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Effect of Post-Emergence Herbicide Applications on Rice Crop Weed Communities in Tolima, Colombia[1]

Efeitos da Aplicação em Pós Emergência de Herbicidas em Comunidades Infestantes de Cultivo de Arroz em Tolima, Colômbia

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ABSTRACT - The weed communities of agricultural systems are dynamic and respond to changes in agronomic practices. This study aimed to evaluate the effect of post-emergence herbicide control programs made by farmers on weed communities and commercial lots of rice. The evaluations were carried out in 96 commercial lots located in the Centro, Meseta and Norte zones of the department of Tolima. In each lot, 1 ha was marked off, in which the evaluations were carried out by randomly throwing a 0.2 x 0.2 m sampling-square 5 times. Samples were taken before the first post-emergence application, after the first post-emergence application, after the second post-emergence application, and once the post-emergence applications were finished. The evaluated variables included density and cover of the weeds and the crops. The IVI of each species was calculated and the control program was analyzed in terms of decreases in the number of individuals for the 15 more encountered species. Before the applications, higher density values were found. The first and second post-emergence applications reduced the average density by 41% and 12%, respectively, throughout the department. Between the first and fourth evaluations, the density of the weeds and crops decreased throughout the department by 51.7% and 39%, respectively. The weed density variable proved to be the most influential in the populations after the herbicide programs were carried out.

Keywords: weed control, pendimethalin, propanil, bispyribac sodium.

RESUMO - As comunidades infestantes de sistemas agrícolas são dinâmicas e respondem às mudanças nas práticas agronômicas. Este estudo tem por objetivo avaliar os efeitos dos programas de controle com herbicidas implantados em pós-emergência por produtores em plantações comerciais de arroz e em comunidades infestantes. As avaliações foram realizadas em 96 lotes comerciais localizados nas regiões do Centro, Meseta e Norte do departamento de Tolima. Foi demarcado 1 ha em cada lote, onde foram feitas avaliações com um quadrado inventário de 0.2 x 0.2 m, lançado aleatoriamente 5 vezes. As amostras foram colhidas antes da primeira aplicação em pós-emergência, após a primeira aplicação em pós-emergência, após a segunda aplicação em pós-emergência, e logo após a finalização das aplicações em pós-emergência. As variáveis avaliadas incluíram densidade e cobertura das plantas daninhas e das culturas. Foi calculado o Índice de Valor de Importância (IVI) de cada espécie, e o programa de controle foi analisado quanto à diminuição no número de indivíduos para as mais de 15 espécies encontradas. Antes das aplicações, foram encontrados valores mais elevados de densidade. A primeira e segunda aplicações em pós-emergência reduziram a densidade média em 41% e 12%, respectivamente, em todo o departamento. Entre a primeira e a quarta avaliação, a densidade das plantas daninhas e culturas sofreu uma redução, no departamento inteiro, de 51.7% e 39%, respectivamente. Foi constatado que a variável densidade de plantas daninhas exerceu maior influência nas populações após a implantação dos programas de controle com herbicidas.

Palavras-chave: controle de plantas daninhas, pendimetalina, propanil, bispyribac de sódio.

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INTRODUCTION

The rice weed community contains 1,800 species worldwide (Rao et al., 2007). Notably, there are species that belong to the Cyperaceae and Poaceae families and that are well adapted to this crop (Rao et al., 2007). This can be seen in the *Echinochloa colona*, *Ischaemum rugosum*, *Fimbristylis miliacea* species as well as in those that belong to the *Cyperus* genus (Rao et al., 2007), which are considered responsible for the majority of yield losses for rice crops in tropical zones. The intensity of losses can vary according to the species, the interference time, the level of infestation in the fields, and the cultivation timing (Rao et al., 2007; Fialho et al., 2010). Likewise, the establishment of populations is influenced by agricultural activities (Pitelli, 2000).

Weed species can be differentiated by levels of competitiveness with crops and differences in frequency, density, growth habits, and level of adaptation to field conditions, with a principal group of weeds that generate economic effects as well as secondary effects that normally do not affect yield (Pitelli, 2000).

Weed communities are dynamic in their responses to agricultural activities over time and their level of importance can constantly change (Booth et al., 2003). The application of control methods is fundamental for rice crops in order to minimize the negative effect of the principal weeds (Fuentes, 2010). Likewise, knowledge of the dynamics and interference of weeds is essential for making decisions for the application of these methods. The community dynamic refers to changes in the composition of the infesting community, considering the relative dominance of each species in the agroecosystems (Jakelaitis et al., 2003). The number of individuals can be used to express the ratio between the populations as a component of the infesting community (Carvalho et al., 2008). Studies on weed communities compare the populations of these plants over time, considering the results of management and relating them to the field conditions (Pitelli, 2000; Carvalho et al., 2008; Moreira et al., 2013).

Herbicides act as filters that select populations within a weed community, affecting the growth of some or impeding emergence. These chemical compounds play a important role in the determination of the composition, diversity, and abundance of the weed flora in a crop (Andreasen & Streibig, 2010). Their use in rice crops is a valuable tool given their practicality and level of efficiency. In Colombia, applications are commonly carried out before the seeds are established, when the rice is in the process of emergence and after the emergence of the plantlets (Fedearroz, 2003). The latter is known as post-emergence applications and uses selective active ingredients, like propanil, cyhalofop butyl and bispyribac sodium, when the rice plants are in the initial stages of development.

According to Gibson et al. (2002), control methods must be used until the rice crop has the competitive ability to overcome weed development. This interval is usually known as the critical period of competition and is defined as the period in which the crop must be free from the adverse effects of weeds (Juraimi et al., 2009). During the critical period of competition, rice plants are between the phases of tillering and primordium (Medina, 2011), which is why it is necessary to utilize control methods such as herbicide applications in order to avoid decreases in yields. Direct sowing and field flooding, general practices in the department of Tolima, play an important role in the management of competition because they result in the establishment of weed populations during the critical period of competition.

It is common to find different reports in the literature on yield losses for rice crops due to the effects of competition from weed communities. Authors such as Chauhan & Johnson (2011) reported 94% and 96% losses when weeds were not controlled. Juraimi et al. (2009) showed losses of 54.5% when weeds were allowed to compete with direct-seeded rice for 75 days after sowing; Ferrero & Tinarelli (2008) found a 90% reduction without weed control; Johnson et al. (2004) reported a reduction of 49% with uncontrolled weed growth and Tomita et al. (2003) found a reduction of 9% without control under rainfed conditions. In general terms, when the measured weed density increases, the grain yield decreases, to a greater or lesser extent depending, of course, on the particular conditions of each harvest (Tindall et al., 2005).

The objective of this study was to evaluate the effect of post-emergence herbicide control programs made by farmers on the weed communities and rice crops in commercial lots of the Centro, Meseta and Norte zones of the department of Tolima (Colombia).

MATERIALS AND METHODS

The present study was carried out between the months of July, 2012 and February, 2013 in commercial rice crops in the department of Tolima (Colombia). The department was divided into three zones for the field sampling, in which the municipalities with the larger cultivated areas were considered. The divisions took into account differences in climate, topography, edaphic qualities, and irrigation availability. The Norte zone contained the municipalities of Lérida, Ambalema, Venadillo and Armero; the Meseta zone was in Ibagué with the municipalities of Ibagué, Piedras and Alvarado; and the Centro zone had the municipalities of Purificación, Guamo, Espinal and Saldaña. A sampling size of 0.1% (96 ha) was used in accordance with the following formula (Spiegel, 1988):

$$n=\frac{N\times Z_{\propto}^{2}\ p\times q}{d^{2}\times(N-1)+Z_{\propto}^{2}\times p\times q}$$

where n is the sample size, N represents 96.319 ha cultivated in these municipalities, $Z_{\propto}^{2}$ equals 1.96^2 with a confidence of 95%, p is the expected proportion of 5%, q equals 0.95 and d^2 is the desired precision of 10%. The zones and municipalities contained sampled hectares that were proportional to the cultivated area found in each location, with the Centro, Meseta and Norte zones sampled at 53%, 21% and 26% of the sample size, respectively.

For the development of the samples of the weed communities and crops, a square sample unit of 0.2 x 0.2 m in size was used, throwing it at random five (5) times within a marked area of one hectare in each lot, following a zigzag pattern. The following variables were evaluated: density, cover, and level of control exercised by the herbicides through the reduction of weed density. For the determination of the cover variable, the DOMIN evaluation table was used. A taxonomic classification of the species was carried out using the studies of Montealegre (2011), Fuentes et al. (2006a, b) as references.

The methodology employed for the distribution of the sample units in the studied area allowed for the evaluation a real area of 384 ha in total for the present study (0.4% of the total cultivated area in the selected municipalities) and of 0.8 ha in each lot.

The evaluations were carried out four (4) times, in accordance with Plaza & Hernandez (2014) and adjusted to the particular management conditions of each rice field, as follows: first, before the first post-emergence application (7 to 22 days after sowing); second, after the first post-emergence application (22 to 35 d.a.s.); third, after the second post-emergence application (37 to 52 d.a.s.); and fourth, at 52 to 65 d.a.s.

The data obtained in the field were subjected to a descriptive analysis of the variables. In each evaluation, the importance value index was calculated in each species using the phytosociological parameters of density, frequency, and cover with the methodology proposed by Mueller-Dombois & Ellenberg (1974) and Curtis & McIntosh (1950). A description of the control variable was done for the fifteen (15) species with the higher importance value indices (IVI). A statistical analysis was carried out for the density measurements with a paired t-test using the statistics software SAS, version 9.2.

For the conjoint analysis of the variables of density, control, cover percentage and IVI registered after the first and second application, a principal components analysis was carried out using the statistical program R, version 3.0. This revealed the variable with the most influence in the weed community after the treatments.

RESULTS AND DISCUSSION

The weed community throughout the department is composed of 42 species, distributed among 20 families and 31 genera. In the Centro zone, 27 species were identified that were grouped into 14 families and 21 genera. In the Meseta zone, there were 31 species from 12 families and 23 genera and, in the Norte zone, there were 38 weeds originating from 18 families and 29 genera.

The measurement of the density of the species before and after the post-emergence herbicide applications and the quantification of the effect of this control method allowed for a close analysis of the efficiency of the applications and the relevance of some aspects related to it. Before the first application, the highest weed density value was registered for the three zones (density 1). The average of the individuals was 41% higher than the average after the application (density 2) (Figure 1). The percentage of control of the first post-emergence application in terms of decrease in the number of individuals was 29%, 34%, and 52% for the Centro, Meseta, and Norte zones, respectively (Figure 1). The densities of the weeds before and after the application were statistically different ($p<0.05$) (Figure 1).

The highest level of control registered in the Norte zone was possibly a response to the fact that the application was carried out earlier in the crop cycle as compared to the other regions (Figure 1). This could have contributed to a higher effect on the weed community that would have been in an early stage of development. The principle of oppurtuntiy of herbicide applications suggests that the majority of weed plants are more susceptible to herbicides during their primary stages of development, beyond which, the controls lose efficiency (Fedearroz, 2003; Fuentes, 2010). This conclusion concurs with the observations of Chauhan & Abugho (2012), who reported a high effect from specific herbicides on *E. colona*, *E. crus-galli* and species of the *Leptochloa* and *Digitaria* genera when applications were carried out up to leaf development stage 4. The lower susceptibility of weeds in the higher stages of develpoment is possibly due to changes in the absorption, translocation, and metabolism of herbicides (Hathway, 1986; Kogan & Perez, 2003), because their degradation can occur more rapidly in larger-sized plants (Singh & Singh, 2004). In this sense, Doll (1981) stated that leaf stages two and three are the ideal periods for post-emergence herbicide applications.

In all of the zones, the density of the weeds before the second application (density 2) was higher than the density after the second application (density 3) (Figure 2). The Norte zone again demonstrated the highest level of weed establishment before the treatment

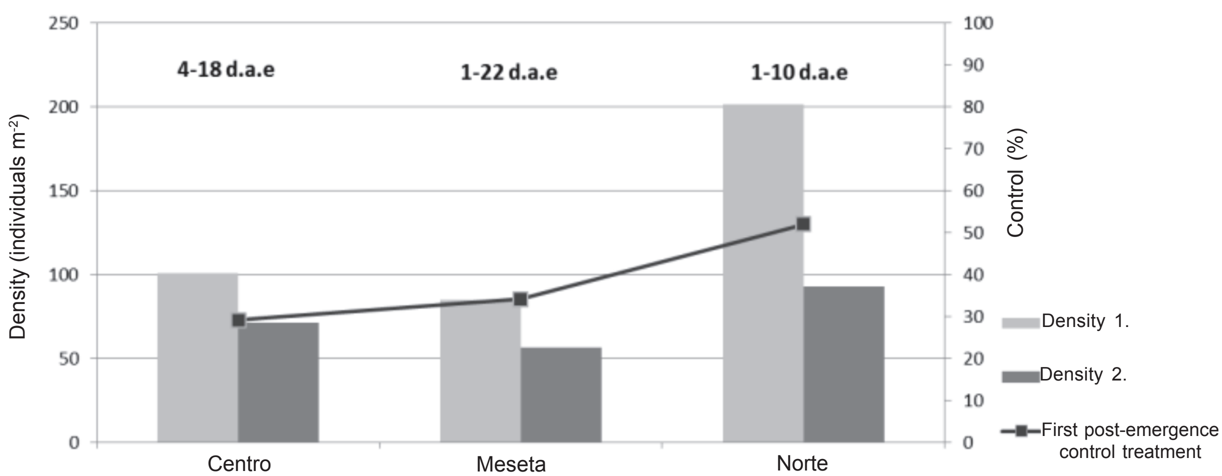

Figure 1 - Changes in density of the weeds in the rice crops of the Centro, Meseta and Norte zones of the department of Tolima as a result of the effect of the first post-emergence control treatment. Reduction of the weed density (% control). Treatment application timing in days after emergence of the crop (d.a.e.).

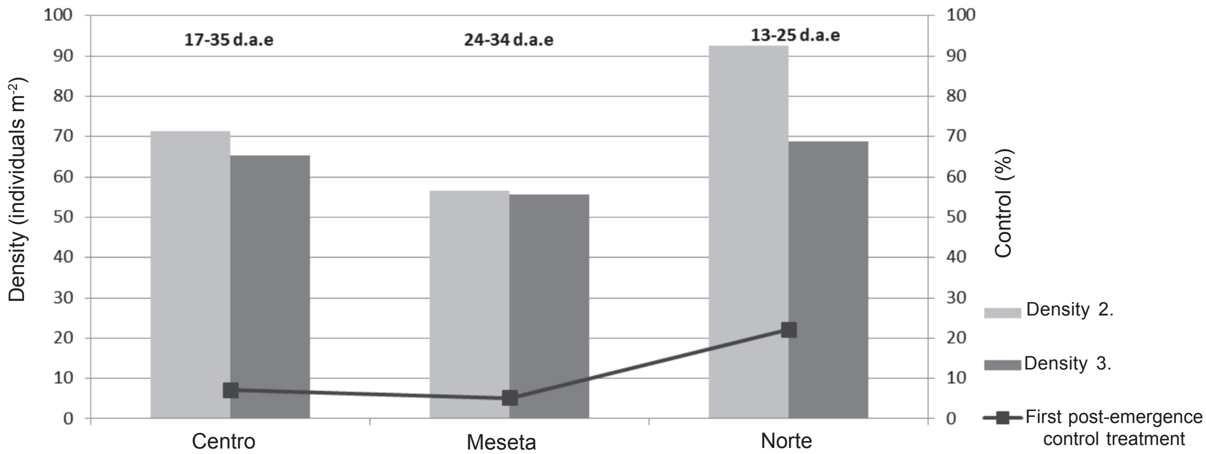

Figure 2 **-** Changes in density of the weeds in the rice crops of the Centro, Meseta, and Norte zones of the department of Tolima resulting from the second post-emergence control treatment. Reduction of the weed density (% control). Treatment application timing in days after crop emergence (d.a.e.).

(Figure 2). After the application, there was an average reduction in the number of individuals of 12% throughout the department (Figure 2). The level of control of the second post-emergence application in terms of decreases in the number of individuals was 7%, 5%, and 22% for the Centro, Meseta, and Norte zones, respectively (Figure 2). The densities of the weeds during evaluations two and three were not statistically different ($p>0.05$) (Figure 2).

The lower decrease in the density of weeds in the Meseta zone could have been due to the fact that the plants had a higher development and lower susceptibility (Figure 2). Likewise, the higher percentage of control in the Norte zone was possibly due to the opportunity of the treatment (Figure 2).

In terms of the competiveness behavior of the weed community with respect to the crops, it was observed that the weeds presented lower numbers, except in the first evaluation in the Norte zone (Figure 3). The weed density in the Centro zone presented its lowest value in evaluation 4; between the first and last evaluations, there was a reduction of 50.6% in the number of individuals (Figure 3). This zone had the highest density of rice plants for all the evaluations and there was a reduction in numbers of 46.38% between evaluations 1 and 4 (Figure 3). In the Meseta zone, there were decreases in the weed density and the crop density throughout the evaluations. The reduction in the number of weeds between evaluation 1 and 4 was 34.7% (Figure 3). The reduction in the number of rice plants between evaluation 1 and 4 was 53.2% (Figure 3). In the Norte zone, there was a reduction of 69.72% in the weed density between evaluations 1 and 4 (Figure 3). In this zone, the number of crop plants in evaluation one was inferior to the number reported in the second evaluation; from that moment on, there was a 17.6% reduction in the number of individuals (Figure 3). This may have resulted from the fact that the first sampling was carried out very early in the cycle, leaving out some rice plants that emerged afterwards, which were registered in the second sampling. In all cases, the weed density was higher in the first evaluation than in the last one (Figure 3). The reduction in the number of weed individuals was higher between evaluation 1 and 2 in all of the zones, possibly due to the effect from the control application (Figure 3).

In the PCA carried out for the variables after the first post-emergence application, it was observed that the first component presented a high correlation coefficient for the density variable; while the second component had a high correlation with the variable of importance value index (IVI) (Table 1; Figure 4). However, as can be seen in Figure 4 and Table 1, the weed density variable had the most influence in the weed community after the first post-emergence herbicide application.

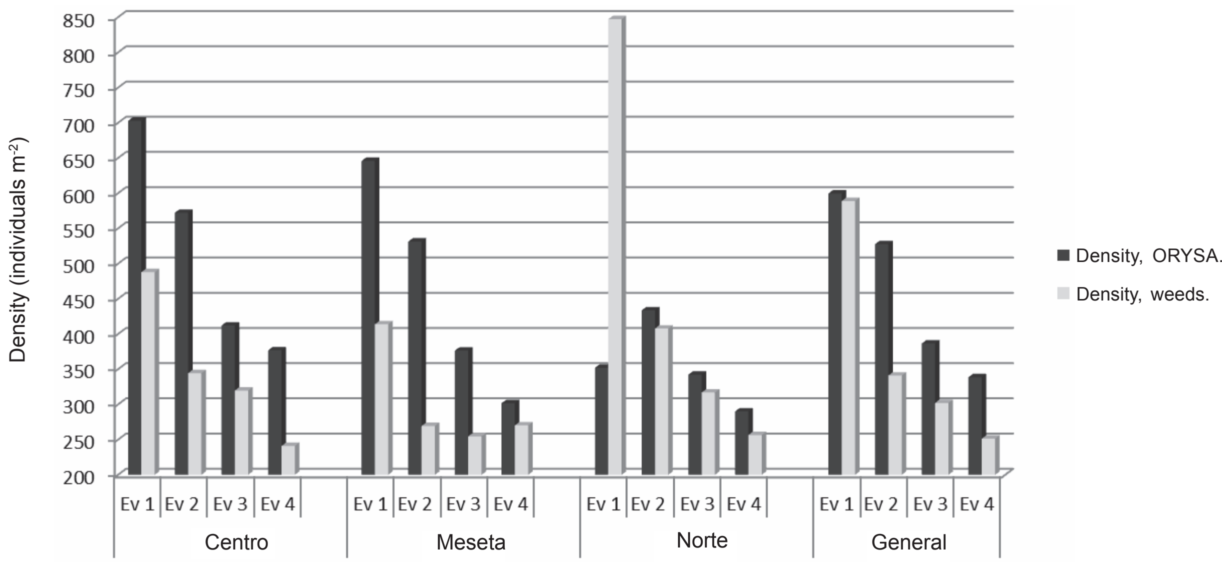

Figure 3 - Changes in the densities of the crops and associated weeds during the evaluations carried out in the rice fields of the Centro, Meseta and Norte zones.

Table 1 - Correlation coefficients between the axes of the principal components analysis (Components or axis 1 and 2) and the variables evaluated in the weed communities found in the rice fields after the first post-emergence herbicide application

Correlation Coefficient Variable-AXIS		
Variable	1	2
IVI	0.20	-0.76
Control (%) post-1	-0.76	-0.53
Cover (%)	0.40	-0.53
Density	0.91	-0.04

On the other hand, in the PCA for the variables after the second post-emergence application, the first component had a high correlation coefficient with the weed cover. The second component had a high correlation with the control variable (Table 2; Figure 5). It is important to note that the weed density variable had a strong correlation with the first component, which, together with the weed cover variable, exercised the most influence on the weed community at the time of evaluation (Table 2; Figure 5).

The influence of the weed density variable in the evaluations subsequent to the applications was possibly due to the biological characteristics of the species that were better adapted and that favored the establish of populations after the control methods. For example, the germination of highly competitive weed seeds in tropical rice crops is generally favored by humid environments. This is the case with *E. colona* (Chauhan & Johnson, 2009a), *I. rugosum* (Bakar & Nabi, 2003; Jarma et al., 2007), *P. boscianum* (Montealegre, 2011) and *C. iria* (Chauhan & Johnson, 2009b). Likewise, the high seeds production capacity of these species, with viability and germination percentages over 80% (Bakar & Nabi, 2003; Jarma et al., 2007; Mendoza, 2007; Chauhan & Johnson, 2009b; Vega-Jarquìn et al., 2010; Chauhan & Johnson, 2010a; Montealegre, 2011), generate a good number of propagules in the soil, which, under ideal germination conditions, leads to the establishment of new populations. In this sense, Rao et al. (2007) suggested that the adaptation of species of the genera *Echinochloa, Cyperus* and *I. rugosum,* under the conditions of direct sowing of rice crops, is possibly due to variability in the germination of their seeds and in the establishment of plantlets in response to the imposed water regime.

The end result of the effect of the herbicides also contributed to the presence of weed individuals after the applications. The half-life of herbicides is also a decisive factor (Cobb & Reade, 2010; Clavijo, 2010; Fuentes, 2010). According to the information of the present study, the active ingredients prevalently used in the first post-emergence application were pendimethalin and propanil.

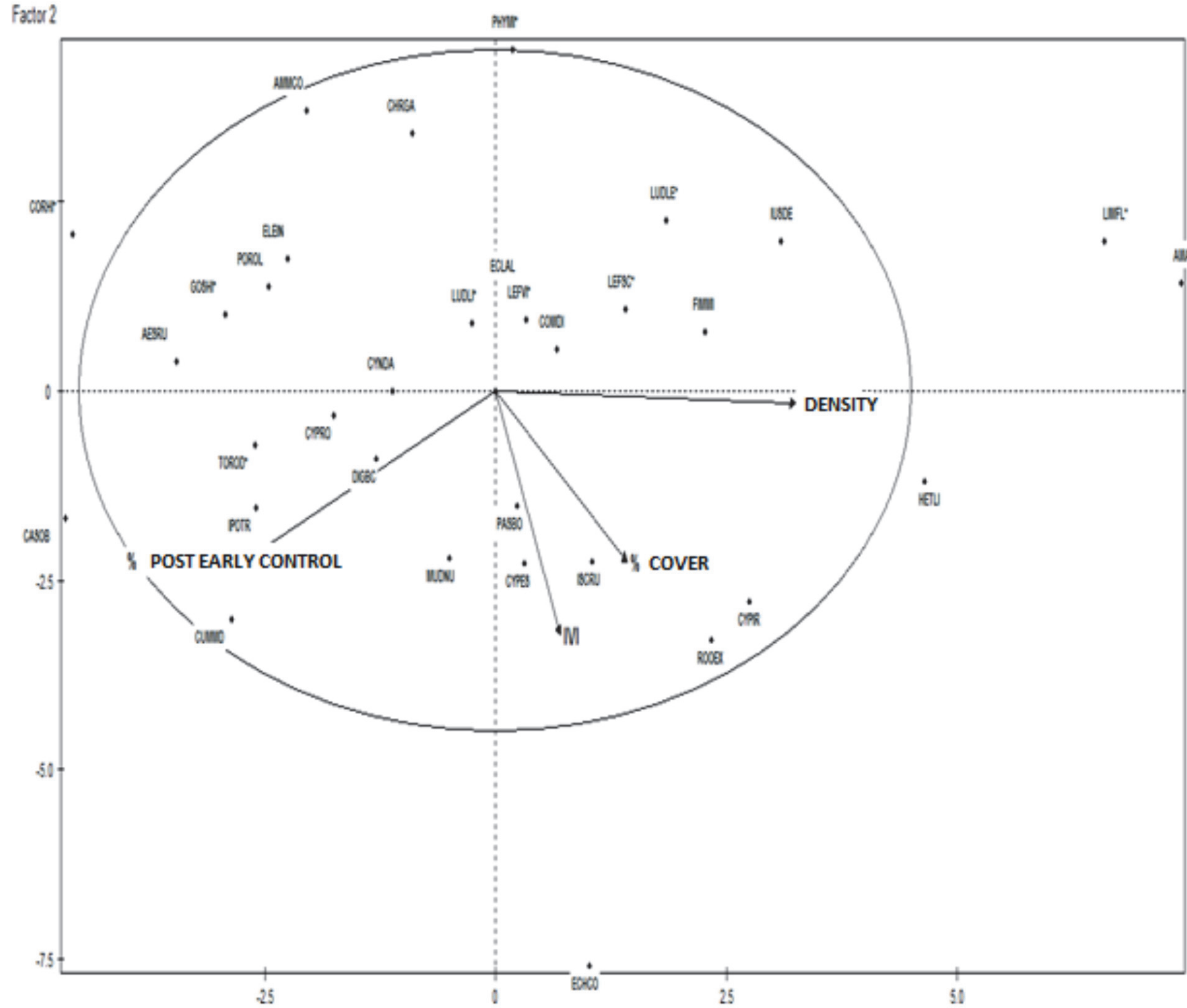

Figure 4 **-** Principal component analysis for the variables: importance value index (IVI), control (%) of the first post-emergence application (% POST-EARLY CONTROL), cover (%) (% COVER), and density (DENSITY) of the weeds after the herbicide control method. Scientific names in BAYER code for weeds.

Pendimethalin is a herbicide that is considered to be very persistent because it has a half-life that varies between 10.5 and 44 days according with soil temperature and moisture (Kogan & Perez, 2003; Alister et al., 2009; Clavijo, 2010; Fuentes, 2010). It is a microtubule assembly inhibitor that controls annual grasses and some dicotyledonous. Propanil a PSII inhibitor, has a half-life of between 1 and 4 days, which makes it slightly persistent (Fuentes, 2010), but offers a good effect for the control of emerged graminea weeds (Clavijo, 2010; Fedearroz, 2003). The active ingredients prevalently used in the second post-emergent application were bispyribac sodium, propanil and pendimethalin. Bispyribac sodium is an ALS inhibitor which offers good control for a wide range of grasses, dicotyledonous and

Table 2 **-** Correlation coefficients between the axes of the principal components analysis (component or axis 1 and 2) and the variables evaluated in the weed communities found in the rice fields after the second post-emergence herbicide application

Correlation Coefficient Variable -AXIS		
Variable	1	2
IVI	0.59	0.55
Control (%) post-2	0.52	-0.65
Cover (%)	0.90	-0.28
Density	0.81	-0.51

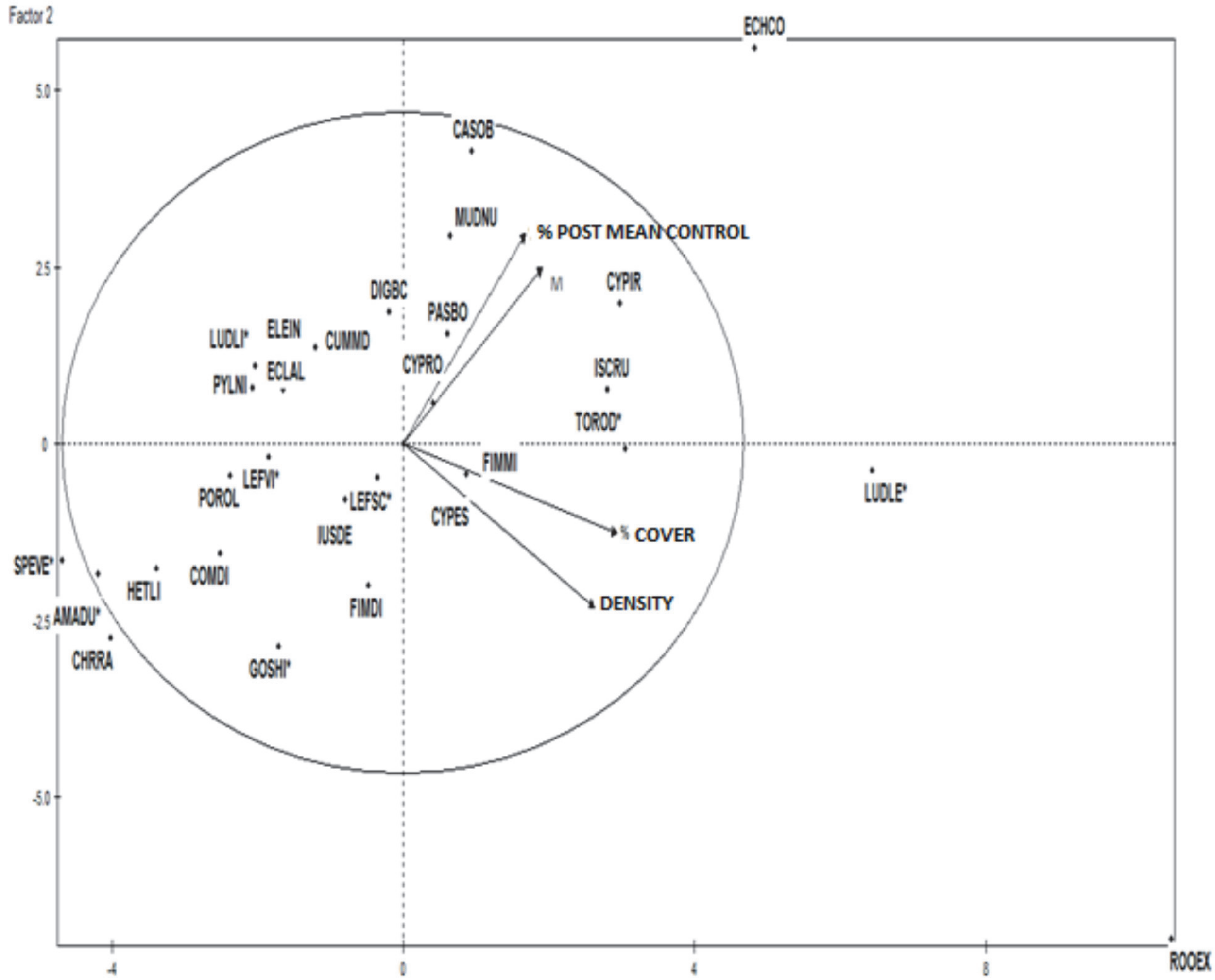

Figure 5 - Principal component analysis for the variables: importance value index (IVI), percentage of control of the second post-emergence application (% CONTROL POST-MEAN), percentage of cover (% COVER) and density (DENSITY) of the weeds after the herbicide application. Scientific names in BAYER code for weeds.

cyperaceae weeds. It is a herbicide that is absorbed by plant foliage (Clavijo, 2010; Fedearroz, 2003) and posseses a half-life between 45 and 60 days (Clavijo, 2010; Fuentes, 2010). The establishment of weed communities after the use of herbicides of these types suggested the presence of a large quantity of seeds in the soil that germinated once the herbicide effects wore off.

The obtained results led to the conclusion that the first post-emergence application reduced the weed density by 41% throughout the department; while the second post-emergence application reduced the number of individuals by 12%. The higher control percentages of the post-emergence applications were seen when the applications were carried out on weeds in their primary stages of development. Between the first and fourth evaluations, there were average decreases throughout the department in the weed and crop densities of 52% and 39%, respectively. The number of weed individuals was the variable with the most influence in the plant communities after the post-emergence herbicide applications.

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