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WEED SUPPRESSION IN SUSTAINABLE INTEGRATED AGRICULTURAL SYSTEMS

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ABSTRACT

Development of integrated agricultural systems emerged in order to increase production and promote several long-term benefits. We aimed to evaluate weed dynamics in agricultural integrated production systems in Brazil, through an experiment implemented in 2009 at Embrapa Western Agriculture, in the city of Ponta Porã, Brazil, with 10 treatments, being two areas under no-till planting system; one conventional tillage area; one forest production area; two crop-livestock integration areas, and four crop-livestock-forest integration areas. Evaluations were performed in the early post-emergence of the 2011/12 cropping season, in completely randomized design. A quadrat with 0.5 m side was released randomly 10 times in each area, and weeds inside each quadrat were counted and collected for determination of dry mass, being estimated the density, frequency, dominance and importance value of each species in each cropping system. Areas were intra-analyzed for diversity by the coefficients of Simpson and Shannon-Weiner, and compared among them for similarity of species by Jaccard's coefficient, being areas grouped by multivariate cluster analysis. The overall most important weed species in the area were Bidens pilosa, Commelina benghalensis, Digitaria horizontalis and Raphanus sativus; there was change in the number and species of individuals according to management type, being broadleaved species predominant. Areas planted with Brachiaria were less infested by weeds. The cultivation of corn intercropped with B. brizantha cv. Xaraés in the second cropping season, post-soybean, between rows of Eucalyptus (Integration Crop-Livestock-Forest - iCLF) proved as the best option to reduce the incidence of weeds in long-term sustainable cropping systems.

Key words: *Brachiaria*, corn, *Eucalyptus,* soybean.

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INTRODUCTION

The development of integrated agricultural systems emerged in order to increase production and take advantage of several benefits, among which the change in the dynamics of weed occurrence, directly or indirectly responsible for much of the productivity losses. These systems have been widespread in several regions of Brazil as alternative to improve sustainability of agriculture.

With the adoption of sustainable integrated production systems such as crop-livestock integration (ICL), it is possible to achieve the objective of producing with sustainability. Several arrangements are possible, and the forestry component may also be inserted. Results of the integrated systems depend on regional climatic conditions, objectives and structure of the farmer, and various other factors.

Among the modalities of integration, the ICL can be highlighted, which is characterized as the production system which integrates agriculture and livestock components in the same area. This system is the most used in Brazil, by intercropping forage species with maize (*Zea mays*), which is subjected to grazing after maize harvest (Ceccon, 2013). Similar intercropping systems were studied for soybean (*Glycine max*), bean (*Phaseolus vulgaris*) and sorghum (*Sorghum bicolor*) (Portes *et al.*, 2000). A third component, forest production, may be inserted into the ICL; the Integrated Crop-Livestock-Forest (ICLF), which integrates agriculture, cattle raising and forest plantations, usually rotating crop and livestock among tree rows in distinct years. Other systems are possible although less usually seen: livestock-forest (ILF) and crop-forest (ICF) integrations (Balbino *et al.,* 2011).

In the tropical and savannah-like regions of Brazil, maize planted after soybean (second crop) in locations where climatic conditions allow this practice, is one of the annual crops that have increased its importance due to the possibility of early planting, increased technology and yields. In addition, maize showed good performance when intercropped with forage species (Silva *et al.*, 2007), which resulted in high soil mulching after harvest with significant weed suppression. In this farming system, forage is handled as an annual plant, being used for forage production after harvesting the grain crop, contributing to formation of straw for planting soybean in the following season, in the no-till system.

Regardless of the integration system used or the purpose of its implementation, the producer should consider that these crop associations, together with the use of no-till planting system, are important practices within an integrated approach for weed management (Silva *et al.*, 2007). A major challenge for farmers is to minimize the harmful effects of weeds on crops, and integrated systems help to achieve this goal.

Weed species may vary in their response to a given management practice (Voll *et al.*, 2005) thus understanding both the occurrence and the composition of weed community inside each management or cropping system is important for planning an efficient set of practices to control these species. By using the innate ability of plants to inhibit the growth of other species, it is possible to maximize yields and reduce costs for weed control (Velykis and Satkus, 2006).

Phytosociological studies allow one to assess species composition and systematically estimate its ecological survival strategies and importance of infestation (Gomes *et al.*, 2010), focusing management practices on the most important weed species. Coefficients of diversity and similarity also support inferences about the level of imbalance of a plant community, and how far weed communities differ between integrated cropping systems, as a consequence of the differential management adopted (Barbour *et al.*, 1998).

We aimed with this study to evaluate the dynamics of weeds in agricultural integrated production systems, in Brazilian savannah-like conditions.

MATERIALS AND METHODS

The experiment was installed in 2009 at the experimental area of Embrapa Western Agriculture, in the city of Ponta Porã, state of Mato Grosso do Sul, Brazil (lat. 22° 32' 56" S lon. 55° 38' 56" W), 680 meters asl, in Haplorthox soil (Amaral *et al.*, 2000), located in the Atlantic Forest Biome, with Cfb climate (Köppen). The area was cultivated with annual crops for the last 30 years prior to experiment assembly. Weeds occurrence was surveyed in 2011. The experiment was installed in completely randomized design with four replications, with 25 m x 30 m (750 m^2) plot size. The sequence of crops associated to each treatment is presented in Table 1, and the evaluations were performed in the early post-emergence of the 2011/12 cropping season.

Prior to the survey, no herbicide with residual effect was applied to the experiment, being control based on the herbicide glyphosate. All treatments with soybean were drill seeded in October, with rows spaced by 0.45 m. For the ICLF (treatments 7-10), crops were planted between rows of *Eucalyptus*, respecting 1 meter of the lines of trees.

The *Eucaliptus* clone planted (*E. urograndis*) is a hybrid between *E. grandis* and *E. urophylla*, spaced in 25 m between eastbound rows and 2 m between plants in the row.

Phytosociological characterization of weed species was carried out in November 2011, prior to planting the 2011/12 crop. For that, the Random Quadrats method (Barbour *et al.*, 1998) was used and 10 areas of 0.50 x 0.50 m were sampled in each plot. 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. Sampling precision was verified by:

$$Pr = \frac{1}{s^2}$$

where s^2 = variance of sample means.
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 conducted for each emerged species. 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:

$$rDe = \frac{I}{TI} \times 100 \qquad rFr = \frac{Q}{TQ} \times 100$$

$$rDo = \frac{DM}{TDM} \times 100 \qquad IV = \frac{rDe + rFr + rDo}{3}$$

where rDe = relative density (%); rFr = relative frequency (%); rDo = relative dominance (%); 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). After these analyses, areas were compared by Jaccard's presence-only similarity coefficient (Barbour *et al.*, 1998) 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. Hierarchical grouping was determined from the distance matrix (dissimilarities) (Barbour *et al.*, 1998) by using the Unweighted Pair Group Method with Arithmetic

Mean (UPGMA) method (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 (Sokal and Rohlf, 1962).

All analyses were ran under the R Statistical Environment (R-development, 2013), using functions made available by the following additional packages: vegan, Hmisc, cluster 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.

RESULTS AND DISCUSSION

Number of plants and dry mass of the weed community

The number of weed individuals in each community changed according to the management. Overall, the total number of weeds increased as the amount of straw on soil decreased i.e. crops that traditionally provide less soil cover, as maize, resulted in increased presence of weeds in subsequent crops. In the area 10 - ICLFb2, no weeds were observed, depicting the high efficacy of crop succession to inhibit weed proliferation, unlike areas 7 and 9 (ICLFa1, ICLFb1) where weeds proliferated under the canopy of trees; in these treatments, about 220 individuals were recorded per square meter of soil (Fig. 1).

Despite the shading exerted by crops, it was found that the straw in agricultural systems is a key prerequisite for the lower incidence of weeds. In the area with *Eucalyptus*+maize+*Brachiaria*, for example, the residual straw mostly composed by *Brachiaria* provided greater soil coverage, which translated in low weed emergence. In treatment 4 - Forestry, the number of weed plants per area was below the levels found for treatments 1, 3, 7 and 9; the remaining individuals were, however, higher in dry mass. Although *Eucalyptus* is able to inhibit germination and / or emergence of some weeds, either by shading or by exudation of allelopathic compounds (Cremonez *et al.*, 2013), competition exerted by weeds may still be significant.

Despite the higher number of weeds in treatment 1 (no-till system) compared to treatment 3 (conventional tillage), there was increased severity of infestation in treatment 3 due to higher total dry mass, which was twice the observed for weeds in the no-till system (Fig. 1). Soil tillage in the conventional system preceding planting stimulated germination of the soil seed bank, while the straw present on the soil in the no-till area inhibited seed germination. As for systems with presence of *Brachiaria*, no difference in dry mass of weeds was observed, but there was a higher number of individuals in the treatment ICLc compared to ICLa. *B. brizantha* cv. Xaraés was grown at ICLa for three consecutive years, while ICLb was being used for agriculture in the same period, receiving *Brachiaria* only in 2011/12 (Fig. 1, Table-1).

Phytosociology

Weeds reported in the experimental area included *Bidens pilosa*, *Commelina benghalensis*, *Digitaria horizontalis* and *Raphanus sativus*, regardless of the system used. Table-2 summarizes the phytosociological analysis, being listed only the four main species found in each area; other species, when present, were grouped as "Other species".

There was a predominance of broadleaved weeds, and *Raphanus sativus* showed the greatest IV for areas 3, 5, 7, 8 and 9 (Table-2). In areas 1 and 2 *Bidens pilosa* was highlighted, while for areas 4 and 6, *Chloris elata* and *Digitaria horizontalis*, respectively, were the most important ones. For area 8 (ICLF with maize + *B. ruziziensis*) only *R. sativus* and *D. horizontalis* were reported. No weeds were found in area 10 (ICLF with *Brachiaria*). The effect of dry mass produced by *Brachiaria* was also verified by Severino *et al*. (2006). *Brachiaria brizantha* cv. Xaraés and *B. ruziziensis*, where present, were highly efficient in suppressing weed occurrence.

As reported in Table-2, *R. sativus*, *B. pilosa*, *C. elata* and *D. horizontalis* were the species with highest overall IV. In area 7, *C. bonariensis* was highlighted for its dominance, not reaching, however, the highest IV. This parameter represents species ability to grow in terms of dry mass, which in turn influences its ability to spread in the canopy and suppress other plants (Barbour *et al.*, 1998). In area 5, the pre-planting burndown did not control *B. brizantha* cv. Xaraés efficiently prior to soybean planting; thus, this species was considered as a weed as it interferes in crop growth. The same was not observed in area 2, where *B. ruziziensis* was efficiently controlled by burndown. The former is considered as hard to be controlled and the latter as easily controlled by glyphosate (Ceccon, 2013).

Diversity

The coefficients of Simpson and Shannon-Weiner indicated formation of three conceptual groups regarding richness and balancing in species occurrence in each area: (i) areas 1, 2, 5 and 6, with greater diversity and therefore proper species balancing; (ii) includes those areas with intermediate diversity (areas 4 and 9), and (iii) all other treatments, with lower diversity; at this group, there may be selection factors which favor the occurrence of certain species in detriment of others.

Simpson diversity index measures, in simple terms, the probability of two individuals randomly collected at the same area, to belong to the same species. The diversity index of Shannon-Weiner, on the other hand, is derived from the Theory of Information and confuses diversity with species richness (Barbour *et al.*, 1998). In the present study, however, both coefficients were quite consistent and although they have different precepts, similar grouping was obtained (Table-3).

According to Correia and Durigan (2004), diversity is not directly related to the level of infestation. In another long-term experiment with a history of 18 years of management, Concenço *et al.* (2011) found 8 , 6 , 2 and 3 weed species, respectively for areas subjected to agriculture-only under conventional soil tillage, no-till agriculture, crop-livestock integration and continuous livestock, respectively. The authors pointed out that even with the largest number of species - and higher diversity, areas under intensive agriculture showed higher incidence of weed species considered as difficult to be controlled; thus, greater weed diversity not always means sustainability of the production system.

Similarity

Cluster analysis by dissimilarity (Fig. 2) indicated formation of four groups according to the similarity of occurrence of weed species. Areas 4 and 10, each one alone, accounted for the first two groups; area 10 was isolated from the others by not presenting any weed species, while the area with *Eucalyptus* forest (area 4) inhibited most important weeds in agricultural systems. The third group was composed by the areas 1, 2, 6, 8 and 9, characterized by the presence of crop succession, and the fourth group included areas 3, 5 and 7, heterogeneous in terms of management (Table-1) and level of infestation (Fig. 1), however not similar to other groups.

Species of *Brachiaria*, associated or not with maize, are good competitors with weeds by quickly shading crop interrows and presenting high dry mass production. *Brachiaria* was largely responsible for eliminating significant part of the occurrence of weeds, which directly reflected in the results obtained.

Composition of weed community changed among treatments, even with just a few years of implementation of differential systems. In general, knowledge of the distribution of weeds in these systems is crucial for the adoption of cultural control methods more efficient to eliminate the most troublesome weeds. In this aspect, the adoption of intercropping of maize with forage species contributes to the suppression of weeds in these production systems.

CONCLUSION

Therefore, the type of planting system influenced the composition of the weed community, showing that farmers have to adopt species which provide soil coverage throughout the year, as the intercrop maize + *B. ruziziensis* or maize + *B. brizantha*. The level of weed infestation also depends on the planting system; crops which accumulates smaller dry mass, or whose dry mass has low C:N ratio, promoted high infestation levels. After soybean harvest, cultivation of maize intercropped with *B. brizantha* in the second cropping season, between rows of *Eucalyptus* (ICLF), proved to be the option with the greatest potential to reduce the weed incidence in integrated production systems.

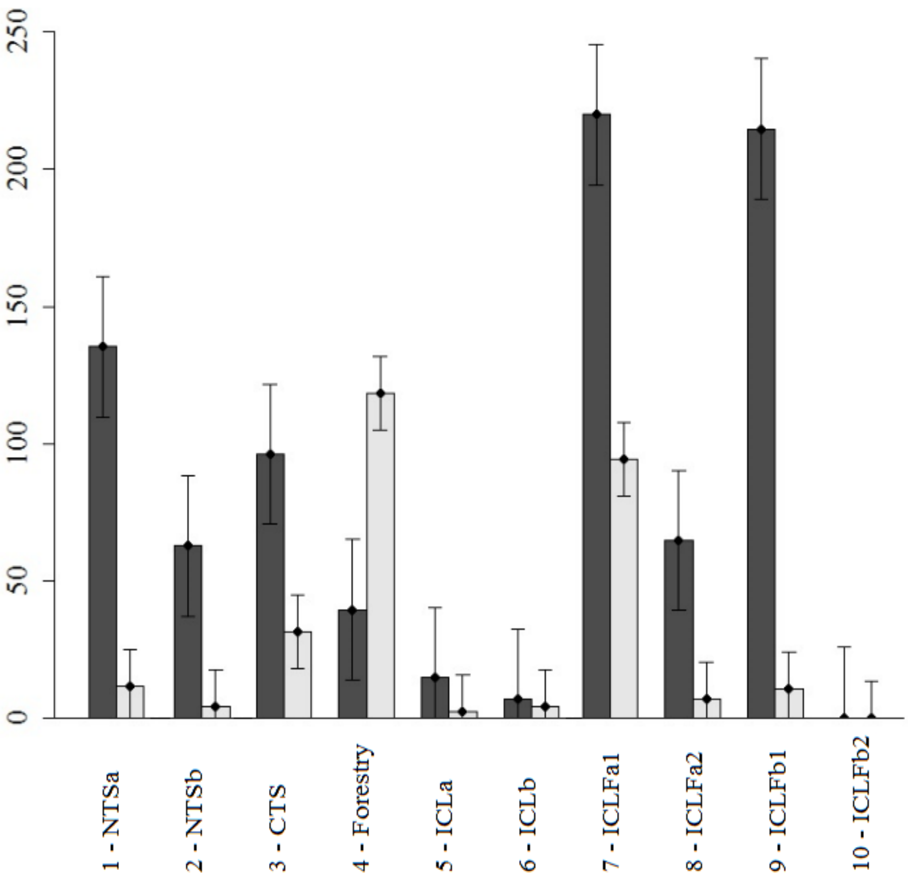

Figure 1. Number of individuals of weed species (█ - m^{-2}) and dry mass of weeds (█ - g m^{-2}) as a function of planting system. Ponta Porã, Brazil, Embrapa Western Agriculture, 2013. Standard errors above bars. NOTE: For treatment description, please check Table-1.

Table-1. Integrated management systems (areas) evaluated at the Ponta Porã trial, and crop succession per area from 2009/10 to 2011/12. Embrapa Western Agriculture, Dourados, Brazil, 2012.

	Cropping Season				
Man. System (area)	2009/10	2010	2010/11	2011	2011/12
1 - NTSa	S	W	S	M	S
2 - NTSb	S	W	S	M+Br	S
3 - CTS	S	A	S	M	S
4 - Forestry	-	E	E	E	E
5 - ICLa	S	X	X	X	S
6 - ICLb	S	W	S	M+X	X
7 - ICLFa1	E+S	E+A	E+S	E+M+Br	E+S
8 - ICLFa2	E+S	E+A	E+S	E+M+Br	E+S
9 - ICLFb1	E+S	E+A	E+S	E+M+X	E+X
10 - ICLFb2	E+S	E+A	E+S	E+M+X	E+X

S = soybean, M = maize, Br = *B. ruziziensis*, X = *B. brizantha* cv. Xaraés, E = *Eucalyptus*, A = oat, W = wheat. NTSa/b = no-till planting system (agriculture-only) with distinct crop successions; CTS = conventional soil tillage system (agriculture-only) with distinct crop successions; ICLa/b = integration crop-livestock; ICLFa/b = integration crop-livestock-forest. For ICLF, numbers "1" and "2" represent, respectively, evaluations in the rows of *Eucalyptus* and in the crops planted between these rows.

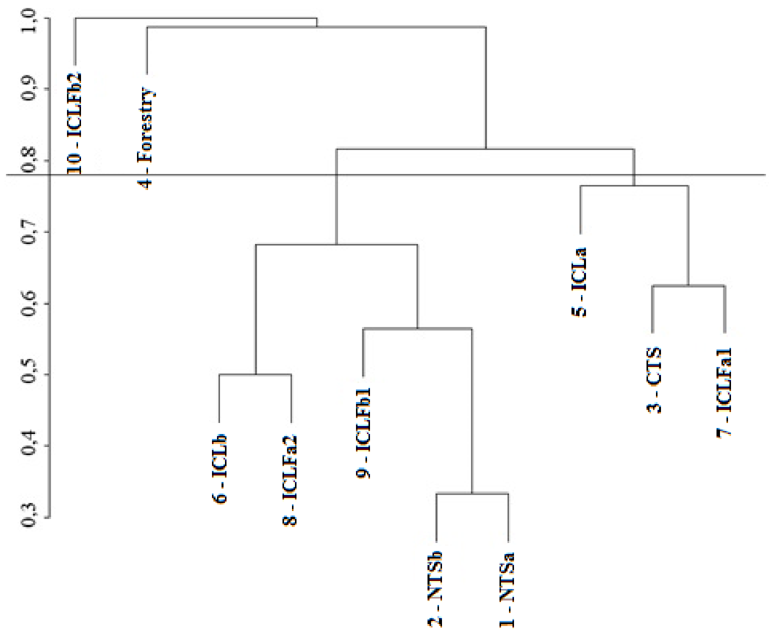

Figure 2. Areas grouping by Cluster analysis based on the binary coefficients of Jaccard, as a function of planting system. Cofenetic correlation coefficient = 0.95. Ponta Porã, Brazil, Embrapa Western Agriculture, 2013.

Table-2. Density (DE), frequency (FR), dominance (DO) and importance value (IV) for weed species, as a function of planting system. Ponta Porã, Brazil, Embrapa Western Agriculture, 2013.

1 – NTSa					6 – ICLb				
	DE	FR	DO	I.V.I.		DE	FR	DO	I.V.I.
Bidens pilosa	34,9	31,2	39,4	35,2	*Digitaria horizontalis*	40	20	68,4	42,8
Euphorbia heterophylla	46,3	25	32,4	34,5	*C. benghalensis*	40	40	31,4	37,1
Raphanus sativus	15,2	18,7	27,7	20,5	*Raphanus sativus*	10	20	0,1	10
Digitaria horizontalis	1,48	6,25	0,04	2,59	*Chamaesyce prostrata*	10	20	0,05	10
Other species	1,97	18,7	0,41	7,04					
2 – NTSb					7 - ICLFa1				
Bidens pilosa	44,1	25	57,9	42,3	*Raphanus sativus*	95,7	26,1	11,2	44,3
Raphanus sativus	22,5	12,5	21,5	18,8	*Conyza bonariensis*	3,02	8,7	88,6	33,4
Digitaria horizontalis	5,38	12,5	14,3	10,7	*Avena sativa*	0,3	52,1	0,05	17,5
Amaranthus viridis	12,9	12,5	1,12	8,84	*Gnaphalium spicatum*	0,3	4,35	0,01	1,55
Other species	15	37,5	5,08	19,2	Other species	0,6	8,7	0,01	3,1
3 – CTS					8 - ICLFa2				
Raphanus sativus	90,2	46,1	68,3	68,2	*Raphanus sativus*	98,9	85,7	99,8	94,8
Zea mays	4,86	7,6	30,7	14,4	*Digitaria horizontalis*	1,03	14,3	0,13	5,15
Bidens pilosa	2,08	23,0	0,64	8,6					
Avena sativa	2,08	15,3	0,28	5,91					
Other species	0,69	7,69	0,02	2,8					
4 – Forestry					9 - ICLFb1				
Chloris elata	76,2	50	69	65,1	*Raphanus sativus*	81,3	33,3	78,1	64,2
Conyza bonariensis	15,2	20	13,8	16,3	*C. benghalensis*	13,5	27,7	12,1	17,8
Brachiaria brizantha	5,08	10	15,4	10,1	*Digitaria horizontalis*	0,64	5,56	5,1	3,77
Sida rhombifolia	1,69	10	1,24	4,31	*Cyperus rotundus*	0,32	5,56	2,29	2,72
Other species	1,69	10	0,43	4,04	Other species	4,18	27,7	2,38	11,4

5 – ICLa					10 - ICLFb2
Raphanus sativus	22,7	28,5	50,8	34	No infestation
Brachiaria brizantha	45,4	14,3	29,4	29,7	
C. benghalensis	22,7	28,5	18,6	23,3	
Leonotis nepetifolia	4,55	14,3	0,83	6,55	
Other species	4,55	14,3	0,27	6,37	

NOTE: For treatment description, please check Table-1.

Table-3. Diversity coefficients of Simpson (D) and Shannon-Weiner (H') as a function of planting system. Ponta Porã, Brazil, Embrapa Western Agriculture, 2013.

Treatments	D	H'
1	0,64	1,17
2	0,73	1,58
3	0,18	0,44
4	0,39	0,78
5	0,69	1,31
6	0,66	1,19
7	0,08	0,22
8	0,02	0,57
9	0,32	0,68
10	- -	- -

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