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## CONTROL EFFICACY AND PHYTOSOCIOLOGICAL CHARACTERIZATION OF WEEDS AS A FUNCTION OF POST-EMERGENCE HERBICIDES APPLIED TO MAIZE

**Abstract** – Studies evaluating the effectiveness of herbicides on weed control, coupled with the sustainability of the weed management system, are of great importance. The present study aims to evaluate the efficacy of post-emergence herbicides applied to maize while inferring the sustainability of the treatments employing an ecological approach. The experiment was installed in a randomized block design with four replications. The treatments consisted of the application of atrazine at the dose of 1500 g ha<sup>-1</sup>; atrazine + mesotrione at 1500 + 72 g ha<sup>-1</sup>; atrazine + tembotrione at 1500 + 100.8 g ha<sup>-1</sup>; atrazine + nicosulfuron at 1500 + 22.5 g ha<sup>-1</sup>; atrazine + glyphosate at 1500 g ha<sup>-1</sup> + 792.5 g ha<sup>-1</sup>, in addition to weeded and infested control treatments. The herbicides were applied at the 4 leaf stage of maize. The phytotoxicity and control efficacy was assessed 7, 14, 21, and 28 days after applying treatments (DAT). In addition, a phytosociological survey of all plots was carried out in the last assessment. Herbicides did not cause phytotoxicity symptoms to the crop. However, associations of atrazine with glyphosate and atrazine with tembotrione promoted the greater effectiveness of weed control. Despite being classified as one of the treatments with better effectiveness, the association between glyphosate and atrazine, caused a more significant reduction in the diversity of the plant community, and alternative weed management practices should be applied to maize cropping fields to avoid weed selection.

**Keywords:** chemical control, diversity, dissimilarity, *Zea mays*.

## EFICÁCIA DO CONTROLE E CARACTERIZAÇÃO FITOSOCIOLÓGICA DE PLANTAS EM FUNÇÃO DE HERBICIDAS DE PÓS-EMERGÊNCIA APLICADOS AO MILHO

**Resumo** - Estudos avaliando a eficácia de herbicidas no controle de plantas daninhas, aliados à sustentabilidade do sistema de manejo de plantas daninhas, são de grande importância. O presente estudo tem como objetivo avaliar a eficácia de herbicidas pós-emergência aplicados ao milho e inferir a sustentabilidade dos tratamentos utilizando uma abordagem ecológica. O experimento foi instalado em delineamento de blocos casualizados com quatro repetições. Os tratamentos consistiram na aplicação de atrazina na dose de 1500 g ha<sup>-1</sup>; atrazina + mesotriona a 1500 + 72 g ha<sup>-1</sup>; atrazina + tembotriona a 1500 + 100,8 g ha<sup>-1</sup>; atrazina + nicossulfurão a 1500 + 22,5 g ha<sup>-1</sup>; atrazina + glifosato a 1500 g ha<sup>-1</sup> + 792,5 g ha<sup>-1</sup>, além dos tratamentos de controle capinado e infestado. Os herbicidas foram aplicados no estágio de 4 folhas do milho. A fitotoxicidade e a eficácia do controle foram avaliadas 7, 14, 21 e 28 dias após a aplicação dos tratamentos (DAT). Além disso, na última avaliação foi realizado um levantamento fitossociológico de todas as parcelas. Os herbicidas não causaram sintomas de fitotoxicidade à cultura. No entanto, associações de atrazina com glyphosate e atrazina com tembotrione promoveram maior eficácia no controle de plantas daninhas. Apesar de ser classificado como um dos tratamentos com melhor eficácia, a associação entre glyphosate e atrazina, causou uma redução mais significativa na diversidade da comunidade vegetal, e práticas alternativas de manejo de plantas daninhas devem ser aplicadas aos campos de cultivo de milho para evitar a seleção de plantas daninhas.

**Palavras-chave:** controle químico, diversidade, dissimilaridade, *Zea mays*.

The inadequate management of weeds in maize can cause a reduction in the crop grain yield potential (Silva et al., 2017). Herbicide application is the primary weed control method used in maize fields due to its effectiveness, higher operating efficiency, and better cost: benefit ratio. However, the choice of the active ingredient to be applied is often inadequate, causing negative impacts on crop grain yield potential and environmental sustainability.

When choosing herbicides, maize farmers usually consider several factors such as crop selectivity, weed flora composition, product availability, and pricing. However, the sustainability of the chosen option is often neglected by the farmer and technician and often by researchers. Sustainability in the present study is defined as the ability of a system, natural or mixed, to resist or adapt to endogenous or exogenous changes. This definition was adapted from the human sciences in the terms discussed by Sartori et al. (2014).

Studies on weed control in crops usually assess herbicide selectivity and efficacy (Damalas et al., 2018; Timossi & Freitas, 2010) but neglect any ecological inference. The intensification of agriculture accompanied by the homogenization of cultivation systems has resulted in a decline in flora diversity in arable fields and the reduced resilience of cultivation systems (Storkey and Neve, 2018). In this way, Concenço et al. (2017) propose that sustainability in arable fields can be inferred through the diversity of the weed community.

The reduction of diversity of the weed community in arable fields is directly related to the selection of tolerant species, and resistant biotypes since the environment and the parental inheritance interact more intensely than researchers usually consider (Concenço, 2016). This scenario can be observed in the main Brazilian grain-producing

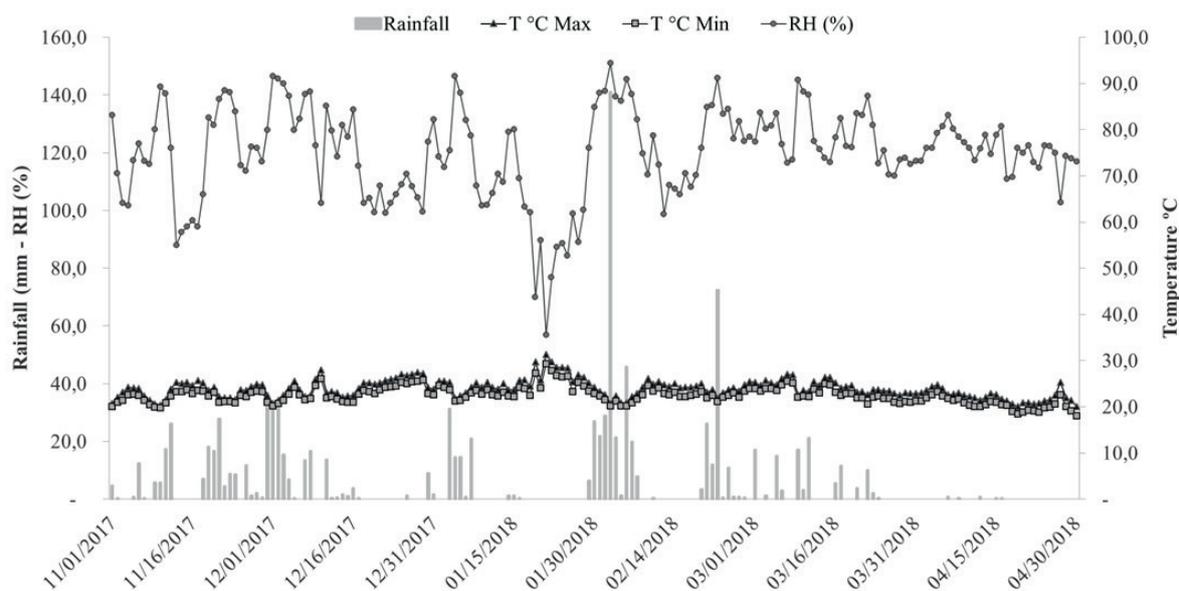
regions that have successfully grown glyphosate-resistant crops (Lucio et al., 2018). When analyzing the effect of regular and exclusive applications of glyphosate for five years in different crop sequences, Puricelli and Tuesca (2005) verified a reduction in weed diversity, tolerant species prevailing, and those with later emergence flows.

The ideal weed management option should provide high levels of control associated with the flora diversity at the cultivation site. In this scenario, phytosociological studies stand out as an essential tool to evaluate the sustainability of control options. It is possible to infer both the control effectiveness and the area's diversity through the appropriate methodology. Among the parameters used to measure this index, the Simpson (D) and the Shannon-Weiner (H') diversity coefficients are widely used (Gurevitch et al., 2006). Simpson (D) quantifies the probability of two individuals randomly collected belonging to the same species; Shannon-Wiener (H') is more influenced by rare species, being helpful to infer about species appearance or disappearance (Concenço et al., 2013).

The present study aims to evaluate the efficacy of post-emergence herbicides applied to maize while inferring the sustainability of the treatments through an ecological approach.

## Material and Methods

The experiment was conducted in field conditions at Sete Lagoas - MG, Brazil (19° 27' 348" S 44° 10' 722" W), between November 2017 and April 2018. The climatological data during the experiment's conduction period are presented in Figure 1. During the experiment, when necessary, there was water supplementation through sprinkler



**Figure 1** - Climatic data observed at the experimental area, when growing maize cv. DKB 310 VT PRO<sub>2</sub>: rainfall (mm), maximum (T °C Max) and minimum (T °C Min) temperatures, and relative air humidity (UR%). Embrapa Milho e Sorgo, Sete Lagoas, MG, 2017/2018.

irrigation, according to the crop's water requirement. The soil of the experimental area was classified as Red-Yellow Latosol (Embrapa, 2018), with the following characteristics: pH (water) = 5.4; P = 21.32 mg dm<sup>-3</sup>; K = 252.7 mg dm<sup>-3</sup>; Ca<sup>+2</sup> = 4.96 cmol<sub>c</sub> dm<sup>-3</sup>; Mg<sup>+2</sup> = 0.4 cmol<sub>c</sub> dm<sup>-3</sup>; Al<sup>+3</sup> = 0.04 cmol<sub>c</sub> dm<sup>-3</sup>; H + Al = 5.02 cmol<sub>c</sub> dm<sup>-3</sup>; and CTC<sub>effective</sub> = 11.37 cmol<sub>c</sub> dm<sup>-3</sup>.

Thirty days prior to the experiment installation, soil tillage was accomplished by plowing and harrowing, and 15 days later, the area was burndown with glyphosate + 2,4-D at 1740 g a.e. ha<sup>-1</sup> + 806 g a.i. ha<sup>-1</sup>.

The experiment was installed in a randomized blocks design with four replications. Treatments consisted of applying five chemical control alternatives and two control treatments one weeded, one infested (Table 1). The experimental plots measured 5.0 x 4.0 m (20 m<sup>2</sup>). The useful area

of the plot corresponded to the four central rows, disregarding 0.5 m from the ends of each row, totaling 8 m<sup>2</sup>. The hybrid DKB 310 VT PRO<sub>2</sub> was seeded at 0.5 m row spacing, aiming to establish three plants per meter in the row (approximately 60,000 plants ha<sup>-1</sup>). Fertility correction was performed according to the technical recommendations for maize (Embrapa, 2018), with the application of 400 kg ha<sup>-1</sup> N-P-K 08-28-16. Topdressing fertilization with nitrogen was performed with maize plants at the 4-leaf stage (V4) by applying 200 kg ha<sup>-1</sup> of N as urea.

The herbicides were applied at the V4 stage, the day before the nitrogen topdressing, and 22 days after sowing. The application was carried out with a CO<sub>2</sub> pressurized backpack sprayer with six nozzles, spaced in 0.5 m, type TT 110.02 (Teejet Technologies<sup>®</sup>), working at 250 KPa, with a volume of spray equivalent to 150 L ha<sup>-1</sup>.

**Table 1** - Treatments and doses of active ingredient (a.i.) or acid equivalent (a.e.) (g ha<sup>-1</sup>) tested in the study. Embrapa Milho e Sorgo, Sete Lagoas. 2018.

Treatments	Dose (g i.a. ha <sup>-1</sup> )	Adjuvant <sup>7</sup>
Infested check	--	--
Weeded check	--	--
Atrazine <sup>1</sup>	1500	Mineral oil
Atrazine <sup>1</sup> + mesotrione <sup>2</sup>	1500 + 72	Mineral oil
Atrazine <sup>1</sup> + nicosulfuron <sup>3</sup>	1500 + 22.5	Mineral oil
Atrazine <sup>1</sup> + tembotrione <sup>4</sup>	1500 + 100.8	Mineral oil
Atrazine <sup>1</sup> + glyphosate <sup>5</sup>	1500 + 792.5	Mineral oil

Herbicide phytotoxicity was assessed 7, 14, 21, and 28 days after application (DAH), based on a visual scale of grades varying from 0 to 100%, where 0 corresponds to the absence of symptoms and 100 to plant death (SBCPD, 1995). Concomitantly, the weed control was also assessed by contrasting the results with the infested and weeded control treatments, where 0 represents infestation level similar to the infested control, and 100% when similar to the mechanically weeded treatment.

Twenty-eight days after herbicide application (DAH), a phytosociological survey was performed using the random quadrats method (Barbour et al., 1998). A quadrat with a 0.5 m side was randomly cast three times in the useful area of each plot, totaling 12 samplings per treatment (n = 12). The weeds inside the quadrat were identified, quantified, and sectioned close to the soil, being separated by species and arranged in paper bags to obtain the dry mass by species. The collected material was taken to an air circulation oven at 60 °C for 72 hours. After obtaining the dry mass, the relative frequencies, densities, and dominances were estimated in order to obtain the importance value (IV), which numerically

expresses the importance of a given weed species in a community, being determined on a percent base as the arithmetic means of density, frequency, and dominance. The coefficients of the diversity of Simpson (D), Shannon-Weiner (H'), and the sustainability of Shannon (SEP) were also obtained according to Concenço et al. (2013) by using the following formulas:

$$de = \frac{I}{TI} * 100 \quad (3)$$

$$fr = \frac{Q}{TQ} * 100 \quad (4)$$

$$do = \frac{DM}{TDM} * 100 \quad (5)$$

$$iv = \frac{de + fr + do}{3} \quad (6)$$

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”.

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

$$H' = \sum (pi * \ln(pi)) \quad (8)$$

$$SEP = \frac{Hd'}{H'} \quad (9)$$

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 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).

One hundred and twenty days after crop emergence (DAE), four maize plants were sampled from the useful area of each plot and analyzed for plant height and ear insertion height, number of rows per ear, number of grains per row, and weight of 1000 grains. In order to determine the yield of maize grains, mechanical harvesting of the useful area of each plot was performed, and grain moisture was then determined and corrected to 13%.

The data set was submitted to analysis of variance by the F-test; when significant, treatment means were compared by Tukey’s test at 5% probability. The phytosociological analysis was conducted according to Concenço et al. (2013). Both analyses were performed in the R statistical environment (R Core Team, 2018).

## Results and Discussion

The herbicides did not cause any symptoms of phytotoxicity to maize in any of the evaluation periods (data not shown). Therefore, the pesticide registration process, is in the companies’ interest that the products are selective to the most significant number of genotypes. However, there are cases of cultivars with differentiated tolerance levels to certain herbicides (Guerra et al., 2010). In this case, the owner company is expected to specify the cultivar’s susceptibility to registered herbicides.

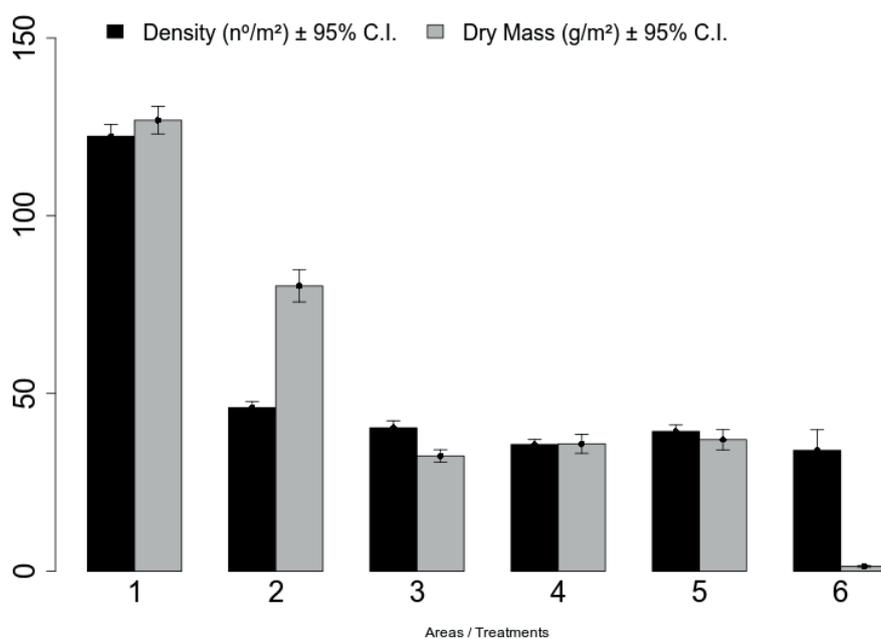
When analyzing the control efficacy, it was reported that, regardless of the evaluation period, the association of glyphosate with atrazine presented a control level above 90% (Table 2). Among the treatments, including any association with atrazine, 28 DAH, glyphosate, and tembotrione showed similar efficacy, and the latter did not differ from mesotrione and nicosulfuron. Atrazine performed worse when applied alone. This molecule is usually associated with other herbicides more effective on grasses, aiming to broaden its control spectrum (Galon et al., 2008; Basso et al., 2018). Atrazine is an important herbicide for weed management in maize, especially when sown in the second cropping season, aiming to control voluntary soybean plants from the previous cropping season (Petter et al., 2016).

There was no difference in weed density between treatments, including herbicide associations (Fig. 2). However, glyphosate + atrazine provided lower dry mass accumulation. It indicates that this treatment is highly efficient and that the species sampled are mainly related to late emergence flows. The positive characteristics of glyphosate, such its broad spectrum of action, absence of residual effect

**Table 2** - Weed control efficiency assessed 7, 14, 21 and 28 days after herbicide application (DAH).

Treatments	7DAH	14DAH	21DAH	28DAH
atrazine	67.50c	61.25c	53.75d	52.50c
atrazine + mesotrione	76.25bc	77.50b	76.25bc	73.75b
atrazine + tembotrione	82.50ab	83.75b	85.00ab	82.50ab
atrazine + nicosulfuron	72.50bc	76.25b	68.75cd	71.25b
atrazine + glyphosate	90.00a	96.50a	97.25a	94.75a
CV (%)	5.87	5.13	9.04	8.57

\*Means followed by the same letters, in the column, do not differ by the Tukey's test at 5% probability.



**Figure 2** - Density of individuals  $m^{-2}$  (■) and their respective shoot dry mass (■ -  $g\ m^{-2}$ ) of weeds as function of treatment (1- infested check; 2- atrazine; 3 – atrazine + mesotrione; 4 – atrazine + tembotrione; 5- atrazine + nicosulfuron; 6 – atrazine + glyphosate).

in soil, control of weeds at different growth stages, besides its reduced cost, have contributed to the rapid adoption of maize cultivars resistant to this herbicide by Brazilian producers (Silva et al., 2018).

The infested control treatment, as expected, showed a higher number of weed species (Table 3). The four main ones corresponded, respectively, to southern sandbur (*Cenchrus echinatus*), pigweeds (*Amaranthus* spp.), Jamaican crabgrass (*Digitaria horizontalis*), and purslane (*Portulaca oleracea*). Among herbicide treatments, which could be used in conventional maize, southern sandbur and Jamaican crabgrass were the two species that presented the highest IV. These two species belong to the Poaceae family, possess C<sub>4</sub> carbon metabolism, present slow initial growth, and are important weeds in maize (Duarte et al., 2007; Fontana et al., 2016).

With the application of glyphosate + atrazine, the southern sandbur remained the primary weed, with morningglories (*Ipomoea* spp.) and Indian goosegrass (*Eleusine indica*), presenting similar IV as two other important species. The maintenance of Jamaican crabgrass as the primary weed species denotes its rich seed bank in the area. It is possible to infer that plants present at the time of the evaluation (28 DAH) were originated from late emergence flows, which can be evidenced by the low accumulation of dry mass in this treatment (Fig. 2). Morningglories and Indian goosegrass are also important as weeds in maize cultivation. These species present slow initial growth and C<sub>3</sub> and C<sub>4</sub> carbon metabolism, respectively (Carvalho et al., 2009; Takano et al., 2016). Morningglories is characterized by being tolerant to glyphosate and, depending on the level of infestation, may prevent the harvest due to its climbing habit. Indian goosegrass presents biotypes resistant to glyphosate in Brazil, contributing to

increase in control failures and the importance of this species in several crops in the country (Heap, 2018).

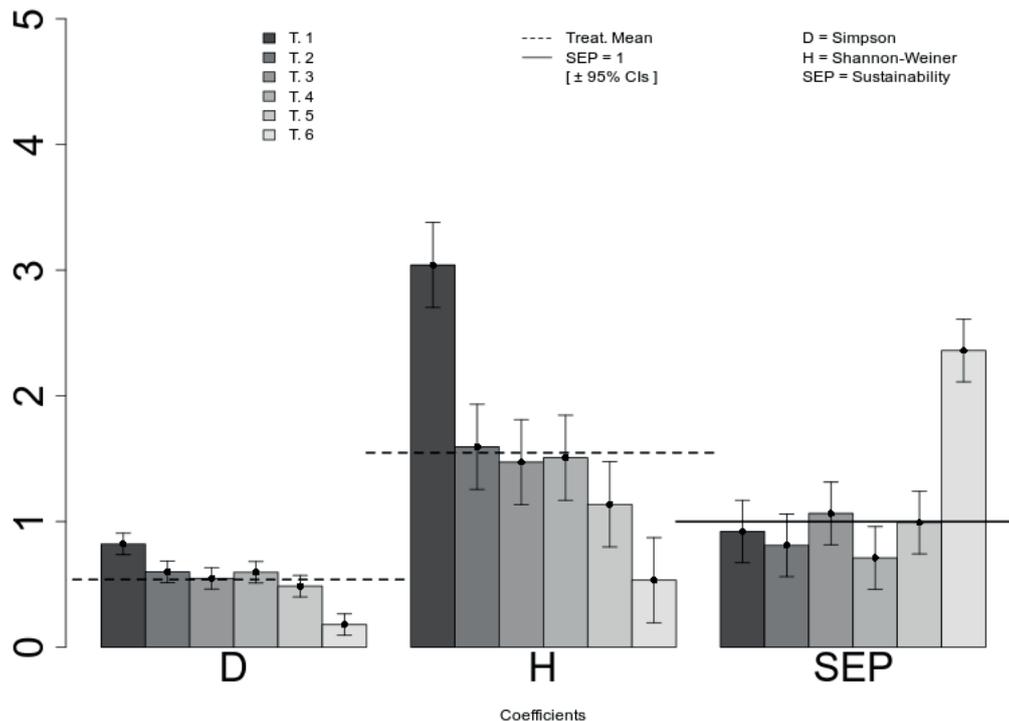
Regarding the evaluation of the diversity indexes, the Simpson coefficient (D) indicated the maximum value for the infested treatment compared to the other herbicide treatments. Among the species, some were controlled by the herbicides while others were not, and among the controlled species, there are probably differences in their susceptibility to the products tested (Fig. 3). The herbicide treatments presented similar values, except for the application of glyphosate + atrazine, which resulted in lower weed diversity. This fact can be interpreted as an initial indication that this control option may be more harmful to the environment in the long term, supposing this treatment is repeated continuously without other weed management techniques. The D values reported in the present study agree with those observed in several other agricultural areas (Oluwatobi & Olorunmaye, 2014).

The ideal would be to combine high levels of weed control with high diversity maintenance in the system (Concenço et al., 2013), but this is not easy to achieve. Thus, concerning arable fields, four situations would be feasible for the interaction *infestation composition vs. diversity*: (1) high diversity, easily controlled weeds; (2) low diversity, easily controlled weeds; (3) high diversity, hard-to-control weeds; and (4) low diversity, hard-to-control weeds (Concenço et al., 2017). The situation (1) is what agronomists should work to achieve in all arable fields; (2) indicates that the weed context is still OK, but it may worsen along time; periodic monitoring of weed changes is necessary; (3) and (4) represent serious problems and radical changes to the weed management practices should be adopted. Furthermore, the Shannon-Weiner coefficient (H') presented similar behavior to that

**Table 3 - Phytosociological characterization of the treatments 28 days after herbicide application (DAH)**

Species	T <sub>1</sub>				T <sub>2</sub>				T <sub>3</sub>				T <sub>4</sub>				T <sub>5</sub>				T <sub>6</sub>							
	De	Fr	Do	IV	De	Fr	Do	IV	De	Fr	Do	IV	De	Fr	Do	IV	De	Fr	Do	IV	De	Fr	Do	IV	De	Fr	Do	IV
ACNAU	1.1	2.6	0.4	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AGECO	2.5	3.9	1.2	2.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
ALRTE	0.8	2.6	0.7	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMADE	0.3	1.3	2.4	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
AMACH	25.1	14.1	25.1	21.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BIDPI	0.3	1.3	0.3	0.6	0.7	3.1	0.1	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
CCHEC	29.7	14.1	28.0	23.9	48.6	34.4	48.4	43.8	60.3	42.3	52.8	51.8	47.7	38.5	58.6	48.2	63.6	47.8	27.6	46.3	90.2	50.0	61.2	67.2				
EPHPI	1.9	3.9	0.2	2.0	0.7	3.1	0.2	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
COMBE	0.5	2.6	0.5	1.2	0.7	3.1	0.5	1.5	0	0	0	0	0.9	3.9	0.8	1.9	0	0	0	0	0	0	0	0	0	0	0	0
CYPPIR	1.6	2.6	0.7	1.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DIGHO	10.9	12.8	13.6	12.4	39.9	38.0	46.4	41.25	28.9	34.6	30.9	31.5	41.1	42.3	40.2	41.2	33.1	39.1	67.8	46.6	0	0	0	0	0	0	0	0
DIGIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.9	4.4	0.7	2.0	0	0	0	0	0	0	0	0
ELEIN	2.7	5.1	2.5	3.5	2.9	9.4	4.4	5.6	4.1	11.5	12.8	9.5	0	0	0	0	2.5	8.7	3.9	5.0	2.0	16.7	30.1	16.3				
EPHHL	0	0	0	0	0	0	0	0	0	0	0	0	1.9	3.9	0.2	2.0	0	0	0	0	0	0	0	0	0	0	0	0
IPOINT	1.9	7.7	3.1	4.2	6.5	9.4	0.1	5.3	3.3	7.7	0.2	3.7	8.4	11.5	0.3	6.7	0	0	0	0	0	0	0	0	0	0	0	0
NICPH	0.3	1.3	0.03	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PTNHY	0.3	1.3	0.8	0.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
POROL	6.5	7.7	17.4	10.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RHYRE	0	0	0	0	0	0	0	0	3.3	3.9	3.3	3.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
RCHBR	8.5	5.1	2.3	5.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
BOILF	3.8	7.7	0.8	4.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
TRQPR	1.7	2.6	0.1	1.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

De = relative density (%); Fr = relative frequency (%); Do = relative dominance (%); IV = importance value (%). ACNAU = *Acanthospermum australe*; AGECO = *Ageratum conyzoides*; ALRTE = *Alternanthera tenella*; AMADE = *Amaranthus deflexus*; AMACH = *Amaranthus hybridus*; BIDPI = *Bidens pilosa*; CCHEC = *Cenchrus echinatus*; EPHPI = *Chamaesyce hirta*; COMBE = *Commelina benghalensis*; CYPPIR = *Cyperus iria*; DIGHO = *Digitaria horizontalis*; DIGIN = *Digitaria insularis*; ELEIN = *Eleusine indica*; EPHHL = *Euphorbia heterophylla*; IPOINT = *Ipomoea triloba*; NICPH = *Nicandra physalodes*; PTNHY = *Parthenium hysterophorus*; POROL = *Portulaca oleraceae*; RHYRE = *Rhynchelytrum repens*; RCHBR = *Richardia brasiliensis*; BOILF = *Spermacoce latifolia*; TRQPR = *Tridax procumbens*. T<sub>1</sub> - infested check; T<sub>2</sub> - atrazine; T<sub>3</sub> - atrazine + mesotrione; T<sub>4</sub> - atrazine + tembotrione; T<sub>5</sub> - atrazine + nicosulfuron; T<sub>6</sub> - atrazine + glyphosate.



**Figure 3** - Plant diversity as function of herbicide treatment. T1 – Infested check; T2 - atrazine; T3 – atrazine + nicosulfuron; T4 – atrazine + tembotrione; T5 - atrazine + nicosulfuron; T6 – atrazine + glyphosate. D = diversity coefficient of Simpson; H' = diversity coefficient of Shannon-Weiner; SEP = sustainability coefficient of Shannon. Dotted lines correspond to treatment means; solid line corresponds to SEP = 1.

observed for D, being the greater diversity observed for the treatment without herbicide (Fig. 3).

In arable fields, the absence of weed control is not justified as a way to maintain the most remarkable environmental diversity since the objective is the production of the economic part of the crop. In this way, farmers must ally the greater effectiveness of herbicides with a minor impact on weed diversity; the ideal would be to have in the area, previously to any herbicide application, a significant number of spontaneous plant species, all of them being easily controlled by the weed management techniques applied. Thus, in the present study, low plant diversity may still be positive

for agricultural systems since the remaining plants following the herbicide application are not hard-to-kill weeds. Furthermore, in certain situations, such as hard-to-kill weeds, the ecological diversity will be inevitably low after the efficient control of these problematic plants. Thus, diversity results in arable fields should always be interpreted on the verge of the weed control results and the crop grain yields obtained (Gurevitch et al., 2006).

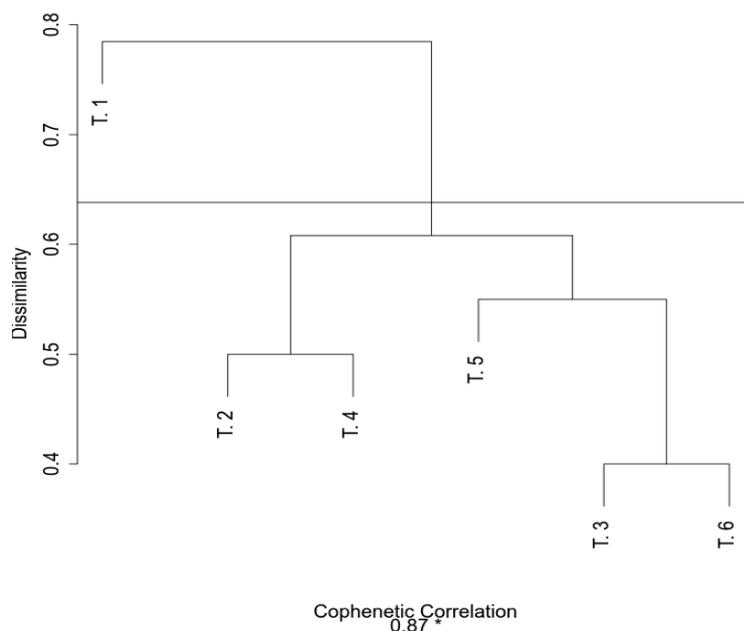
The sustainability coefficient of Shannon-Weiner (SEP) (Fig. 3) allows for inferences regarding the sustainability of productive systems from static data (McManus & Pauly, 1990).

Variations between  $H'$  (based on weed density) and the same index calculated based on species dominance ( $Hd'$ ), close to zero (resulting in  $SEP \sim 1$ ), indicate maximum system longevity or sustainability of the adopted weed management practices (Concenço et al., 2013). In this sense, glyphosate + atrazine presented a higher value ( $SEP > 1$ ), indicating the possible lower sustainability of this control option (Fig. 3). This result, indeed, should be investigated in distinct edapho-climatic environments in future studies. The SEP coefficient can infer sustainability from static data, but this does not mean that a single study would be enough to infer the sustainability of given herbicide treatment in a single year and location.

The present study's data show that all chemical control alternatives, except glyphosate + atrazine,

presented sustainability coefficients near "1", the theoretically ideal value for SEP (McManus & Pauly, 1990). However, it is expected that none of the treatments, if used alone and continuously, would maintain this coefficient over the years without the association with other weed management practices. The adoption of integrated weed management is necessary in any area of agricultural production in order to maintain its sustainability over time. The adoption of different control measures delays the selection of tolerant and resistant species to the herbicides, the loss of diversity, and the dependence on herbicides (Geddes & Gulden, 2018).

Based on the similarities of species occurrence (Fig. 4), the cluster analysis indicates that there was no impact of the herbicides on the appearance or disappearance of weeds compared to



**Figure 4** - Cluster analysis by dissimilarity of the treatments in terms of weed composition (T1= infested check; T2= atrazine; T3= atrazine + mesotrione; T4= atrazine + tembotrione; T5= atrazine + nicosulfuron; T6= atrazine + glyphosate).

herbicide treatments, which was also corroborated by the Shannon-Weiner index (Fig. 3). All herbicide treatments differed from the uncontrolled control (T1) but did not differ from each other concerning the dynamics of the occurring species; they caused an ecological impact - even if slight, on the cropping system. No agricultural system can produce food with zero impact on the environment; even extractive systems have some impact (Ribas et al., 2007; Freitas et al., 2018).

Despite the difference in effectiveness in the control of the weed community, no variations were observed for plant or ear insertion height, the number of rows per ear or grains per row, weight of 1000 grains, or grain yield. The level of interference is related to characteristics related to the weed community (specific composition, density, distribution); the crop (cultivar, spacing, density); edapho-climatic conditions during cultivation; cultural practices; and the period of coexistence of crop and weeds (Silva et al., 2009). Thus, good initial control of the weed community in association with factors favorable to growth (availability of water, light, and nutrients), the specific composition of the weed community (plants with slow initial growth), growing conditions (cultivar, spacing, and density) resulted in the low impact of the weed community on crop yield.

It is important to emphasize that, even if there is no loss of income or grain yield, it is recommended to adopt weed control measures. The lack of control of the weed community can lead to an increase in the seed bank and contribute to the increase in weed density and distribution, resulting in more significant interference over the years.

## Conclusions

The association of atrazine + glyphosate and atrazine + tembotrione were the most efficient treatments for weed control. However, the application of atrazine + glyphosate had a more significant impact on weed diversity, indicating that this treatment should be further studied in terms of sustainability. New studies in different environmental conditions and years are necessary to infer the sustainability of chemical control alternatives better.

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