*	3.05	7.41	4.63	*5.03*
Cynodon dactylon	20.62	25	11.14	*18.92*	17.04	11.54	2.86	*10.48*	2.1	5.26	0.67	*2.68*	12.21	14.81	5.12	*10.71*
Cyperus distans				*0*				*0*	8.39	5.26	18.72	*10.79*				*0*
Cyperus esculentus	10.58	15	12.91	*12.83*	42.22	15.38	30.55	*29.38*	20.98	21.05	14.95	*18.99*	44.27	18.52	61.71	*41.5*
Cyperus odorantus	1.64	5	3.76	*3.47*	1.48	3.85	2.54	*2.62*				*0*				*0*
Echinochloa crus-galli	6.02	10	51.69	*22.57*	15.56	15.38	16.35	*15.76*	2.8	10.53	2.23	*5.19*	3.05	7.41	4.31	*4.92*
Eleocharis elegans				*0*				*0*				*0*				*0*
Eleocharis sp.	2.01	10	1.68	*4.56*	1.48	3.85	0.32	*1.88*				*0*	8.4	11.11	1.67	*7.06*
Fimbristylis autumnalis				*0*				*0*				*0*	6.11	7.41	9.56	*7.69*
Fimbristylis sp.	19.34	15	9.57	*14.64*	6.67	11.54	9.68	*9.3*	13.29	21.05	26.47	*20.27*	9.92	11.11	7.3	*9.44*
Hypochoeris sp.				*0*				*0*				*0*				*0*
Killinga brevifolia	39.23	10	8.50	*19.24*	4.44	3.85	12.86	*7.05*	30.77	15.79	25.7	*24.09*	6.87	7.41	2.99	*5.76*
Lolium multiflorum	0.36	5	0.12	*1.83*	3.70	3.85	2.69	*3.41*	16.08	10.53	1.7	*9.44*				*0*
Oryza sativa				*0*	0.74	3.85	0.11	*1.57*	1.4	5.26	0.53	*2.4*	4.58	7.41	1.04	*4.34*
Paspalum notatum				*0*				*0*				*0*				*0*
Pluchea sagitallis	0.18	5	0.64	*1.94*				*0*				*0*				*0*
Polygonum hydropiperoides				*0*	4.44	15.38	12.19	*10.67*				*0*	0.76	3.7	0.36	*1.61*
Porophyllum sp.				*0*	1.48	7.69	9.71	*6.29*				*0*				*0*
Rhynchospora sp.				*0*				*0*				*0*				*0*
Spermacoce capitata				*0*				*0*				*0*				*0*
Trifolium sp.				*0*				*0*				*0*	0.76	3.7	1.3	*1.92*

Table 3. Continued

	T5				T6				T7				T8			
Weed species	de[1]	fr	do	iv	de	fr	do	iv	de	fr	do	iv	de	fr	do	iv
Aeschynomene denticulata	0.55	3.57	13.06	*5.73*				*0*				*0*				*0*
Alternathera filoxera				*0*				*0*				*0*				*0*
Brachiaria sp.	1.65	3.57	0.51	*1.91*				*0*	6.15	6.25	0.33	*4.24*				*0*
Conyza canadensis	2.20	7.14	2.37	*3.9*				*0*	1.54	6.25	3.22	*3.67*				*0*
Cynodon dactylon	18.13	10.71	5.07	*11.3*	15.17	11.11	13.53	*13.27*	23.08	18.75	38.93	*26.92*	20.00	14.29	30.41	*21.57*
Cyperus distans				*0*				*0*				*0*				*0*
Cyperus esculentus	16.48	17.86	43.43	*25.92*	19.31	27.78	43.68	*30.26*	18.46	18.75	24.35	*20.52*	10.91	28.57	27.33	*22.27*
Cyperus odorantus				*0*				*0*				*0*				*0*
Echinochloa crus-galli	5.49	7.14	3.41	*5.35*	2.76	11.11	11.84	*8.57*				*0*	5.45	7.14	13.07	*8.55*
Eleocharis elegans				*0*	4.14	5.56	2.73	*4.14*				*0*				*0*
Eleocharis sp.	1.10	3.57	0.36	*1.68*	2.07	5.56	0.5	*2.71*				*0*				*0*
Fimbristylis autumnalis				*0*				*0*				*0*				*0*
Fimbristylis sp.	27.47	17.86	11.48	*18.94*	51.03	22.22	20.04	*31.1*	26.15	18.75	10.49	*18.46*	12.73	14.29	8.86	*11.96*
Hypochoeris sp.	0.55	3.57	0.76	*1.63*				*0*				*0*				*0*
Killinga brevifolia	18.13	10.71	16.73	*15.19*	2.07	5.56	5.07	*4.23*	13.85	6.25	6.03	*8.71*	38.18	7.14	13.84	*19.72*
Lolium multiflorum	7.14	7.14	1.71	*5.33*				*0*				*0*	3.64	7.14	1.11	*3.96*
Oryza sativa				*0*	2.76	5.56	0.67	*3*				*0*				*0*
Paspalum notatum				*0*				*0*				*0*	1.82	7.14	0.17	*3.04*
Pluchea sagitallis	0.55	3.57	0.81	*1.64*	0.69	5.56	1.94	*2.73*	6.15	12.5	15.67	*11.44*	5.45	7.14	4.29	*5.63*
Polygonum hydropiperoides	0.55	3.57	0.29	*1.47*				*0*				*0*	1.82	7.14	0.92	*3.29*
Porophyllum sp.				*0*				*0*				*0*				*0*
Rhynchospora sp.				*0*				*0*	3.08	6.25	0.61	*3.31*				*0*
Spermacoce capitata				*0*				*0*				*0*	1.82	7.14	0.92	*3.29*
Trifolium sp.				*0*				*0*				*0*				*0*

Gray: relative components of the iv, as follows: [1] de = density (%); fr = frequency (%); do = dominance (%); *Italic:* iv = importance value (%).

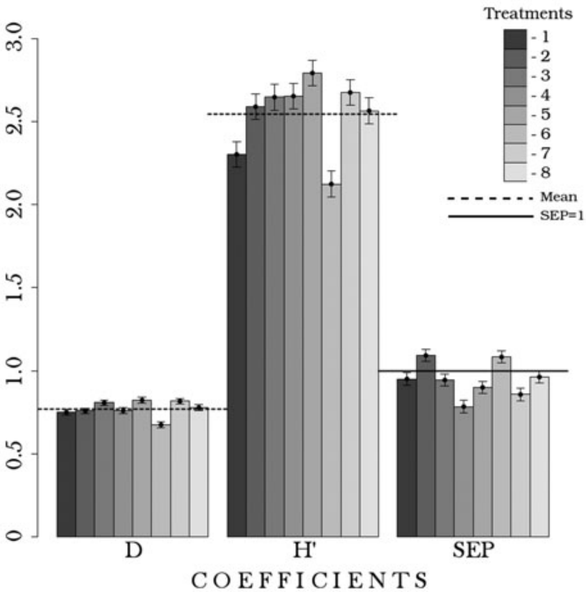

Figure 2. Diversity of weed species in rice fields as affected by herbicides. D = Simpson's diversity index; H' = Shannon-Weiner diversity index; SEP = Shannon-Weiner Evenness Proportion. Dashed lines are treatment averages; solid line represents SEP = 1.0. For treatments 1–8, see Table 1.

(D) indicated all treatments presented equal diversity, with exception of T6 (Figure 2). D values reported herein are in accordance to the observed in most agricultural conditions (Oluwatobi and Olorunmaye, 2014), being most influenced by abundance of species. For most treatments (except T6), weed species with numerous offspring were reduced but not eliminated from the sample. In other words, herbicide impact on species with high occurrence tended to be equal for most treatments (Figure 2). T6 was composed by a single pre-emergence application of imazethapyr + imazapic and caused an imbalance in occurrence of the prolific species *Fimbristyllis* sp. and *Killinga brevifolia*, whose densities were 19.34 and 39.23 at the control, and 51.03 and 2.07 at T6, respectively (Table 3).

Shannon-Weiner was also on average compared to the overall diversity usually reported for agricultural fields (Jastrzebska *et al.*, 2013), with T1 and T6 presenting lower diversity compared to the other treatments (Figure 2). One should remember that Shannon-Weiner's index is most affected by rare plant species; both treatments presented nine weed species each one (Table 3), with, respectively, five and six weeds with density below 10% (rare species), with only three of them common to both treatments ($\mathcal{J}_{1,6} = 0.38$). Thus, T1 and T6 differ in diversity from the other treatments, but they are similar among them (Barbour *et al.*, 1998) in terms of rare weed species. The SEP coefficient is able to infer about sustainability of management applied to production systems from static data (McManus and Pauly, 1990), and variations of H' and Hd' (Equation 9) close to zero (resulting in SEP ~ 1.0) indicate

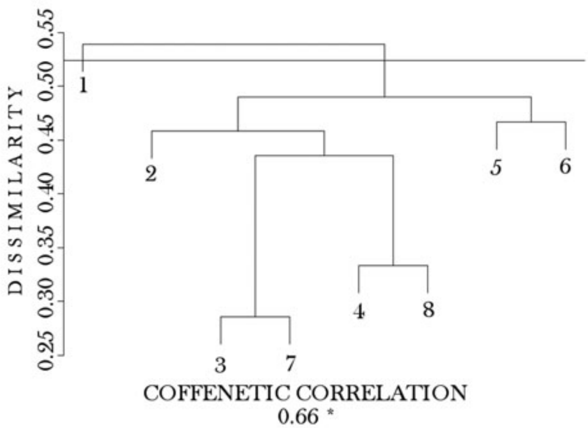

Figure 3. Cluster analysis for treatment dissimilarity of weed species in rice fields as affected by herbicides. For treatments 1– 8, see Table 1.

longevity of the management practice applied and consequently of the production system (Concenço 2015).

Only one area and only two years of experimentation are not sufficient for evaluating sustainability, but comparison of treatments (Figure 2) indicated that the sustainability coefficient (SEP) was acceptable for all treatments. All herbicide treatments are not supposed to maintain their control levels along years when they are applied alone and in absence of management practices such as crop rotation, being an integrated management approach needed. The addition of winter crops as ryegrass is reported in the literature as an alternative for weed suppression. While T1, T3 and T8 were the treatments most suitable in terms of sustainability, T4 (higher dose of penoxsulam) was the most problematic one.

The cluster analysis by similarity of species occurrence (Figure 3) showed that only the control differed from the other treatments in terms of weed composition. When this information is linked to the level of infestation (Figure 1), it is possible to infer that all herbicides affected both infestation and composition of weed species. This impels to a need for continuous follow-up of areas treated with herbicides for shifts in weed flora. In addition, herbicides ought to be rotated from one year to the other aiming to avoid selection of those weed species most adapted to survive to a given herbicide treatment. Species selection is most serious for those weeds whose survival strategy is mainly based on density; prolific species that survive herbicide treatments rapidly increase their proportion in the area. This is what probably occurred with *E. crusgalli* and its elimination would probably cause such phenomenon in *Fimbristyllis* sp. and *K. brevifolia* (Table 3), as previously discussed.

CONCLUSION

E. crusgalli, *Fimbristyllis* sp., *C. esculentus* and *K. brevifolia* were the weeds to which most concern should be directed when growing rice under sprinkler irrigation in lowland areas of Southern Brazil. Their competition strategies are based on density.

Herbicides used should be efficient in controlling at least these four weed species. A selecting action of herbicides on weed species was botanically characterized, as the weed species reported after two cropping seasons depended on the herbicide treatment applied.

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