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Article

Characterization of the Weed Flora in Rice Areas under Distinct Cropping Systems and Herbicide Managements

Caracterização da Flora de Plantas Daninhas em Áreas de Arroz sob Diferentes Sistemas de Cultura e Manejos de Herbicida

CONCENÇO, G.[1]*
ANDRES, A.[1]
SCHREIBER, F.[2]
SILVA, A.F.[3]
MOISINHO, I.S.[2]
CORADINI, M.C.[2]

ABSTRACT - The aim of this study was to evaluate the occurrence of weeds in flooded rice areas, as a function of planting system and herbicide programmes in the previous cropping year. The experiment was installed in field conditions, in randomized complete blocks design, arranged in factorial scheme 3 x 2, with eight replications. In factor A, treatments consisted on conventional tillage, minimum tillage and no till cropping systems, coupled to the application (traditional control) or not (semi-ecological system) of herbicides (Factor B). One year after rice cultivation, preceding the planting of the next cropping season, phytosociological evaluations of the weed communities present in the treatments were carried out. We assessed the overall infestation level and weed species composition, which were classified by their respective density, frequency and dominance abilities. We also estimated the diversity coefficients of Simpson and Shannon Weiner, and the sustainability coefficient of Shannon; treatments were also grouped by similarity in weed species composition. Rice growing systems (traditional or semi-ecological) promote remarkable differences in weed occurrence. Herbicide-based crops select specific companion weed species, but crop rotation or winter cover crops are not a *sine qua non* condition for success since a good herbicide programme is planned. For the Semi ecological system, crop rotation, thick winter soil mulching and association with animal presence and grazing are essential for the short, medium and long-term inhibition of weeds.

Keywords: chemical control, semi-ecological rice, phytosociology, southern Brazil.

RESUMO - O objetivo deste trabalho foi avaliar a ocorrência de plantas daninhas em arroz irrigado por inundação, em função do sistema de plantio e do manejo de herbicidas na safra anterior. O experimento foi instalado em campo, em delineamento experimental de blocos casualizados dispostos em esquema fatorial 3 x 2, com oito repetições. O fator A foi o sistema de cultivo, sendo sistema convencional, cultivo mínimo ou plantio direto, associados à aplicação (manejo tradicional) ou não (sistema semiecológico) de herbicidas (Fator B). Um ano após o cultivo do arroz, precedendo o novo plantio, foram efetuadas as avaliações fitossociológicas das comunidades infestantes. Foram avaliadas a infestação geral e a composição de espécies infestantes nos tratamentos, que foram classificadas pela sua densidade, frequência e dominância relativas de ocorrência. Foram ainda estimados os coeficientes de diversidade de Simpson e Shannon Weiner, bem como a sustentabilidade de Shannon; os tratamentos foram agrupados pela similaridade de ocorrência das espécies infestantes. Os sistemas de cultivo de arroz (tradicional ou semiecológico) promovem diferenças marcantes na ocorrência de plantas daninhas. O controle com base em herbicidas seleciona plantas companheiras

*** Corresponding author:**
<germani.concenco@embrapa.br>

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[1] Embrapa Clima Temperado, Pelotas-RS, Brasil; [2] Universidade Federal de Pelotas, Capão do Leão-RS, Brasil; [3] Embrapa Milho e Sorgo, Sete Lagoras-MG, Brasil.

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específicas, mas a rotação de culturas ou coberturas de inverno não parece ser condição sine qua non para o sucesso desses sistemas, desde que o programa de manejo herbicida seja adequado. Para o sistema semiecológico, a rotação de culturas e espessa camada vegetal de cobertura de inverno, bem como sua associação com o pastejo animal, parecem essenciais para o manejo de plantas daninhas no curto, médio e longo prazos.

Palavras-chave: controle químico, arroz semiecológico, fitossociologia, sul do Brasil.

INTRODUCTION

In a cropping system, some management practices are necessary to provide a favorable environment for crops to produce efficiently; but usually, these same practices favor the establishment of weeds more adapted to the given management system. In addition to management practices such as the cultivation system, soil and climate traits influence the weed population (Godoy et al., 1995).

The use of herbicides for weed control is widely adopted, mainly in wide cropping areas or where the mechanical weed control method is not effective or viable (Pacheco et al., 2016). However, several weed flows could occur during the crop cycle, and a single herbicide application may be not enough for an efficient weed control (Ikeda et al., 2008). According to Vargas et al. (2009), plants may vary in their susceptibility, following a herbicide application. In addition, herbicide abuse or mismanagement would ultimately result in the appearance of weed biotypes resistant to herbicides.

The lack of knowledge on existing weed species in a particular crop and the inadequate use of control methods often result in the excessive use of herbicides, increasing the risk of environmental contamination. In this sense, the identification of the weed species and the frequency in which they occur into cropping systems, is essential to subsidize the selection of the most appropriate herbicide (Pitelli, 2000).

In no till cropping system, weed seeds tend to be located near the soil surface; this information should be used as tool for weed management, since these seeds may be most easily stimulated to germinate and later eliminated by chemical means (Monquero and Christoffoleti, 2005). Furthermore, the use of cover crops and the maintenance of mulching on the soil surface during fallow would both possibly release allelopathic compounds to soil, and reduce light capture by weed seeds and seedlings, thus reducing the overall infestation (Hiltbrunner et al., 2007; Kruidhof et al., 2008; Teodoro et al., 2011).

The type of material used as cover crop, however, will influence the composition of the weed community (Kruidhof et al., 2008, 2009; Radicetti et al., 2013; Favarato et al., 2014). As example, the use of black oat straw alone or intercropped with white lupine, inhibited *Oxalis* spp., *Galinsoga quadriradiata* and *Stachys arvensis*, but not other species with the same efficiency (Favarato et al., 2014). Similarly, some weed species are favored by a given soil management system; e.g., *Digitaria* is usually favored in the no till system while *Cyperus* is benefited by soil tillage (Silva et al., 2005; Kropff et al., 2009).

According to Kuva et al. (2007), changes resulting from innovative agricultural production such as the crop-livestock (CLI) and crop-livestock-forest (CLFI) systems impact the size of the weed population, since they act as a periodic or non periodic ecological factor. Usually, the most adapted weed species to that level of environmental disturbance will prevail, which reflects on the soil seed bank (Soares et al., 2011) and on the long term weed infestation.

Soil tillage systems promote physical-chemical changes to seeds microenvironment (Mulugueta and Stoltenberg, 1997); thus, the real demand for chemical control of weeds should rely on a previous survey. This will help technicians to understand the weed species dynamics which occur on the distinct rice cropping systems (Voll et al., 2003), estimated by the emergence rates from the soil seed bank. For this purpose, the phytosociological survey has been used as tool for the characterization of the infestation pattern in agricultural areas, allowing to describe the structure of the weed community in a given field (Barbour et al., 1998).

Therefore, the aim of this study was to evaluate the occurrence of weeds in flooded rice areas, as a function of planting system and herbicide programmes in the previous cropping year.

MATERIAL AND METHODS

The experiment was installed in field conditions, at Embrapa Clima Temperado, Terras Baixas experimental station, Capão do Leão – RS, Brazil, in randomized complete blocks design, arranged in 3 x 2 factorial scheme with plots measuring 4 x 4 m, with eight independent replications. Treatments consisted on conventional tillage, minimum tillage (harrowing) and no till cropping systems (Factor A), coupled to the application (traditional control) or not (semi-ecological system) of herbicides (Factor B). Rice was sowed in nine rows spaced in 0.175 m, on 09 Nov. 2016 with 100 kg ha^{-1} of the variety Guri Inta CL. The basic fertilization applied at the planting furrow consisted of 300 kg ha^{-1} of N P K 5 25 25.

For the tillage system (Factor A), in the conventional system (Factor A, level 1), the area underwent plowing and disking prior to planting. In the minimum cultivation (Factor A, level 2), the area underwent two light diskings, 20 days before planting rice. For no-till (Factor A, level 3), the vegetation mulching was burndown with 1,440 g a.e. ha^{-1} of glyphosate, 20 days prior to planting rice.

As for the chemical treatments, those without herbicide (Factor B, level 1) did not receive any application, not even for burndown prior to planting; the natural area mulching was only accommodated closer to soil by the planting operations. In plots where herbicides were to be applied (Factor B, level 2), the area was burndown 20 days before planting, with 1,440 g ha^{-1} of glyphosate. Subsequently, 73.5 g ha^{-1} of imazapyr + 24.5 g ha^{-1} of imazapic (140 g c.p. ha^{-1} of Kifix) + 400 g ha^{-1} of clomazone were applied right after rice planting. Thirty-five days after emergence, the application of 375 g ha^{-1} of quinclorac was necessary for controlling jointvetch (*Aeschynomene* spp.).

Flood irrigation was established on 08 Dec. 2016, 20 days after crop emergence, at the beginning of tillering (~ V3), by establishing a water layer of 7 cm, which was maintained throughout the cropping cycle. After harvesting, in April 2017, ryegrass (*Lolium multiflorum*) was established as winter cover crop at rate of 25 kg ha^{-1} of seeds. No cuts were made to ryegrass throughout the cycle, nor any fertilizer was applied to the winter crop.

On 27 Oct. 2017, phytosociological evaluations of the weed communities present in the treatments were carried out. The sampling method adopted for surveying the weed occurrence was that of the Random Quadrats, as proposed by Barbour et al. (1998), being randomly sampled one quadrat per plot (n = 8), with 0.25 m of side. In the quadrat area, fleabane (*Conyza* spp.), fringerush (*Fimbristylis* sp.), Ryegrass (*Lolium multiflorum*) and beardgrass (*Polypogon* sp.), which predominated in the area, were quantified; the other weed species reported, were grouped as "others". Plants were cut to the soil level, packed in paper bags by species, and dried into forced air circulation oven at ~ 75 °C for three days, for later dry mass measurement. The number of plants (number m^{-2}) and its total dry mass (g m^{-2}) for each weed species (absolute infestation) were presented in bar graphs as a function of treatment, with the respective sampling standard errors.

The absolute infestation data set was tested for normality by the Shapiro-Wilk test, prior to estimating the density (based on number of individuals), the frequency (based on the spatial distribution of the species) and the dominance (based on capacity to accumulate mass) in relative terms, which were used to obtain the importance value for each species in each factor/treatment, according to Pandeya et al. (1968) and Barbour et al. (1998), as follows:

$$rDe = \frac{I}{TI} * 100 \qquad \text{(eq. 1)}$$

$$rDo = \frac{DM}{TDM} * 100 \qquad \text{(eq. 3)}$$

$$rFr = \frac{Q}{TQ} * 100 \qquad \text{(eq. 2)}$$

$$IV = \frac{rDe + rFr + rDo}{3} \qquad \text{(eq. 4)}$$

where *rDe* = relative density (%); *rFr* = relative frequency (%); *rDo* = 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 within the community, depending on its ability to cause damage (severity of occurrence), based on the three parameters mentioned above.

The areas were also intra analyzed by the diversity coefficients of Simpson (D) and Shannon-Weiner (H’) (Barbour et al., 1998). The sustainability coefficient (SEP) was also estimated according to McManus and Pauly (1990), as follows:

$$D = 1 - \frac{\sum ni * (ni - 1)}{N + (N - 1)} \quad \text{(eq. 5)} \qquad H' = \sum (pi * \ln(pi)) \quad \text{(eq. 6)} \qquad SEP = \frac{Hd'}{H'} \quad \text{(eq. 7)}$$

where *D* = Simpson and *H’* = Shannon-Weiner diversity indexes (both 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 sustainability coefficient; and *Hd’* = Shannon-Weiner diversity index (based on dominance).

Subsequently, the areas were compared by Jaccard’s binary asymmetric similarity coefficient (*J*). Based on the Jaccard coefficient, the similarity matrix was prepared and from it the dissimilarity matrix (1 similarity) was obtained, as follows:

$$J = \frac{c}{a + b - c} \quad \text{(eq. 8)} \qquad Di = 1 - J \quad \text{(eq. 9)}$$

where *J* = Jaccard’s coefficient of similarity; *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.

The multivariate hierarchical clustering analysis was performed from the dissimilarity matrix by the UPGMA hierarchical clustering method (Sneath and Sokal, 1973). The critical level for group separation was based on the arithmetic mean of the similarities in the original matrix (Barbour et al., 1998), while not considering the crossing points between the same areas in the matrix (where *Di* = 0). Grouping validation was performed 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. All coefficients and graphs were obtained in the statistical environment R (R Development, 2017).

All formulas and procedures, both for sampling and for describing the communities as well as species grouping, followed the recommendations by Barbour et al. (1998) for synecological analyzes.

RESULTS AND DISCUSSION

In general, herbicide application, independent of the tillage system, reduced the density of the monitored weed species by almost half, compared to the non-applied treatments (Figure 1). However, regarding the no tillage system, infestation levels and dry mass of the species were equivalent in treatments with and without herbicide application, being also less infested by weeds in the absence of chemical weed control. This illustrated how important is the mulching supplied by a winter crop to suppress weed infestation in rice.

The largest volume of dry mass deposited on the soil surface in the no till system seems to have performed two functions; in the area without herbicide application (semi-ecological management), the straw was responsible for avoiding or at least reducing the access of weed seeds and seedlings to light (Silva et al., 2009; Teófilo et al., 2012), which contributed to a lower weed establishment in the area. In treatments with herbicides, besides the effect of shading, the straw may have been responsible also for capturing part of the applied herbicide and caused possible losses, because when the herbicide is retained in the straw it becomes more exposed to the environment, being subjected to degradation processes (Iupac, 2017). This may have caused somehow a reduction in weed control in the previous year with the application of herbicides to the no till system, compared to other systems (Figure 1).

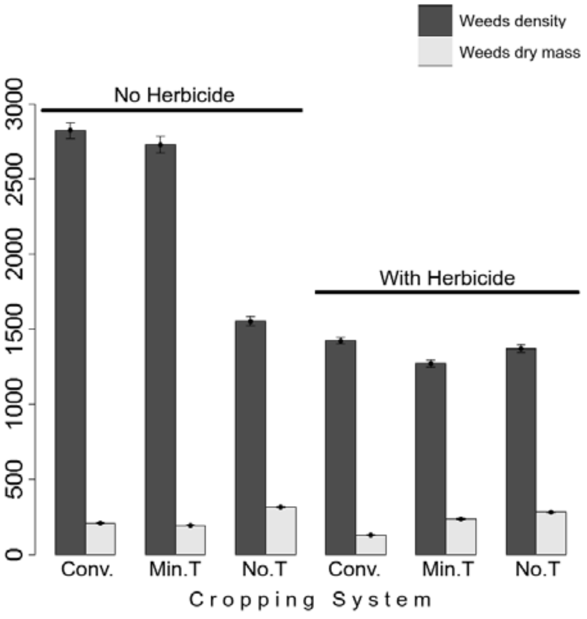


Figure 1 **-** Infestation density (nº m^{-2}) and dry mass (g m^{-2}) of weed species in Conventional, Minimum tillage and No tillage systems, when herbicides were applied or not to the field.

Godoy et al. (1995) reported that the soil tillage in the conventional planting system did not promote reduction in weed infestation compared to burndown herbicide application in the no till areas. Pacheco et al. (2016) reported that soybean cultivation followed by fallow, as well as the succession soybean-millet-crotalaria-rice in no till system was less infested than their equivalents in conventional tillage system at the beginning of the soybean cycle. However, at the end of the harvest the weed biomass values were high for both systems. These authors reported that *Urochloa ruziziensis* (Congo grass) and *Pennisetum glaucum* (yellow foxtail) sowed prior to harvesting soybean, as well as *Urochloa ruziziensis* in intercropping with corn in no till, helped to reduce the population and dry mass of *Spermacoce latifolia* (broadleaf buttonweed), *Chamaesyce hirta* (Asthma plant), *Amaranthus viridis* (slender amaranth), *Digitaria sanguinalis* (hairy crabgrass) and *Cenchrus echinatus* (southern sandbur).

Both Simpson and Shannon Weiner diversity indexes, with herbicide application, were generally higher than treatments without application (Figure 2). Weeds reported in the area with herbicides, independent of the cropping system, were very likely to have equivalent susceptibility to the applied herbicides. However, for treatments without application, the low diversity index expresses the predominance of only some species with greater competitive ability, which ended up taking over most of the available area.

In the semi-ecological treatments (without herbicides), the conventional system presented D and H' diversities superior to the minimum and no till systems, which may be related to the fact that, during the crop cycle in the conventional system, there was less area coverage and after soil tillage in the following year, there was a higher number of weeds, due to the lower competitive intensity among the species. According to Lindquist and Maxwell (1991) and also Guersa and Martinéz-Guersa (2000), the conventional tillage tends to give rise to persistent soil weed seed banks, since it incorporates and distributes seeds uniformly in the soil profile, and this distribution is influenced by the frequency of tillage.

In the area with herbicide treatments, SEP was equivalent to environmental stability (SEP ~ 1), according to the standard errors (Figure 2). This probably results from the supposed similarity in sensitivity of the weed species present to the herbicides applied in the previous year, which may have caused equalization in the occurrence of the species in terms of number of individuals and accumulation of dry mass, as well as seed production. In the no herbicide area, the behavior observed in the minimum tillage may be highlighted, where the small number of species observed and the exaggerated predominance of certain species, resulted in

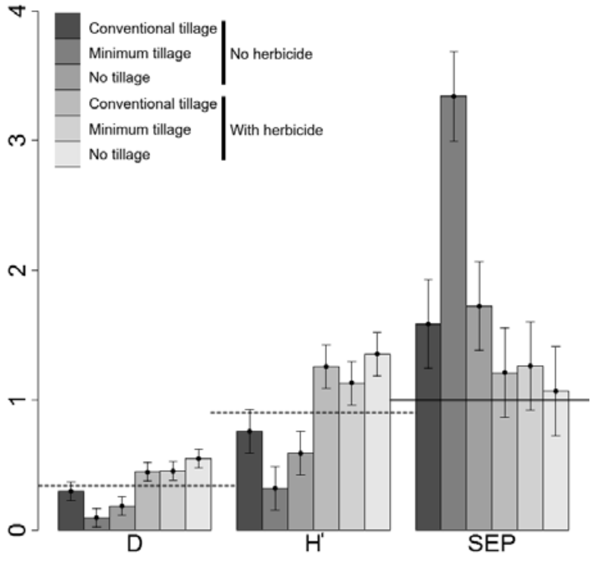


Figure 2 **-** Diversity coefficients of Simpson (D), Shannon Weiner (D) and Shannon Weiner sustainability index (SEP), in Conventional, Minimum tillage and No tillage systems, when herbicides were applied or not to the field.

low values of D and H' and high SEP (Figure 2). The latter reflects the disproportionate accumulation of dry mass in the predominant weeds compared to their number of individuals. In other words, the environment has very high levels of certain factors that are demanded in great quantity by some species; these privileged species have exaggeratedly developed, dominating the area and inhibiting the occurrence of other species (Figure 2).

With the application of herbicides, there was a decrease in importance value for most weeds compared to treatments without application, but increasing as consequence the importance of *Conyza* spp. and *Polypogon* sp. in the conventional system, and *Fimbristylis* sp. and *Polypogon* sp. in the minimum tillage system (Table 1). These species are probably less susceptible to the applied herbicides compared to the others present in the area. In the no till system, most of the species had an increase in their importance value, where *Conyza* sp. and *Polypogon* sp seemed to be favored. This fact contributed to the differentiation between treatments observed in the dissimilarity clustering analysis (Figure 3), where the no till with herbicide application differed from the others with high degree of certainty.

Table 1 **-** Density, frequency, dominance and important value of weed species in Conventional cropping system, Minimum cropping system and No-tillage system, when non-applied and applied herbicides

	Non applied herbicide				Applied herbicide				
	Conventional cropping system								
Species	de*	fr*	do*	iv*	Species	de*	fr*	do*	iv*
Conyza sp.	0.14	8	0.21	2.78	*Conyza* sp.	0.98	13.33	1.82	5.38
Fimbristylis sp.	0.64	24	13.75	12.8	*Fimbristylis* sp.	1.83	10	3.31	5.05
L. multiflorum	81.94	32	72.49	62.14	*L. multiflorum*	72.15	26.67	58.88	52.57
Polypogon sp.	0.42	8	1.6	3.34	*Polypogon* sp.	12.1	26.67	27.6	22.12
Others	16.86	28	11.94	18.93	*Others*	12.94	23.33	8.38	14.88
	Minimum cropping system								
Conyza sp.	0.29	9.09	0.69	3.36	*Conyza sp.*	0	0	0	0
Fimbristylis sp.	0.44	27.27	6.83	11.51	*Fimbristylis* sp.	1.73	22.73	12.12	12.19
L. multiflorum	95.01	36.36	74.31	68.56	*L. multiflorum*	68.87	36.36	59.04	54.76
Polypogon sp.	0	0	0	0	*Polypogon* sp.	26.26	31.82	26.93	28.34
Others	4.25	27.27	18.17	16.56	*Others*	3.14	9.09	1.92	4.72
	No-tillage system								
Conyza sp.	0	0	0	0	*Conyza* sp.	0.58	15.38	2.99	6.32
Fimbristylis sp.	3.87	33.33	13.13	16.78	*Fimbristylis* sp.	0	0	0	0
L. multiflorum	89.95	33.33	76.54	66.61	*L. multiflorum*	59.18	30.77	54.21	48.05
Polypogon sp.	0.52	8.33	0.06	2.97	*Polypogon* sp.	29.45	23.08	34.79	29.11
Others	5.67	25	10.27	13.65	*Others*	10.79	30.77	8.02	16.53

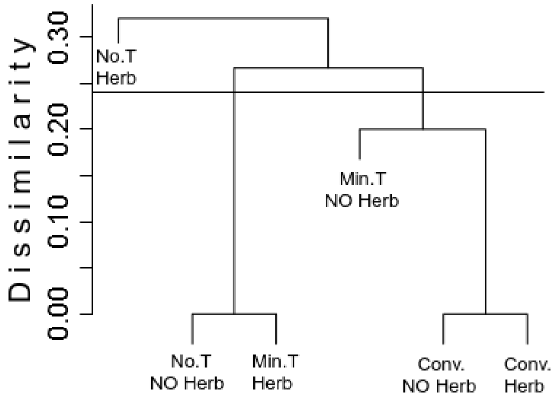
* de = relative density (%); fr = relative frequency (%); do = relative dominance (%); iv = importance value (%).

In this sense, the use of mulching crops, either intercropped or planted after harvesting of annual crops, as well as crop rotation, assist in the long-term weed management (Pacheco et al., 2009), due to the physical barrier imposed by the straw. In addition, the release of allelopathic substances to soil by some cover crops provides a reduction in the emergence and growth of weeds in the no till system (Tokura and Nóbrega, 2006; Monquero et al., 2009; Silva et al., 2009). The range and efficiency of the allelopathic effects of cover crop residues, however, depends on the rate of decomposition, the characteristics of the straw that persists on the soil surface and the weed population (Tokura and Nóbrega, 2006).

The physical effect of the straw layer, associated to the thermal and soil water changes and the amount of light filtered by the straw, end up by influencing weed germination (Borges et al., 2014). In the case of maize, the use of ryegrass cover during winter helped to reduce weed infestation and favored the crop (Moraes et al., 2013).

Therefore, rice growing systems (traditional or semi-ecological), promote remarkable differences in weed occurrence. Herbicide crops select, over time, companion weed species as they are most adapted to the management system. These species tend to predominate in the area in detriment of other weeds and plant species, causing great reductions in crop productivity. Although in these systems, crop rotation and the presence of winter cover crops are preponderant to successful weed management, they are not a *sine qua non* condition for successful cropping.

Semi ecological systems where the use of herbicides for weed management is not allowed, require a different strategy. The use of crop rotation, thick winter soil mulching and their association with animal presence and grazing are essential for the short, medium and long-term inhibition of weed occurrence. In these areas, hoeing – either by man powered or mechanized means – will probably be essential to ensure the success of rice cropping in a semi-ecological system.



Cophenetic Correlation
0.78 *

Figure 3 **-** Grouping by weed dissimilarity of cropping systems – Conventional system, Minimum tillage and No-tillage system, when herbicides were applied or not to the field. No.T = no tillage system; Min.T = minimum tillage system; Conv. = conventional tillage system.

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