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Integration crop-livestock: Is it efficient in suppressing troublesome weeds? A case study

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There is need to characterize the impact of the integration crop-livestock on weed infestation in production fields; higher infestation would result in lower system sustainability mainly due to the increased demand for agrochemicals, especially herbicides. Thus, we aimed with this study to assay weed dynamics in a farmer's managed, long-term crop-livestock system, through a case study adopting the phytosociological perspective. The monitored fields measured 282 ha at the municipality of Amambai-MS, Brazil. Each area was sub-divided into two sections ("1" and "2") for organization of quadrat distribution. A complete monitoring, which included both instantaneous infestation and soil seed bank studies, was conducted in both areas, which were managed under long-term crop-livestock integration, cycling every two years between soybean-corn succession and cattle raising (livestock). Phytosociological characterization of weed species was accomplished in 2011 based on the Ecological Approach. Estimations of relative density, frequency, dominance and Importance Value Index were obtained. Areas were also intra-characterized by the diversity coefficients of Simpson and modified Shannon-Weiner, and then grouped by cluster analysis. Crop-livestock integration proved to be efficient in suppressing some troublesome weed species, but others still prevail in integrated production fields; for Center-West region of Brazil, pigweed, beggartick and sourgrass tend to be preponderant weed species in crop-livestock areas; weed management should go beyond cultural practices, demanding the right herbicide to be applied at the right time aiming to control the weed species which were able to prevail even in the integrated production environment.

Key words: Integrated systems, phytosociological survey, soil seed bank, crop rotation.

INTRODUCTION

Weed infestation in soybeans can dramatically reduce yield if not properly managed. Losses in grain yield may reach 90% depending on the intensity of infestation, weed species present and moment of emergence (Sodangi et al., 2013). In the past, the use of an integrated management approach reduced demand for

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herbicides (Monquero, 2014); in the last decade, however, management programs almost totally abandoned the integrated approach heading to the abusive increase in herbicide application, with undesired consequences for economic, ecological and environmental aspects (Aktar et al., 2009; Bueno et al., 2011).

With the advent of transgenic soybeans resistant to the herbicide glyphosate (recommended for post-emergence weed control), which was supposed to hinder herbicide application in this crop, herbicide demand had in fact sharply increased due to the selection of troublesome weeds (Meyer and Cederberg, 2010). Chemical mismanagement with frequent application of herbicides with same mechanism of action, in absence of crop rotation, led to the selection of weed biotypes resistant to herbicides, being the main ones in Brazil three species of horseweed (*Conyza bonariensis*, *Conyza canadensis* and *Conyza sumatrensis*), sourgrass (*Digitaria insularis*), ryegrass (*Lolium multiflorum*) and goosegrass (*Eleusine indica*) (Vivian et al., 2013; Heap, 2014), which are all resistant to glyphosate. These species are widespread in soybean due to the misuse of Roundup Ready® technology, which bases weed control primarily on glyphosate.

Integrated crop-livestock systems have been adopted in several regions of Brazil. The benefits of integrated systems include increased soil fertility due to the accumulation of organic matter, improved nutrient cycling, increased fertilizer efficiency, better soil aggregation and also favor a more biologically active edaphic environment compared to other cropping systems (Salton et al., 2014). Rotation of crops with livestock can also help to break pest, disease, and weed cycles, thus reducing production costs and reducing the environmental risk posed by the proliferation of agrochemicals (Vilela et al., 2008).

Distinct cropping systems affect weed composition and its occurrence by changing the pool of management practices applied to the area, which will change the nature and amount of resources available for weeds, and help excluding from the system those weed species highly specialized in exploring a single or a few environmental resources, leaving room for less specialized and more flexible plant species (Gurevitch et al., 2009), which are usually not troublesome weeds.

Understanding not only the level of occurrence but also the composition of the weed community under each cropping system is important to achieve efficient control. Research data shows that management systems with low soil disturbance allow formation of a more diverse weed seed bank in soil. We hypothesize that long-term crop-livestock integration system promotes reduction in emergence of troublesome weed species while it increases the occurrence of less problematic plant species. Phytosociological studies allow assessing species composition of a given canopy and their estimation of density, frequency and dominance as well as the importance index for each species in the community, supporting inferences about a given group of plants (Gomes et al., 2010) and also about a given management.

There is need to characterize the impact of the integration crop-livestock on weed infestation in production fields; higher infestation would result in lower system sustainability mainly due to the increased demand for agrochemicals, especially herbicides. Thus, we aimed with this study to assay weed dynamics in a farmer's managed, long-term crop-livestock system, through a case study.

MATERIALS AND METHODS

Field location and brief on management

The monitored fields measured 282 ha, being the first one called “Esperança” with 172 ha (-23° 00' 11.5”; -55° 00'43”) whose soil presented 17% clay, and the second one called Janaina, with 110 ha (-22° 58' 34.2”; -55° 00' 11.9”) whose soil presented 30% clay, both located at the municipality of Amambai-MS, Brazil. Each area was sub-divided into two sections (“1” and “2”) for organization of quadrat distribution. A complete monitoring, which included both instantaneous infestation and soil seed bank studies, was conducted in both areas, which were managed under long-term crop-livestock integration, cycling every two years between soybean-corn succession and cattle raising (livestock). The following crop sequence was used for more than seven years: (AGRICULTURE) Soybean in summer followed by corn intercropped with *Brachiaria ruziziensis* in the second crop; (LIVESTOCK) after two years of agriculture, cattle was raised over *Brachiaria* spp. All plantings were fully made under no-till system; soil was never prepared since the installation of crop-livestock.

When the field is under agriculture, soybean is planted in early October being harvested by late February, being corn planted in early March intercropped with *B. ruzizensis*. The forage (*B. ruziziensis*) is a C_4 carbon cycle species, which remains stagnated among corn plants due to shading, being able to establish after corn harvest. This species will serve as mulching until planting, if soybean is to be cropped on the next season, or will form the pasture in the area if it is shifting to the 2-year livestock cycle.

When areas were surveyed, they were entering the second year of agriculture. Soybean was planted in 27 and 29 September 2012, respectively for Esperança and Janaina, with variety Embrapa BRS 284, in rows spaced in 0.45 m with 14 seeds per meter of furrow. Fertilization was accomplished in the planting furrow according to the official recommendations (Embrapa, 2011).

Assessment 1 – Instantaneous infestation

Phytosociological characterization of weed species present in both areas was carried out on early October, 15 days after soybean emergence (DAE). For that, the Random Quadrats method (Barbour et al., 1998) was used and 20 quadrats with 0.50 m side were sampled in each area. All the emerged seedlings inside each quadrat were identified by species, collected and stored in paper bags, being dried in oven with continuous air circulation for posterior dry mass determination.

Estimations of relative density (based on number of individuals), relative frequency (based on the distribution of the species in the area) and relative dominance (based on the ability of each species to accumulate dry mass) were done for each species present. The Importance Value (I.V.), which ranks species in terms of importance within the studied area, was also determined Pandeya et al., 1968; Barbour et al., 1998), with the following equations:

$$rDe=\frac{I}{TI}*100 \quad (1)$$

$$rFr=\frac{Q}{TQ}*100 \quad (2)$$

$$rDo=\frac{DM}{TDM}*100 \quad (3)$$

$$I.V.=\frac{rDe+rFr+rDo}{3} \quad (4)$$

where *rDe* = relative density (%); *rFr* = relative frequency (%); *rDo* = relative dominance (%); *I.V.* = importance value; *I* = number of individuals of species *x* in the area *r*; *TI* = total number of individuals in the area *r*; *Q* = number of quadrats assessed in area *r* where species *x* is present; *TQ* = total number of quadrats assessed in area *r*; *DM* = dry mass of individuals from species *x* in the area *r*; *TDM* = total dry mass of weeds in the area *r*. Areas were also intra-characterized by the diversity coefficients of Simpson (D) and modified Shannon-Weiner (H') (Barbour et al., 1998), as follows:

$$D=1-\frac{\sum ni*(ni-1)}{N*(N-1)} \quad (5)$$

$$H'=\sum(pi*\ln(pi)) \quad (6)$$

where *D* = diversity coefficient of Simpson; *H'* = diversity coefficient of Shannon-Weiner (based on density); *ni* = number of individuals from species "*i*"; *N* = total number of individuals in the sample; *pi* = proportion of individuals in the sample from species "*i*".

After these analyses, areas were compared by Jaccard's presence-only similarity coefficient (Barbour et al., 2014) in a way to estimate the current degree of weeds similarity between areas. Based on Jaccard's binary coefficient, areas were grouped by cluster analysis considering the qualitative trait only (presence or absence of the species), according to the dissimilarities obtained from the inverse of Jaccard's similarity matrix, as follows:

$$J=\frac{c}{a+b-c} \quad (7)$$

$$Di=1-J \quad (8)$$

where *J* = Jaccard's similarity coefficient; *a* = number of plant species in area "*a*"; *b* = number of plant species in area "*b*"; *c* = number of plant species common to areas "*a*" and "*b*"; and *Di* = dissimilarity.

Hierarchical grouping was determined from the distance matrix (dissimilarities) by using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) method (Sokal and Rohlf, 1962; Sneath and Sokal, 1973). Grouping validation was accomplished by the cophenetic correlation coefficient, using the Pearson linear correlation between the cophenetic matrix and the original matrix of distances.

All analyses were ran under the R Statistical Environment (R Core Team, 2014), using functions made available by the following additional packages: vegan, Hmisc, and ExpDes. All formulas and procedures, both at sampling and description of the areas, as well as at species clustering, followed the requirements suggested by Barbour et al. (1998) for synecological analyses.

Assessment 2 – Soil seed bank

For the soil seed bank study, a 2 kg soil sample from 0 - 5 cm depth of soil was also collected in each one of the locations sampled with quadrats in Assessment 1, so there would be a location correlation between studies. Soil was taken to greenhouse where it was revolved and clods dismounted, being put into 2 L plastic pots which were kept wet by daily irrigation at about 70% field capacity all throughout the assessment (Figure 1).

Every 20 days from 0 to 80 days after assembly, all plants emerged from soil seed bank were counted, collected, stored and processed in the same way used for Assessment 1. Soil was revolved again for a new emergence period of 20 days where a new evaluation would be done. The only difference between Assessments 1 and 2 is that plants present at Assessment 2 were stimulated to germinate from soil seed bank while plants considered at Assessment 1 were collected directly in the field.

RESULTS AND DISCUSSION

Analysis of areas for weed infestation, both in surface (Figure 2) and soil seed bank surveys (Figure 3) indicate average level of occurrence of weeds when compared with infestations pointed out by Van Acker et al. (1993) and Mohammadi and Amiri (2011). In absolute terms, however, there were differences between areas when measured "*in situ*" or through the soil seed bank. The surface analysis (Figure 2) indicated equivalent level of infestation between areas, except for Esperança 1; analysis of the seed bank, on the other hand, found Janaina 1 and 2 areas with the greatest potential of infestation (Figure 3), which may require more accurate management of weeds in this area due to the high skill of reinfestation from seed bank in the soil.

The survey of occurrence of weeds in the field (Figure 2) was decomposed by weed species, being the Importance Values for infestation (VI%) presented in Table 1. The VI% considers the offspring production potential of the species (species density), its relative spread in the area (frequency) and the ability of individuals from that species to accumulate dry mass and dominate plants from other species (dominance). Plants which perform better in these three items are the most troublesome weeds. Number of weeds (m^{-2})

In areas "Janaina" (1 and 2), the two most important weed species were pigweed (*Amaranthus retroflexus*) and sourgrass (*D. insularis*); in areas "Esperança" (1 and 2), however, pigweed was replaced by beggartick (*Bidens pilosa*) which together with sourgrass occupied a prominent position on the importance of infestation (Table 1). Beggartick was responsible for up to 49% of the infestation importance in Esperança 1 , which coupled

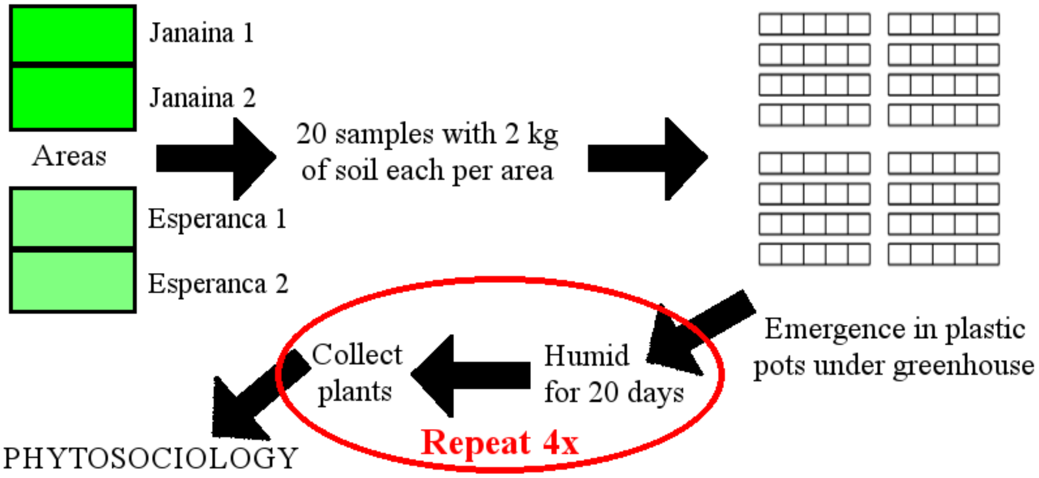

Figure 1. Schematics for assessment of weed species emerged from soil seed bank. Embrapa Western Agriculture, Dourados-MS, Brazil, 2014.

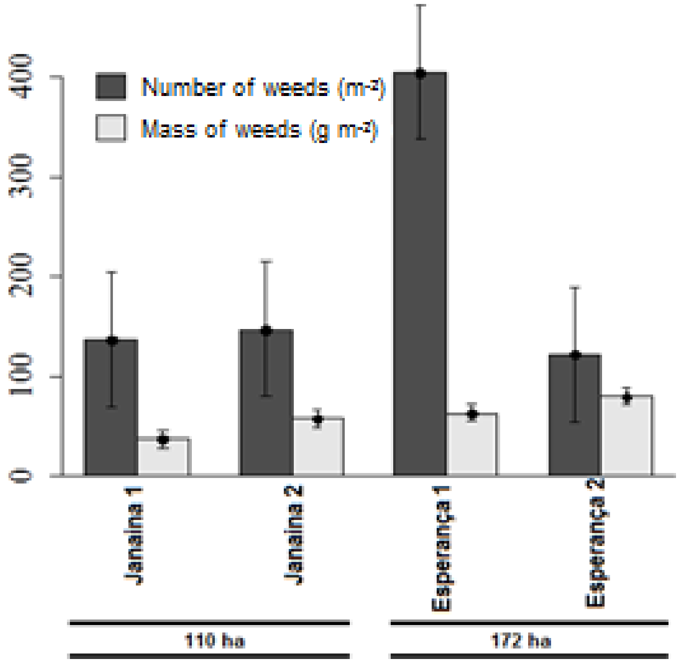

Figure 2. Number of individuals and dry mass of weeds as a function of area assessed, based on the field assessment in early post-emergence of no RR soybean. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

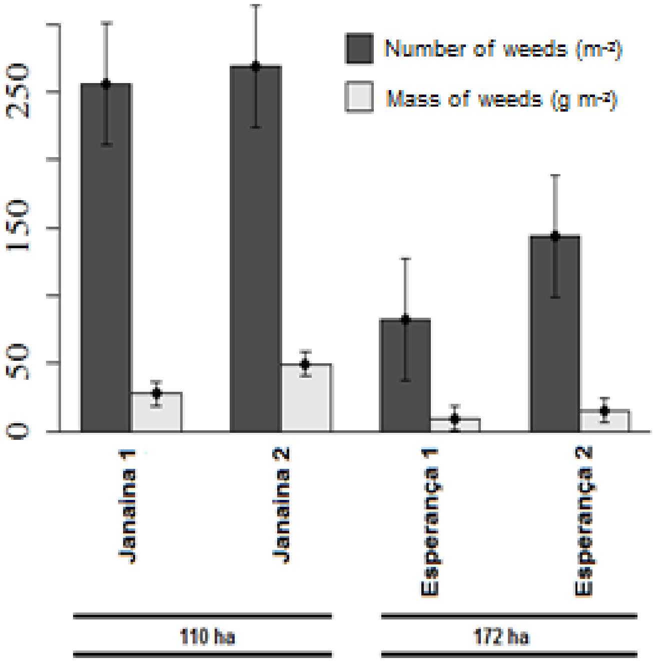

Figure 3. Number of individuals and dry mass of weeds as a function of area assessed, based on the soil seed bank study with soil collected in early post-emergence of no RR soybean. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

with the highest level of infestation in this area (Figure 2). This indicates a need for integration of control methods with herbicides to reduce beggartick occurrence.

The assessment of potential infestation through the soil seed bank, according to the method presented in Figure 1, indicated presence of 17 weed species in soil able to germinate and to infest the area supposing physical space is available (Table 2); in the surface assessment (Table 1), only 11 species were found.

Beggartick was the most important weed in all areas (Table 2), representing about 50% of potential infestation. This indicates that, supposing there is space available, this species is abundant in soil and could very easily become predominant in all fields. In Janaina 1, pigweed

Table 1. Value of Importance (V.I.) of weed species reported in the field survey held early post-emergence of soybean, in four areas located in the municipality of Amambai, MS, Brazil. Embrapa Western Agriculture, 2012.

Weed species	Common name	Janaina 1	Janaina 2	Esperança 1	Esperança 2
		Value of Importance **(%)**			
Amaranthus retroflexus	*Redroot pigweed*	30.8	26.23	2.13	1.74
Amaranthus viridis	*Slender amaranth*	0	1.56	0	0
Avena sativa	*Oat*	0	0	0	6.33
Bidens pilosa	*Hairy beggarticks*	9.58	24.15	49.57	34.16
Conyza bonariensis	*Horseweed*	0	0	1.7	17.56
Digitaria insularis	*Sourgrass*	31.85	30.25	35.23	33.35
Eleusine indica	*Goosegrass*	0	0	4.21	0
Euphorbia heterophylla	*Wild poinsettia*	5.11	8.52	4.85	0
Ipomoea spp.	*Morning glory*	19.06	3.54	0	0
Richardia brasiliensis	*Tropical Mexican clover*	0	0	2.31	6.86
Sida spp.	*Sida*	3.6	5.73	0	0

Marked cells (■) indicate the most important weed species in each area based on their V.I..

Table 2. Value of importance (V.I.) of weed species reported in the soil seed bank study carried out with soil collected post-emergence of soybean, in four areas located in the municipality of Amambai, MS, Brazil. Embrapa Western Agriculture, 2012.

Weed species		Janaina 1	Janaina 2	Esperança 1	Esperança 2
	Common name	**Value of importance (%)**			
Amaranthus hybridus	Smooth pigweed	6.97	5.76	0	0
Amaranthus retroflexus	Redroot pigweed	12.22	9.69	0	0
Avena sativa	Oat	0	0	0	1.06
Bidens pilosa	Hairy beggarticks	56.02	44.05	50.67	44.68
Cardiospermum halicacabum	Balloon vine	0	11.29	0	1.76
Commelina benghalensis	Benghal dayflower	0.66	15.12	0	0
Digitaria horizontalis	Jamaican crabgrass	1.38	1.95	6.09	3.74
Digitaria insularis	Sourgrass	4.87	3.41	36.61	20.86
Eleusine indica	Goosegrass	0	0	1.66	6.63
Euphorbia heterophylla	Wild poinsettia	0	0.65	0	1.03
Gnaphalium coarctatum	Cudweeds	3.96	5.05	1.52	1.03
Leonotis nepetifolia	Lionsear	0	0	3.45	0
Richardia brasiliensis	Tropical Mexican clover	8.38	0	0	13.54
Senna obtusifolia	Sicklepod	0.72	0	0	0
Sida spp.	Sida	4.26	1.48	0	1.03
Solanum sisymbrifolium	Sticky nightshade	0.56	1.56	0	0
Spermacoce latifolia	Oval leaf false buttonweed	0	0	0	4.64

Marked cells (■) indicate the most important weed species in each area based on their V.I..

figured as the second most important weed also in the study of seed bank, being replaced by spiderwort (*Commelina benghalensis*) at Janaina 2. In Esperança (1 and 2), sourgrass was the second most important weed (Table 2).

Rizzardi et al. (2003) studied the impact of beggartick on soybean yield as well as its threshold control level (TCL), concluding that the TCL varied from 0.4 to 33 plants m^{-2} depending on a series of factors; because of this, the authors highlighted that additional researches are demanded to improve the application of TCL and that it should be considered with caution since it does not consider the replenishing of the seed bank by plants left uncontrolled for not achieving the TCL. This, according to

Table 3. Weed species diversity as a function of field and study method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012.

Area	Field study		Soil seed bank study	
	D[1]	H'[2]	D[1]	H'[2]
Janaina 1	0.57	1.12	0.71	1.55
Janaina 2	0.61	1.1	0.73	1.61
Esperança 1	0.26	0.56	0.57	1.01
Esperança 2	0.46	0.91	0.71	1.54

[1] D = diversity coefficient of Simpson; [2] H' = diversity coefficient of Shannon-Weiner.

Sattin et al. (1992) and Sartorato et al. (1996), would greatly shift the future occurrence of weeds on the following years often demanding additional management practices to be applied.

In the specific case of beggartick, Gomes et al. (2013) report effect of *Lupinus angustifolius* (narrowleaf lupin) extracts on beggartick in concentrations where it is not effective on crops like corn, being this an option to be grown in cooler environments where beggartick is widely proliferated and needs to be contained. Similarly, rapeseed reduces the germination ability of beggartick, being also an option for contributing to reductions in beggartick infestation in following years (Rigon et al., 2014).

Sourgrass (*D. insularis*) is other weed species which was present in this case study and concerns farmers and technicians. Some glyphosate-resistant sourgrass biotypes were found infesting annual and perennial crops in Brazil (Carvalho et al., 2013); thus, attention must be given to sourgrass management aiming to prevent plant survival and its increase in cropping systems. Being a perennial and hard-to-kill weed species post-emergence of crops, it should be efficiently controlled prior to crop planting and infestation in localized spots need to be eliminated to avoid seed dispersal mainly by wind (Gemelli et al., 2012; Carvalho et al., 2013).

Price and Kelton (2011) reported *Digitaria sanguinalis* among the most important weeds in conservation agriculture; according to the authors, both the cover crop and application of herbicides contributed for reduction of infestation in integrated cropping systems, being either of them alone barely efficient in suppressing weeds. Mondo et al. (2010) found that *D. insularis* in non-sensitive to light for germination, being able to establish even in areas under cover crops.

Being a positively photoblastic species (Yamashita and Guimarães, 2011), *Conyza* spp. demands light for its germination, which is less available in Integration Crop-Livestock systems due to a constant soil shading supplied by the different plant layers present in the field. In addition, animal traffic in the area may aggravate problems with weed species (Balbinot Jr. et al., 2008), demanding cover crops to be included in the cropping system. Thus, *Conyza* spp., the most important weed species in agriculture at Brazilian Center-West region, ws not important in the field survey and did not appear at all in the soil seed bank study (Tables 1 and 2).

Diversity is a concept which considers balanced plant communities in a given field as a consequence of good management (Pandeya et al., 1968). The diversity coefficient of Simpson (D) quantifies, in simple terms, the probability of two individuals randomly collected in the same area to be from the same species. The diversity coefficient of Shannon-Weiner (H'), on the other hand, derives from the Theory of the Information and sometimes confuses diversity with richness of species (Barbour et al., 1998). The diversity of species (Table 3), with no exception, was higher in the study of the soil seed bank, indicating that both areas present latent potential for infestation.

For both studies (field survey and soil seed bank), diversity was always lower for Esperança (1 and 2) compared to Janaina (Table 3) and differences were more remarkable at the field survey; in this situation, Esperança presented species diversity 39% inferior to the observed for Janaina indicating that pigweed, beggartick and sourgrass (Table 1) may be efficient competitors in suppressing the occurrence of other species present in the soil seed bank (Table 2). Thus, if the most important weeds (Table 1 and 2) are removed from the production system by species-aimed management, they would be sooner replaced by others with higher VI%.

Similarity analysis showed a match of 86% in weed composition for Janaina 1 and 2, while Esperança 1 and 2 were also pooled with 63% similarity. Janaina and Esperança, however, differed in similarity (Figure 4). According to Barbour et al. (1998), Jaccard similarity values above 25% is enough to indicate similarity between two given areas; in this sense, although not very similar, areas Janaina and Esperança are still similar (at 35% similarity) but the management applied to each area is starting to select differential weed species in each area because they are adapted to that management.

Figure 5 shows the similarity in composition of infestation in the same areas, based on the soil seed bank study. Janaina 1 and 2 still presented high correlation (68% similarity), whereas Esperança 1 and 2 differed not only from Janaina, but also between them.

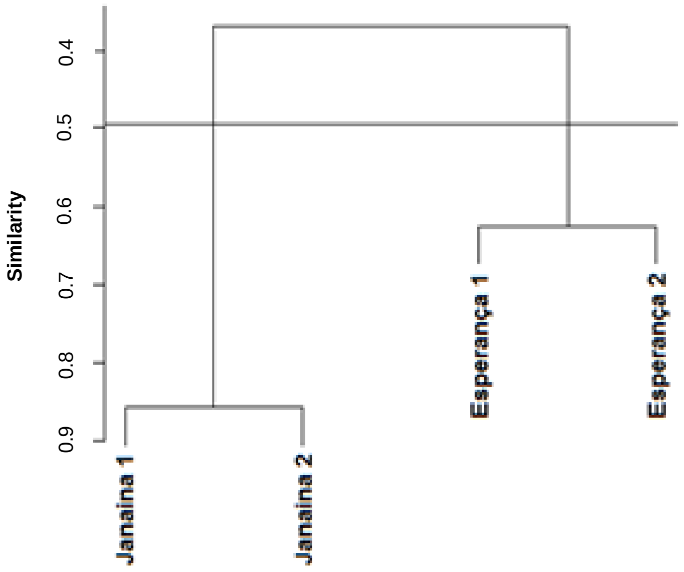

Figure 4. Multivariate cluster analysis of areas with field survey data of weeds occurrence, according to their similarity (coefficient of Jaccard), grouped by the UPGMA method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012. Cofenetic correlation = 0.87. Threshold level = 0.49.

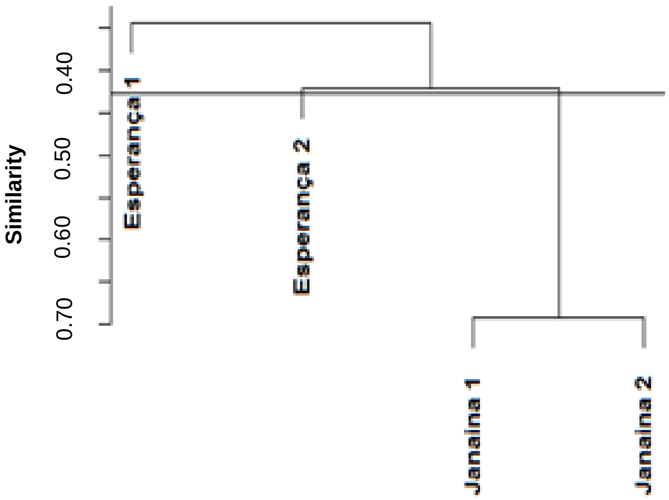

Figure 5. Multivariate cluster analysis of areas with soil seed bank data of weeds occurrence, according to their similarity (coefficient of Jaccard), grouped by the UPGMA method. Embrapa Western Agriculture, Dourados-MS, Brazil, 2012. Cofenetic correlation = 0.93. Threshold level = 0.43.

This may indicate that the previous management applied to Esperança may have been differential between areas 1 and 2, or that the management adopted in recent years has been sufficiently diversified and sustainable to eliminate some of the weed species from the area (Figure 5). In fact, six weed species were found at Esperança 1 while 11 were found in Esperança 2 (Table 2). Integration crop-livestock helps smoothing problems with weed species in production systems. There are two mechanisms that can be related to the lower infestation and delayed emergence of seedlings in areas that have livestock. The first mechanism regards allelopathic issues. Aconitic acid is a substance that is commonly exudated by grasses such as *Brachiaria* species, which is responsible both for direct inhibition of plant growth (Putnan and DeFrank, 1983; Friebe et al., 1995) and for growth stimulus of endophytic fungus capable of attacking seeds in soil (Voll et al., 2004). According to Voll et al. (2010), aconitic acid affects the soil seed bank and its germination, which results in smaller competitive ability of the overall weedy community against the crop at the area.

The second mechanism regards the direct presence and action of livestock at the area – grazing (Popay and Field, 1996) and trampling (Marchezan et al., 2003), which could both reduce production of new seeds and vegetative propagules from weed species, and help forcing quiescent seeds to dormancy and later loss of their viability.

Although this case study highlighted a relatively more diverse environment in a farmer's managed crop-livestock integration, there are still some weed species which were capable of adapting themselves to the changing environment of a crop-livestock area with 2-year cycle. Although the currently most important most important weed species in Central Brazil cropping systems – horseweed – was almost absent from the fields, other important species prevailed.

Integration crop-livestock proved to be efficient in reducing *Conyza* spp. (horseweed) occurrence since seeds of this species are positively photoblastic (Vidal et al., 2007). These seeds not only require light to germinate but also the proper spectral composition, in particular the ratio of red: far-red wavelenghts (Chen et al., 2013). The presence of the forage every two years probably forced quiescent seeds to dormancy with posterior loss of viability due to the constant mulching on soil associated to the previous two commented factors.

Although horseweed is efficiently inhibited by crop-livestock integration, pigweed, sourgrass and beggartick prevailed. These species are recognized as important weeds and its presence in the long-term crop-livestock integration reports that some weeds are suppressed by the diversified management while others demand additional control practices to be applied.

Conclusions

Crop-livestock integration proved to be efficient in suppressing some troublesome weed species, but others still prevail in integrated production fields. For Center-West region of Brazil, pigweed, beggartick and sourgrass tend to be preponderant weed species in crop-livestock areas. Weed 0 management should go beyond cultural practices, demanding the right herbicide to be applied at the right time aiming to control the weed species which were able to prevail even in the integrated production environment.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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