# Sustainability of cassava cultivation in indigenous communities of Brazilian Pantanal

## Sustentabilidade do cultivo de mandioca em comunidades indígenas do Pantanal Brasileiro

## Sostenibilidad del cultivo de yuca en comunidades indígenas del Pantanal Brasileño

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**Abstract**
We aimed with this study to help maximizing cassava production for subsistence in indigenous communities at the Brazilian Pantanal, by introducing minimal changes to the usual indigenous way of cultivation aiming to reduce human labor in weed management in this crop. For that, we tested distinct intercrops and phosphate sources, taking the Babassu Indigenous Village, located in Miranda-MS, Brazil, as a reference. The experiment involved the intercrop of cassava with pigeon pea (*Cajanus cajan*), jack-bean (*Canavalia ensiformis*) and millet (*Pennisetum americanum*) and the source of phosphate fertilizer (mycorrhizal inoculants, $P_2O_5$ and without fertilization / mycorrhizal inoculum). Soil samples were collected to study the soil seed bank of spontaneous species. We adopted the phytosociological method to assess the absolute level of infestation, its composition density, frequency, dominance and importance value, and diversity coefficients of Simpson and Shannon-Weiner, as well as the Shannon Evenness Proportion (a sustainability coefficient) for all treatments. Areas were also grouped by similarity of plant species. Cultivation of cassava for subsistence in indigenous areas also selects certain spontaneous species, and management should focus in removing mostly by hand those established in the crop row; the damage to the crop may be higher in years of high abiotic stresses. There is no effect of phosphate supply source (P) in the level or composition of spontaneous species. There is clear evidence that the continued cultivation of cassava for subsistence in indigenous areas of the Brazilian Pantanal is sustainable over time, mainly when intercropped with other food species.
**Keywords:** Phytosociology; Intercrop; Weeds; Pantanal; Indigenous communities.

**Resumo**
Objetivamos maximizar a produção de mandioca para subsistência em comunidades indígenas do Pantanal Brasileiro, e verificar sua sustentabilidade ecológica, introduzindo mudanças mínimas no modo de cultivo indígena usual. Para tanto, testamos consórcios de cultivos e fontes de fosfato, tendo como referência a Aldeia Indígena Babaçu, localizada em Miranda-MS, Brasil. O experimento envolveu o consórcio de mandioca com feijão-guandú (*Cajanus cajan*), feijão-de-porco (*Canavalia ensiformis*) e milheto (*Pennisetum americanum*) e fonte de fertilizante fosfatado (inoculantes micorrízicos, $P_2O_5$ e sem fertilização / inóculo micorrízico). Amostras de solo foram coletadas para estudar o banco de

sementes do solo de espécies espontâneas. Adotamos o método fitossociológico para avaliar o nível absoluto de infestação, sua composição densidade, frequência, dominância e valor de importância, e coeficientes de diversidade de Simpson e Shannon-Weiner, bem como a proporção de uniformidade de Shannon (um coeficiente de sustentabilidade) para todos os tratamentos. As áreas também foram agrupadas por similaridade de espécies. O cultivo de mandioca para subsistência em áreas indígenas também seleciona certas espécies espontâneas, e o manejo deve se concentrar em remover principalmente à mão aquelas estabelecidas na linha de cultivo; os danos à cultura podem ser maiores em anos de alto estresse abiótico. Não há efeito da fonte de suprimento de fosfato (P) no nível ou composição das espécies espontâneas. Há evidências claras de que o cultivo continuado de mandioca para subsistência em áreas indígenas do Pantanal brasileiro é sustentável ao longo do tempo, principalmente quando consorciado com outras espécies alimentares.
**Palavras-chave:** Fitossociologia; Consórcios; Espécies espontâneas; Pantanal; Comunidades indígenas.

**Resumen**
Nuestro objetivo es maximizar la producción de yuca para la subsistencia en las comunidades indígenas del Pantanal brasileño y verificar su sostenibilidad ecológica, introduciendo cambios mínimos en el modo de cultivo indígena habitual. Probamos consorcios de cultivos y fuentes de fosfato, teniendo como referencia la Aldea Indígena Babaçu, ubicada en Miranda-MS, Brasil. El experimento involucró al consorcio de yuca con gandul (*Cajanus cajan*), frijol de cerdo (*Canavalia ensiformis*) y mijo (*Pennisetum americanum*) y fuente de fertilizante fosfatado (inoculantes micorrízicos, $P_2O_5$ y sin fertilización / inóculo micorrízico). Se recolectaron muestras de suelo para estudiar el banco de semillas. Adoptamos el método fitosociológico para evaluar el nivel absoluto de infestación, su densidad de composición, frecuencia, dominancia y valor de importancia y los coeficientes de diversidad de Simpson y Shannon-Weiner, así como el índice de uniformidad de Shannon (un coeficiente de sostenibilidad). Las áreas también se agruparon por similitud de especies. El cultivo de yuca para subsistencia en áreas indígenas también selecciona ciertas especies espontáneas, y el manejo debe enfocarse en remover principalmente a mano aquellas establecidas en la línea de cultivo; el daño a los cultivos puede ser mayor en años de alto estrés abiótico. No hay efecto de la fuente de suministro de fosfato (P) sobre el nivel o la composición de las especies espontáneas. Existe una clara evidencia de que el cultivo continuo de yuca para la subsistencia en las áreas indígenas del Pantanal brasileño es sostenible en el tiempo, especialmente cuando se intercalan con otras especies alimentarias.
**Palabras clave**: Fitosociología; Consorcios; Especies espontáneas; Pantanal; Comunidades indígenas.

## 1. Introduction

The food production practices at Terena indigenous communities, which are concentrated in the State of Mato Grosso do Sul, Brazil, mainly involves the cultivation of cassava, common bean, cowpea, rice and corn crops, with cassava being the main staple food. Approximately 50% of cassava production is destined for self-supply (immediate consumption, flour, starch and animal feed). The rest of the production is destined for the markets of the municipalities of Miranda, Corumbá and Campo Grande, or is traded by other inputs.

The slow initial growth, large plant spacing, the need for frequent weeding during the first crop stages, and the movement of the soil twice each cycle (during planting and harvesting) are agronomic characteristics of cassava plantations, which leave the soil unprotected for two to three months after planting. This may cause large soil losses through erosion (Souza et al, 2006). Cassava has a small branched root system and low density of absorbent hairs in roots, being considered obligatory mycotrophic. Sieverding (1991), among others, demonstrated that cassava is highly dependent on arbuscular mycorrhizal symbiosis. In this context, inoculation with strains of selected mycorrhizal-arbuscular fungi, no-tillage or minimum cultivation associated with the use of mulching plants, in addition to offering more favorable conditions for plant growth and development, can increase productivity levels of cassava (Otsubo et al., 2008; Souza et al., 1999; Silva et al., 2007).

The spontaneous plant species, naturally established among cassava plants, compete with the crop for water, light and nutrients, considerably decreasing crop productivity (Miranda, 1995). The removal of such species demands, on average, 50% of the labor required in cassava cultivation due to its very slow initial growth (Moura, 2000). The degree of weed interference with the crop can be altered by edaphic and climatic conditions, as well as by crop management. Thus the association of cassava with other species, as intercropping, in indigenous areas makes it possible to release labor for other activities in the village by reducing weed competitiveness against the crop, and the consequent loss of cassava productivity.

We aimed with this study, to help maximizing cassava production for subsistence in indigenous communities at the Brazilian Pantanal, by introducing minimal changes to the usual indigenous way of cultivation aiming to reduce human labor in weed management in this crop.

## 2. Methodology

For reaching our objective, we tested distinct intercrops and phosphate sources, taking the indigenous community Babassu (19º 57' 06" S; 56º 05' 49" W) as reference, in the municipality of Miranda, State of Mato Grosso do Sul, in 2013 and 2014. The climate in the region, according to the Köppen classification, is *Aw* (humid tropical climate with rainy season in summer and dry in winter). Average temperatures in the coldest month are between 18 - 20 ºC; the dry period extends up to five months, and rainfall ranges between 1,000 and 1,700 mm annually. The corresponding average altitude is 126 m ASL. The experiment was conducted in split-plot design, with 6 replications.

Cassava monoculture, cv. IAC 576, in the traditional indigenous system (single rows, no intercrop), was compared with intercrops established with the following species of green manure: pigeon pea (*Cajanus cajan*), jack-bean (*Canavalia ensiformis*) and millet (*Pennisetum americanum*). The single row system was established in plots consisting of six cassava rows spaced in 1 m, and 0.7 m plant spacing into rows, in a total of 13 plants per row. The double row system (intercrop) consisted of two cassava rows spaced in 0.7 m between them, and 2 m spacing between different double rows, totaling also 13 plants per row. Thus, each field plot measured 9.1 m x6.0 m for monoculture, and 10.8 m x 9.1 m for intercrops.

Subplots consisted of three treatments, namely: use of mycorrhizal inoculum; 100 kg ha$^{-1}$ $P_2O_5$ (magnesium thermophosphate with 18% $P_2O_5$); and without fertilization / mycorrhizal inoculum. In the inoculation with mycorrhizal fungus, a 7.5% solution of cassava starch was used, aiming at better adherence of the inoculum to cassava stem cuttings; we used 2.5 kg for approximately 108 cuttings.

The plots were conducted for two years (a full cropping cycle) with no weed management, when we harvested the crops and collected soil samples for assessing the occurrence of spontaneous plant species through the soil seed bank, as stated by Concenço et al. (2013). Our choice for phytosociology as method for assessing the occurrence of spontaneous species, was due to its ability to also infer about ecological sustainability of cropping systems with the type of data we have collected (Barbour et al., 1998). In each plot of the field experiment, two samples of 2 kg of soil were collected into rows, plus two other samples at interrows of cassava, both at a depth of 0 - 5 cm, which were deposited in plastic pots of compatible capacity, duly identified, further transported to the greenhouse belonging to Embrapa Agropecuária Oeste, Dourados-MS, Brazil, where the experiment of spontaneous weeds was installed.

The soil seed bank study started with pot arrangement on benches into the greenhouse, and maintenance of moist soil (irrigation twice a day) to stimulate seed germination. Four plant collections were carried out in the experiment, at 20, 40, 60 and 80 days after experiment start. In each assessment, all emerged seedlings and plants into each pot were identified, counted, collected and stored by species, being dried into oven with forced air circulation at 60 ºC, for later determination of the dry mass. The soil was then turned over to start a new 20-day germination / emergence cycle.

The number of plants (nº m$^{-2}$) and the total dry mass (g m$^{-2}$) of the potential infestation in the different treatments were presented in histograms, with the respective sample standard errors. For each species, the density (number of individuals), frequency (spatial distribution of the species) and dominance (capacity to accumulate mass) were estimated, which were used to obtain the importance value for each species in each area, according to Pandeya et al. (1968) and Barbour et al. (1998), as follows:

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

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

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

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

where *rDe* = relative density (%); *rFr* = relative frequency (%); *rDo* = relative dominance (%); *I.V.* = importance value (%); *I* = number of individuals of species *x* in area *r*; *TI* = total number of individuals in area *r*; *Q* = number of samples assessed 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 (I.V.) locates each spontaneous plant species within the community, according to its ability to cause damage (severity of occurrence) based on the three parameters previously mentioned. Areas were also intra-analyzed for species diversity by using the Simpson (D) and Shannon-Weiner (H') indexes (Barbour et al., 1998), and finally the Shannon Evenness Proportion (SEP) sustainability coefficient was determined according to McManus and Pauly (1990), being:

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

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

$$SEP = \frac{Hd'}{H'} \quad (7)$$

where *D* = Simpson's diversity coefficient; H' = Shannon-Weiner's diversity coefficient (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's evenness proportion coefficient; *Hd'* = Shannon-Weiner's diversity coefficient (based on dominance).

Subsequently, areas were compared with each other by Jaccard's asymmetric binary similarity coefficient. Based on the Jaccard coefficients, the similarity matrix was elaborated, and from this the dissimilarity matrix (1-similarity) was obtained, as follows:

$$J = \frac{c}{a + b - c} \quad (8)$$

$$Di = 1 - J \quad (9)$$

where *J* = Jaccard's similarity coefficient; *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 analysis of hierarchical grouping was performed from the dissimilarity matrix, using the UPGMA method (Unweighted Pair Group Method with Arithmethic Mean) (Sneath and Sokal, 1973). The critical level for group separation in cluster analysis was based on the arithmetic mean of the similarities in the original Jaccard matrix (Barbour et al., 1998), disregarding the crossing points between the same areas into the matrix. Grouping validation was done by the cophenetic correlation coefficient (Sokal and Rohlf, 1962), obtained by Pearson's linear correlation between the original dissimilarity matrix and the cofenetic matrix. The diversity and similarity coefficients, as well as the cluster analysis (Cluster), were obtained into the R statistical environment (R - development, 2018)

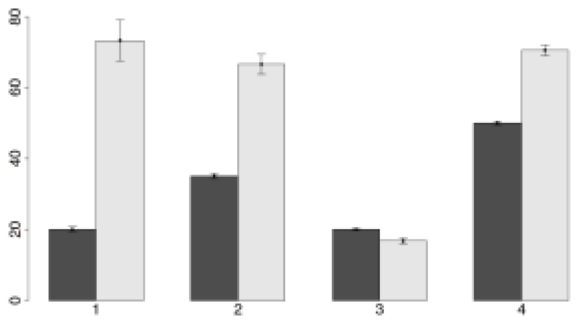
All formulas and procedures, both for sampling areas and describing communities and grouping species, followed the recommendations of Barbour et al. (1998) for synecological analyzes.

## 3. Results and Discussion

The level of occurrence of spontaneous plants differed according to the intercropping system, both for number of specimens as for dry mass (Figure 1a). For both, the lowest occurrence level was reported when cassava was intercropped with jack-bean; the dry mass of spontaneous plants in this treatment was ~ 30% of that observed for other treatments. Dry mass for the other treatments was equivalent, while for the number of spontaneous species, the intercrop with millet resulted in infestation levels similar to that observed in the intercrop with jack bean, being the largest infestation reported for the single cassava (monoculture) cultivation (Figure 1a).

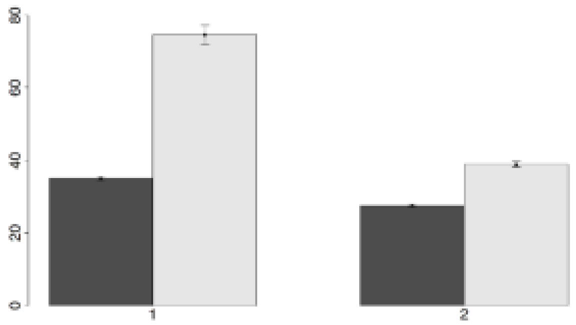
**Figure 1**. Plant density (■ - n° m$^{-2}$) and dry mass (■ - g m$^{-2}$) as function of intercropped species with cassava (A), assessed position (B) and P source (C). Standard errors are presented on bars. Babassu Indigenous Village, Miranda-MS, Brazil, 2014.

(A)



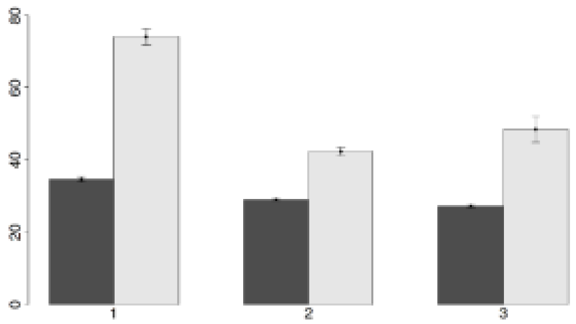

| | |
|---|---|
| **1** = M + M - cassava + millet<br>**2** = M + G - cassava + pigeon pea<br>**3** = M + F - cassava + jack bean<br>**4** = Cassava | ■ = plant density (n° m$^{-2}$)<br>■ = plant dry mass (g m$^{-2}$) |

(B)




| | |
|---|---|
| **1** = into cassava row<br>**2** = cassava inter-row | ■ = plant density (n° m$^{-2}$)<br>■ = plant dry mass (g m$^{-2}$) |

(C)




| | |
|---|---|
| **1** = Mycorrhiza<br>**2** = no P<br>**3** = Mineral P | ■ = plant density (n° m$^{-2}$)<br>■ = plant dry mass (g m$^{-2}$) |

Source: Authors.

When the level of infestation into the planting row and between rows was compared (Figure 1b) no difference was reported, with approximately 32 plants m$^{-2}$. The dry mass accumulated by these plants, however, differed with larger plants being reported into planting rows (Figure 1b), which are ~ 75% larger than spontaneous plants located between distinct crop rows. Two facts contribute to this result: (1) among the four treatments considered to obtain the level of weed infestation into rows and between crop rows - intercropping systems (Figure 1a), only one of them did not have an intercropped species; thus, in the other three groups the crop inter-rows were mostly covered by the intercropped species than the crop rows; and (2) while the vegetation mulching of the intercropped species protects the crop row, its proximity to the cassava planting line could affect the development of the crop itself.

Thus, the lack of shading in cassava planting rows indicates that there is an advantage in intercropping it with other plant species in order to reduce labor demand for weed control in the inter-rows, but indigenous communities still would have to focus efforts on pulling out spontaneous plants established into the cassava planting row. The elimination of these spontaneous plants from the crop planting row may not affect cassava productivity in years where water stress does not occur, but they can make a difference to the food security of indigenous people in years when the crop grows under severe abiotic stresses.

The source of phosphate, whether applied to treatments intercropped with other species or single cassava, did not influence the number of spontaneous plants (Figure 1c); differences were reported, however, for plant size. Spontaneous plants with dominant shoot were observed when mycorrhiza was used as source of phosphate availability (P), and plants presented 42% higher dry mass in this treatment compared to the absence of P or its supply by mineral source (Figure 1c). It is hypothesized that this difference in plant size is probably due to a greater stimulus to other soil microorganisms and biochemical processes, that optimized the availability of other resources to the spontaneous community, and / or its use by these plants.

The phytosociological analysis of intercropping systems indicated the occurrence of 4, 6, 6 and 10 species of spontaneous plants, respectively for cassava intercropped with millet (M + M), pigeon pea (M + G), jack-bean (M + F) or single cassava (M) (Table 1). For the intercroppings, problematic spontaneous species such as *Acanthospermum australe* (spiny-bur), *Richardia brasiliensis* (Brazil pusley) and *Talinum paniculatum* (fameflower), in addition to *Siegesbeckia orientalis* (common St. Paul's wort) and *Oxalis latifolia* (sorrel), were absent and were observed only for single cassava (Table 1). In general terms, species of lesser importance as weeds were observed in intercropped crops, such as sorrel, which represented 59.65% of the importance value of infestation (IV) in the treatment M + M; *Leonotis nepetifolia* (klip dagga) with IV = 33.86% in M + G and 28.8% in M + F; and *Aeschynomene rudis* (jointvetch) with IV = 24.85% in M + F (Table 1).

**Table 1**. Phytosociological analysis of spontaneous plant species in cassava planted single or intercropped with green manure species. Babassu Indigenous Village, Miranda-MS, Brazil, 2014.

| **Spontaneous** | **(1) M. + M.** | | | | **(2) M. + G.** | | | | **(3) M. + F.** | | | | **(4) Cassava** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **plant species** | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** |
| *S. grisebacchii* | 12.5 | 20 | 8.19 | **13.56** | | | | | 12.5 | 14.29 | 2.99 | **9.93** | | | | |
| *D. insularis* | | | | | 7.14 | 10 | 5.64 | **7.59** | | | | | | | | |
| *A. rudis* | | | | | | | | | 12.5 | 14.29 | 47.76 | **24.85** | 5 | 6.67 | 7.09 | **6.25** |
| *N. physaloides* | | | | | | | | | 12.5 | 14.29 | 10.45 | **12.41** | | | | |
| *P. oleracea* | | | | | 7.14 | 10 | 1.88 | **6.34** | | | | | | | | |
| *S. orientalis* | | | | | | | | | | | | | 10 | 6.67 | 1.06 | **5.91** |
| *D. horizontalis* | | | | | 28.57 | 30 | 43.23 | **33.93** | 12.5 | 14.29 | 1.49 | **9.43** | 20 | 26.67 | 65.6 | **37.42** |
| *A. hybridus* | 12.5 | 20 | 13.99 | **15.5** | | | | | 25 | 14.29 | 4.48 | **14.59** | 10 | 6.67 | 0.71 | **5.79** |
| *L. nepetifolia* | 12.5 | 20 | 1.37 | **11.29** | 35.71 | 20 | 45.86 | **33.86** | 25 | 28.57 | 32.84 | **28.8** | 25 | 20 | 1.77 | **15.59** |
| *S. rhombifolia* | | | | | 7.14 | 10 | 1.13 | **6.09** | | | | | | | | |
| *S. micranthum* | | | | | 14.29 | 20 | 2.26 | **12.18** | | | | | 5 | 6.67 | 9.57 | **7.08** |
| *A. australe* | | | | | | | | | | | | | 5 | 6.67 | 7.8 | **6.49** |
| *R. brasiliensis* | | | | | | | | | | | | | 5 | 6.67 | 1.06 | **4.24** |
| *T. paniculatum* | | | | | | | | | | | | | 5 | 6.67 | 1.77 | **4.48** |
| *O. latifolia* | 62.5 | 40 | 76.45 | **59.65** | | | | | | | | | 10 | 6.67 | 3.55 | **6.74** |

* **M + M** = cassava + millet; **M + G** = cassava + pigeon pea; **M + F** = cassava + jack-bean.
**DE** = relative density (%); **FR** = relative frequency (%); **DO** = relative dominance (%); **IV** = importance value (%).
Source: Authors.

This, however, does not mean that spontaneous species of great importance as weeds have not been reported in intercropped treatments. For example, in M + G (Table 1), Jamaican crabgrass (*Digitaria horizontalis*), an important and highly competitive weed species, represented 33.93% of the IV, demanding care from the indigenous community so that its occurrence does not harm cassava productivity, thus ensuring food security. In the M + F intercrop, smooth pigweed (*Amaranthus hybridus*) represented IV = 14.89%; although this level of occurrence is not yet alarming, in years of severe abiotic stresses this spontaneous species can predominate and cause significant harm to cassava, even in intercropped systems, as it is very stress tolerant and produces a large number of seeds (Maluf, 1999).

When the composition of species into rows is compared to that reported for inter-rows for treatments, it was found only 5 species into cassava rows, and 13 species occurring between rows (Table 2). When this information is cross-checked with the level of infestation (Figure 1b), it appears that the significant level of infestation in the planting rows is attributed to a few species (Table 2), with predominance of sorrel and klip dagga, both usually not important as weeds, but also with a very significant occurrence of Jamaican crabgrass and smooth pigweed, which demand greater care at times when the other components of the production system favor their occurrence. This is confirmed by the greater dry mass of spontaneous plants found into crop rows (Figure 1b), which can be attributed to the high dominance of Jamaican crabgrass and the high density of smooth pigweed in terms of IV (Table 2). In the inter-rows (Table 2), the presence of intercropped species was not sufficient to reduce the importance of Jamaican grabgrass, which indicates that this species deserves special attention to avoid damage to cassava productivity.

**Table 2.** Phytosociological analysis of spontaneous plant species in cassava, as function of assessed position into the field. Babassu Indigenous Village, Miranda-MS, Brazil, 2014.

| Spontaneous plant species | (1) Cassava rows | | | | (2) Inter-rows | | | |
|---|---|---|---|---|---|---|---|---|
| | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** |
| *S. grisebacchii* | | | | | 9.09 | 10.53 | 8.36 | **9.33** |
| *D. insularis* | | | | | 4.55 | 5.26 | 4.82 | **4.88** |
| *A. rudis* | | | | | 9.09 | 10.53 | 16.72 | **12.11** |
| *N. physaloides* | | | | | 4.55 | 5.26 | 2.25 | **4.02** |
| *P. oleracea* | | | | | 4.55 | 5.26 | 1.61 | **3.81** |
| *S. orientalis* | | | | | 9.09 | 5.26 | 0.96 | **5.1** |
| *D. horizontalis* | 21.43 | 27.78 | 33.5 | **27.57** | 13.64 | 15.79 | 32.48 | **20.64** |
| *A. hybridus* | 17.86 | 16.67 | 7.71 | **14.08** | | | | |
| *L. nepetifolia* | 28.57 | 27.78 | 14.74 | **23.7** | 22.73 | 15.79 | 20.9 | **19.81** |
| *S. rhombifolia* | | | | | 4.55 | 5.26 | 0.96 | **3.59** |
| *S. micranthum* | 7.14 | 11.11 | 4.86 | **7.7** | 4.55 | 5.26 | 1.29 | **3.7** |
| *A. australe* | | | | | 4.55 | 5.26 | 7.07 | **5.63** |
| *R. brasiliensis* | | | | | 4.55 | 5.26 | 0.96 | **3.59** |
| *T. paniculatum* | | | | | 4.55 | 5.26 | 1.61 | **3.81** |
| *O. latifolia* | 25 | 16.67 | 39.2 | **26.96** | | | | |

**DE** = relative density (%); **FR** = relative frequency (%); **DO** = relative dominance (%); **IV** = importance value (%).Source: Authors.

Regarding phosphate source (P), 5, 9 and 9 spontaneous species were reported for treatments with mycorrhiza, without P and with mineral P, respectively (Table 3). In mycorrhiza treatment, there was predominance of Jamaican crabgrass, showing that this $C_4$ species is probably highly efficient in capturing P (Silva et al., 2007), which was not added to soil in this treatment, representing alone IV > 50% in this treatment. For supply of mineral P, there was predominance of sorrel, which seems to be most efficient in the use of P (Silva et al., 2007); in the treatment without P supply, species occurrence was balanced with small predominance of klip dagga and jointvetch (Table 3), which are not usually important weed species in cassava.

**Table 3**. Phytosociological analysis of spontaneous plant species in cassava, as function of source of P supply. Babassu Indigenous Village, Miranda-MS, Brazil, 2014.

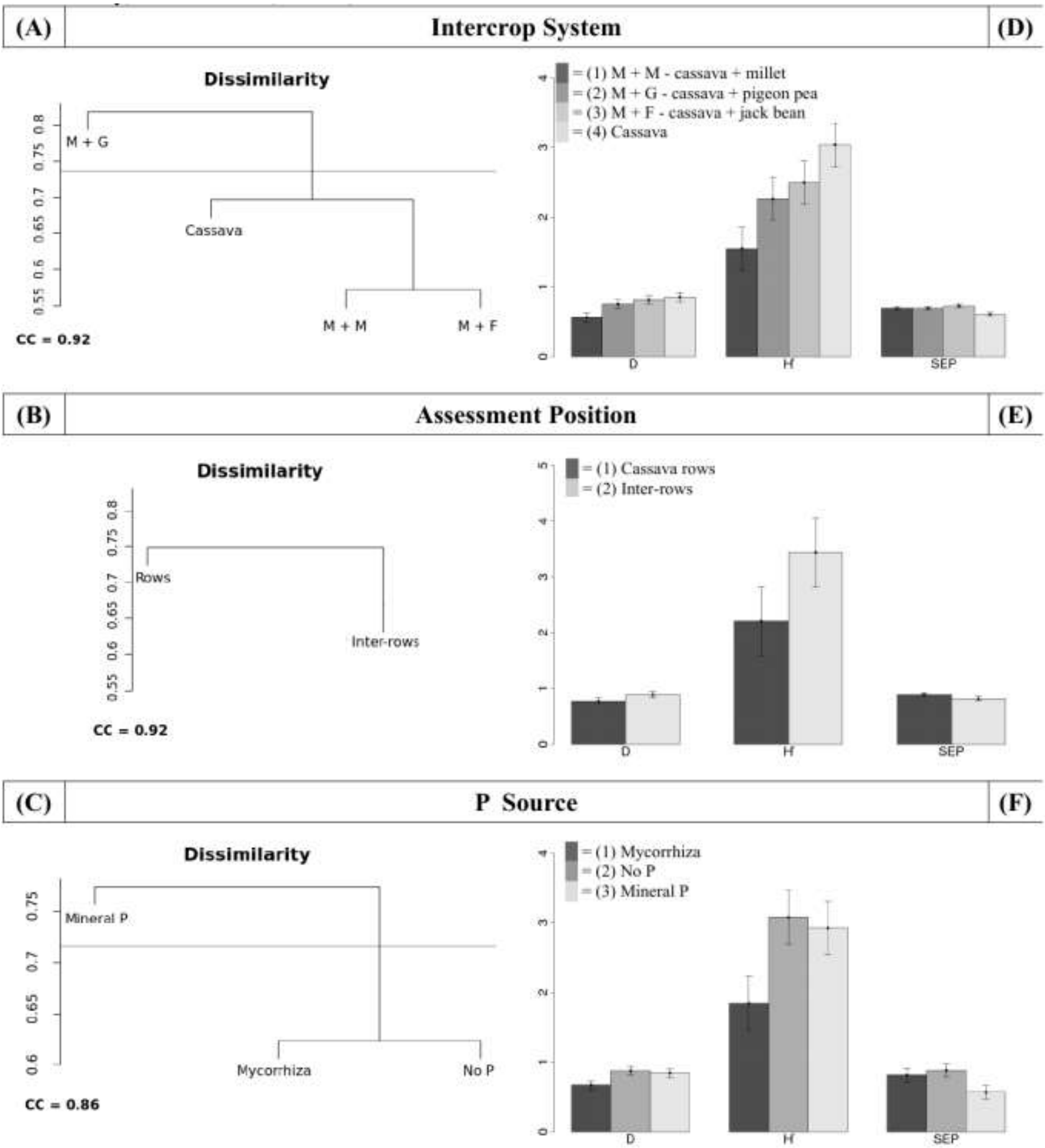
| **Spontaneous** | **(1) Mycorrhiza** | | | | **(2) No P** | | | | **(3) Mineral P** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **plant species** | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** | **DE** | **FR** | **DO** | **IV** |
| *S. grisebacchii* | | | | | 6.25 | 7.14 | 10.3 | **7.9** | 6.67 | 9.09 | 0.75 | **5.5** |
| *D. insularis* | | | | | | | | | 6.67 | 9.09 | 5.62 | **7.13** |
| *A. rudis* | | | | | 12.5 | 14.29 | 22.32 | **16.37** | | | | |
| *N. physaloides* | | | | | | | | | 6.67 | 9.09 | 2.62 | **6.13** |
| *P. oleracea* | | | | | | | | | 6.67 | 9.09 | 1.87 | **5.88** |
| *S. orientalis* | | | | | 12.5 | 7.14 | 1.29 | **6.98** | | | | |
| *D. horizontalis* | 36.84 | 50 | 63.73 | **50.19** | 12.5 | 14.29 | 17.6 | **14.8** | | | | |
| *A. hybridus* | | | | | 6.25 | 7.14 | 17.6 | **10.33** | 26.67 | 18.18 | 1.87 | **15.57** |
| *L. nepetifolia* | 42.11 | 25 | 19.85 | **28.99** | 18.75 | 21.43 | 21.89 | **20.69** | 13.33 | 18.18 | 7.87 | **13.13** |
| *S. rhombifolia* | 5.26 | 8.33 | 0.74 | **4.78** | | | | | | | | |
| *S. micranthum* | 5.26 | 8.33 | 6.62 | **6.74** | 12.5 | 14.29 | 2.58 | **9.79** | | | | |
| *A. australe* | | | | | | | | | 6.67 | 9.09 | 8.24 | **8** |
| *R. brasiliensis* | | | | | | | | | 6.67 | 9.09 | 1.12 | **5.63** |
| *T. paniculatum* | | | | | 6.25 | 7.14 | 2.15 | **5.18** | | | | |
| *O. latifolia* | 10.53 | 8.33 | 9.07 | **9.31** | 12.5 | 7.14 | 4.29 | **7.98** | 20 | 9.09 | 70.04 | **33.04** |

**DE** = relative density (%); **FR** = relative frequency (%); **DO** = relative dominance (%); **IV** = importance value (%). Source: Authors.

The difference in the number of spontaneous species reported as function of the source of P (Table 3), as previously highlighted, does not allow us to state that a greater number of spontaneous species occur in treatments with mineral P and without P compared to mycorrhizae, because the cophenetic correlation coefficient, and consequently the reliability of the cluster (Figure 2c), was low and non-significant. Thus, this difference in the number of species occurring between forms of P availability may have been merely the work of natural variation.

Regarding the assessed position (crop rows or inter-rows), the difference in plant composition was significant (Figure 2b) as the dissimilarity coefficient of Jaccard was ≤ 75% (Concenço et al., 2013) (Table 2; Figure 2b). As for the intercrops (Table 1; Figure 2a), only the association of cassava with pigeon pea (M + G) resulted in different composition from the other treatments, as Jaccard's dissimilarity was ≤ 74% (Figure 2a), with no influence, however, of this on the reported level of infestation (Figure 1a).

**Figure 2**. Diversity and sustainability coefficients, and treatment clustering by similarity in occurrence of spontaneous plant species, as function of intercropped species (A;D), assessment position onto the field (B;E) and source of P supply (C;F). Babassu Indigenous Community, Miranda-MS, Brazil, 2014.




**D** = Simpson's diversity; **H'** = Shannon-Weiner's diversity; **SEP** = Shannon Evenness Proportion (sustainability coefficient). Hierarchical clustering was obtained based on Jaccard's dissimilarities, by the UPGMA method. *** ; ns** = significant and non-significant cophenetic correlation, respectively. Source: Authors.

Diversity is a concept that considers the balance of plant communities in a given agricultural area as a consequence of good management (Pandeya et al., 1968). Simpson's diversity coefficient (D) quantifies, in simple terms, the probability that two individuals randomly collected in the same area, to belong to the same species, being more influenced by dense species. Shannon-Weiner's diversity coefficient (H'), on the other hand, is derived from the Information Theory (Shannon, 1948) and confuses diversity with species richness (Barbour et al., 1998), being most influenced by the occurrence of rare species.

The behavior of the diversity coefficients indicates that, for intercrop systems (Figure 2d), into plot assessment position (Figure 2e) or P source (Figure 2f), the group of species most responsible for the reported changes was the one that included the rare species, as considerable differences were observed between treatments for H' without reflection at equivalent level for D. Furthermore, the reported coefficients (around 1.0 for D and 3.0 - 3.5 for H') support the inference that the current values of diversity are suitable for non-intensive systems, and tend to increase even more as signaled by the changes in H'. It is known in advance that the assessed area is new and was in the second year of cultivation at the time of the assessment. This is the first evidence, based on specific sustainability coefficients, that growing cassava for subsistence in indigenous villages can be sustainable over time.

The SEP coefficient (Figures 2d,e,f) is capable of inferring about the sustainability of practices applied to productive systems from static data (McManus and Pauly, 1990). In simple terms, SEP promotes an overall comparison of species into a given area in terms of its density and dominance survival strategies; differences closer to zero for this comparison (Hd' ~ H'), resulting respectively in SEP ~1 (see equation 7), indicate greater stability in species distribution due to the equivalence in competitive ability between dense (numerous offspring) and dominant (fast growth and high dry mass accumulation) plant species.

Evidently, only two years (cumulative efffect in soil) are not enough for definitive inferences about sustainability in indigenous cassava plantations, but the values observed for all treatments, SEP ~ 1.0, corroborate the diversity coefficients when indicating that the non-intensive systems of cassava cultivation in indigenous areas, tend to sustainability over time with no major concerns.

## 4. Conclusion

The cultivation of cassava for subsistence in indigenous areas selects certain species of spontaneous plants, which must be eliminated to avoid losses in productivity and to guarantee food security of the village;

In the case of intercrop of cassava with other species, weeds established into the cassava row should be eliminated by hand or mechanical weeding (hoeing) if they are recognized as weeds (mostly Jamaican crabgrass, smooth pigweed, Brazil pusley and jointvetch). Damages caused by these species can be greater in years of high abiotic stresses such as drought or heat stress;

There is strong evidence that the continued cultivation of cassava in indigenous areas, aiming at the subsistence of the village, is sustainable over time, especially when cassava is intercropped with green manure or mulching plant species;

There is no effect of phosphate (P) source on the level or composition of spontaneous species occurring in the assessed cassava plantations for indigenous subsistence.

Futher studies must be carried out to evaluate more accentuated environmental variations and their influence depending on the years of cultivation. Thus, it will be possible to provide even more relevant information about this research topic.

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