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WEED DYNAMICS UNDER TWO MANAGEMENT METHODS IN AN AGROFORESTRY SYSTEM

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ABSTRACT

Weeds are a problem in conventional farming systems and an even bigger problem when dealing with *agro forestry* systems due to the difficulties of controlling machinery in these spaces. This study evaluates the occurrence of weeds under two control methods in an *agro forestry* system. The monitoring took place for 20 months under two weed control regimes: mechanized and semi-mechanized. It used calculations of relative *frequency* relative density, Shannon diversity, Pielou equitability and the SAS STEPDISC PROC procedure to identify the most discriminant species of each treatment. The species with the highest frequency and relative density in the treatments were *B. verticillata*, *S. cordifolia*, *U. plantigenea*, and *D. sanguinalis* in mechanized and *Sabiceaamazonensis* and *Scleriagaertneri* Raddiin semi-mechanized. The mechanized regime presented greater diversity, equitability, and richness of weeds. The most prevalent species according to PROC STEPDISC were *Digitariasanguinalis* (L.) and *Urochloaplantaginea* for mechanized and *Scleriagaertneri Raddi* and *Sabiceaamazonensis* for semi-mechanized.

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INTRODUCTION

Weeds are a potential problem in agroforestry systems, as well as in monoculture systems. These plants tend to compete with crops of interest and generate production losses, which can reach around 80 to 100% (Fonte *et al*., 2009). In this way, in addition to adding higher production costs, these plants can assume the role of hosts of pathogens and pests relevant to the crop of interest (Vasconcelos *et al*., 2012). Currently, the most used method for weed management is the application of chemical products since it offers greater effectiveness in controlling these plants than the other methods used, notably when used in planting lines (Oliveira *et al*., 2018). Despite being an advantageous procedure, some weed genera such as Eleusine, Lolium, and Amaranthus present tolerance to chemical control (Vila-Aiub, 2019). Alternative forms of management used in association with this can favor control, such as mechanical methods, since seeking to avoid losses in the process and the harvest yield (Pannacci, 2014). The use of cutting machines or furrowers is highly effective in controlling broadleaf weeds, while at the same time reflecting inefficiency on the fine leaf weed community, and thus some species tend to prevail in the area, such as the families Poaceae and Amaranthaceae, reaching greater importance (Mccool *et al*., 2018). The authors also point out that the association of different mechanical methods can raise the effectiveness of the control over the weed community. Even if there is the possibility of mechanized suppression, there are cases in which the management of weeds is unfeasible with the use of agricultural machinery due to the machinery having dimensions that exceed the planting spacing found in agroforestry systems (Xavier *et al*., 2018). In these systems, the management of weed plants is done manually or semi-manually, through weeding and mowing, especially in small properties, requiring more time and labor, making weed control more expensive (Xavier *et al*., 2018). Since each management method, whether chemical, mechanized or manual, will affect the weed community differently, especially concerning its floristic composition (Oliveira *et* *al*., 2018), it is proposed, in this work, to evaluate the dynamics of the weed community in systems agroforestry with different types of management.

MATERIALS AND METHODS

Study area: The experiment was carried out in the experimental agroforestry production system at the Experimental Field Unit (EFU) at the Federal University of West Pará (UFOPA), located at Km-37 of the PA-370, Santarém/Curuá-Una Highway (02º 24 "52" S and 54º 42 "36" W), in the municipality of Santarém, WestPará State, Brazil. The area has historically been used for the development of livestock raising, with emphasis on cattle breeding, for about 26 years(from 1980 to 2006) with a subsequent fallow period of 10 years, until the implementation of the agroforestry system in 2016. The predominant climate in the area, according to the Köppen classification, is hot and humid, with rainfall concentrated in the first half of the year, average annual temperature between 25º to 28ºC, average relative air humidity of 86%, and average annual rainfall of 1.920 mm.year^{-1}, ranging between 170 mm.month^{-1} and 60 mm.month^{-1}(Alvarez *et al*., 2013).According to Almada *et al*. (2021), the soil in this region is of the Argisol Dystrophic Yellow Latosol type, with contents of sand between 439 and 679 g.kg^{-1}, silica from 64 to 99 g.kg^{-1}, and clay between 234 to 479 g.kg^{-1}.

Management systems: The experimental agroforestry production system was installed in March, 2016 and occupies a useful area of 1 ha, where it is divided into two management systems (50mx50m each), with two repetitions each: Mechanized (MEC) and Semi-mechanized (SMEC).Their arrangement in the field comprises of two blocks with distinct species arrangement (Fig. 2).

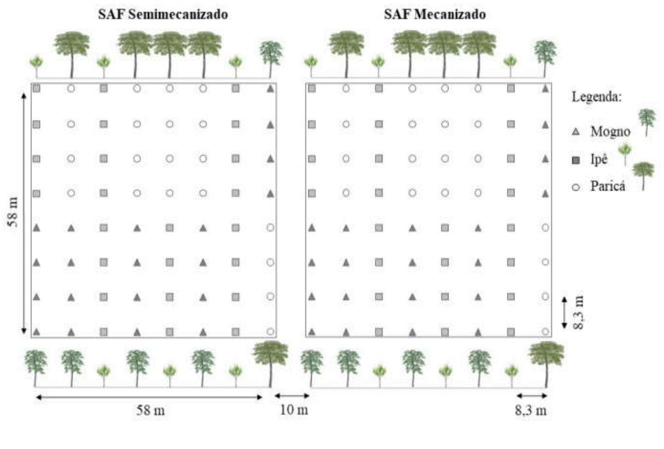

Fig. 2. Schematic drawing of the experimental agroforestry system and distribution of arrangements of species

Arrangement 1 is composed of "IpêAmarelo" (*Handroanthus serratifolius* (Vahl) S.O. Grose) and"Paricá" (*Schizolobium amazonicum* (Huber) Ducke). In the second arrangement, the following species were introduced: Brazilian Mahogany (*Swietenia macrophylla* King), Ipêamarelo (*Handroanthus serratifolius* (Vahl) S.O. Grose) and Banana (*Musa* sp.). However, the species *Musa sp.* was excluded from the system due to mortality of 90% of its individuals. The variation between the blocks consists of the management regime, in which the SMEC treatment conducted in blocks 2 and 4 (Figure 2) was performed with manual and semi-manual tools, without the addition of chemical industrial fertilizer.In the MEC treatment, conducted in blocks 1 and 3, a tractor and plow, and chemical fertilizer were used in the maintenance of the crops. In the first treatment (SMEC), the area was cleared with partial removal of the vegetation using a chainsaw and hand tools (scythe and hoe), and without the use of burning, which was not carried out in order to maintain the organic remains fromthe clearing of the soil cover. The second regime employed was total vegetation removal, using a tractor with a rake fork and subsequent harrowing. There was no soil correction done in any of the treatments.The fertilizers consisted of application of organic manure fertilizer (100 kg per row) in SMEC and chemical fertilizer NPK (15: 52: 0) and NPK (9:28:20) in MEC, both implemented only during the planting of the forest seedlings. Plantation maintenance was based on weeding, pruning, and mowing, with the use of a brushcutter for the SMEC blocks and cleaning with a tractor-pulled plow and brushcutter in the MEC blocks.

Data collection

Rainfall was measured daily using a conventional rain gauge throughout the monitoring to establish monthly rainfall. Only one block of each regime was used for the development of this experiment, blocks MEC - 1 and SMEC - 2, since the others correspond to only one repetition of these.The monitoring period was 20 months, from July, 2017 to March, 2019. The use of only two blocks is justified because the time taken for collection is long, as well as it being impossible to monitor all blocks. Within each block, 12 random plots were laid out between the planting lines (Figure 2), triangular in shape, withan area of 0.5 m^2. The aerial parts of the weeds were quantified and collected for botanical identification via the specialized literature, and in partnership with the parabotanistat the Forest Seed Laboratory at the Federal University of WestPará. Unidentified species have been described as morphospecies.

Data analysis

After identification and quantification, the phytosociological parameters of absolute frequency (1) and relative frequency (2), as proposed by Mueller-Domboise*t al*. (1974). The Diversity calculations were obtained using the Shannon-weaver diversity index and the Pielou Equitability Index. For homogeneity of variance, the Levene test was used, and to verify the normality of the data, the Shapiro-Wilks test was used at 5% significance. Box-Cox transformation was used to achieve normality and homogeneity of data. In order to identify the species that best discriminate the observed variables, we utilized the PROC STEPDISC selection process, with STEPWISE selection of the SAS System, which has the function of identifying the variables that best discriminate the treatments, and aggregates and classifies a group of variables that are considered normal and multivariate with a common covariance matrix (SAS Institute, 2009). The following criteria were used for species selection: 1) the significance level of the F test from covariance analysis, with treatment as the dependent variable and the species chosen as covariates; and 2) squared partial correlation to predict the most significant treatment starting from covariate species, thereby controlling the effects of the species selected by the model (SAS Institute, 2009). The repeated-measure analysis of variance procedure (ANOVA) of the SAS system, with PROFILE specification, was used to analyze whether there was any difference in treatments for each species highlighted by PROC STEPDISC.

RESULTS AND DISCUSSION

During the 20 months of monitoring, the accumulated rainfall was 3395.7 mm, with monthly variation of between 4 mm.month^{-1}and 356 mm.month^{-1} (Fig. 3). The variation of humidity in the environment influences the development of weeds and regulates factors such as germination, flowering and dispersal (Cantero-Martinez *et al*. 2007).
Twenty-seven weed species were found in both management systems (Table 1), MEC and SMEC, in which the main botanical families were Cyperaceae (22.2%), Poaceae (14.8%) andFabaceae (7.4%), which together represent 44.4% of the total species. Ferreira *et al*. (2015) also found a predominance of these families in the same hierarchy as described here when evaluating the phytosociology of eight areas of pasture. Thus, factors such as system age and area history explain why species prior to the agroforestry system continue to dominate the environment. The species with the highest relative frequencies for the MEC system were*B. verticillata.* (18.85%), *S. cordifolia* (10.87%)*, U. plantaginea* (7.21 %) and *D. sanguinalis* (7.03), which together account for 36.93% of plants in the system.

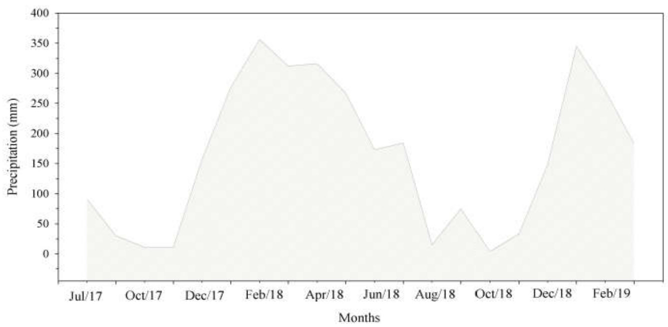

Fig. 3. Rainfall in the experimental area in the 20 months of monitoring (July, 2017 to March, 2019) in the municipality of Santarém, Pará state, Brazil

When considering relative density, these species remain prominent, with only different levels of hierarchy, where *B. verticillata* (25.35%) presents higher density, followed by*U. Plantaginea* (13.75 %) and *D. sanguinalis* (12.97 %) and, finally, *S. cordifolia* (13.75 %), which, in relation to frequency, was the second most important. *Borreria verticillata* stood out as being the species with the highest density, as described in literature for areas with unbalanced soil, because the species has growth rates that are higher than the others when in areas of soil with signs of degradation (Jesus *et al*., 2016). Pacheco *et al.* (2016) describes *B. verticilata* occurring in large quantities in areas with no ground cover. In the SMEC system, the most frequently found species were*S. Amazonensis* (20.00%), *S. gaertneri* (16.42) and*B. verticilata* (10.37%), which collectively represented 46.79% of the area's flora. Density data also showed high importance for the first two species for this regime; since both occupied 51.55% (*S. amazonensis* (30.88 %) and*S. gaertneri* (20.67 %)of species by area. The high density of a species associated with its high frequency may indicate inclination as potential weeds in their environment. Observing the frequency and relative density of the species, it is noted that the rubiaceae family, although not representative in number of species, stood out in terms of numbers of individuals, and was distributed in two species (*B. verticilata*and *S. amazonensis*) with high density and frequency in both control methods.Ikeda *et al.* (2008), also found predominance of this family involving both genera, which occurred in areas of burned *cerrado*. The Pielou Equitability Index demonstrated the equilibrium between species in an area (Lima *et al*., 2014), since it showed a trend towards zero when a species is prone to dominate the community in which it is inserted (Dajoz, 2006). The highest homogeneity occurs in the SMEC system, though it is reversed in the last three months when it begins to show greater heterogeneity, which was a consequence of the hoeing that occurs in this period, and favored species such as *S. gaertneri*, which benefited from this clearing method and increased its population (Silva *et al*., 2016). The highest values of H'found in this study were 0.92 for MEC and 0.80 for SMEC (Fig. 4A), and showed a very low diversity level, since the Shannon-Weaver diversity index ranged from 3 to 1, where above 3 indicates high diversity and below 1 very low diversity (Cavalcantiet l., 2004). This low diversity is influenced by the high plasticity of *B. verticilata*and *D. sanguinalis* (L.) in the MEC, and *S. Amazonensis* in the SMEC. These occupy a good area of cover in the field, or are associated with the seed bank depleted by the previous land use system, cultivation of grass for pasture, and carry over part of that seed bank by soil tillage for current system of cultivation implementation. Between the treatments, MEC had the highest diversity index, when comparing the beginning and end of the observations for each treatment, with H'values between 0.70 and 0.92.The lower diversity in the SMEC block was associated with the greater shade it had over the ground (Fig. 4A), since this area had a higher tree component per square meter than the MEC system. Mhlanga; Chauhan and Thierfelder (2016) discuss how shading inhibits the growth and establishment of positive photoblastic plants, and advocate the use of shading for the control weeds, through the use of crops with a larger leaf area, thus reducing light that reaches the soil of the crop.

Although light is an essential germination factor, some species may also germinate in its absence, either due to adaptability or physiology (Marques *et al*., 2012). Species such as *S. amazonensis* present negative photoblasts, and therefore had a high presence level in the SMEC block. The litter existing in the SMEC treatment promoted greater levels of shade for the ground, besides providing physical barriers for individuals that can germinate in the shade.In these individuals, this promoted the formation of thinner stems, which lead to greater fragility in individuals (Brighenti *et al*., 2011), and facilitated seed predation by the microbiota and reduced plant diversity (Nyamangara *et al*., 2013). The fluctuation of the higher richness index between treatments followed rainfall levels obtained from the rain gauge, where the quantity of water availability in each system apparently affected the richness (Fig. 4B).The SMEC regime, with soil cover, favored less water stress during the drought period, and caused less fluctuation in the number of species, while the opposite occurred in the MEC system, due to greater soil cover with dead plant matter. Cantero-Martínez *et al*. (2007), discuss systems with higher water availability in order to provide better conditions for the establishment of more species, since water availability is a crucial factor for plants to so that they can address their physiological needs.

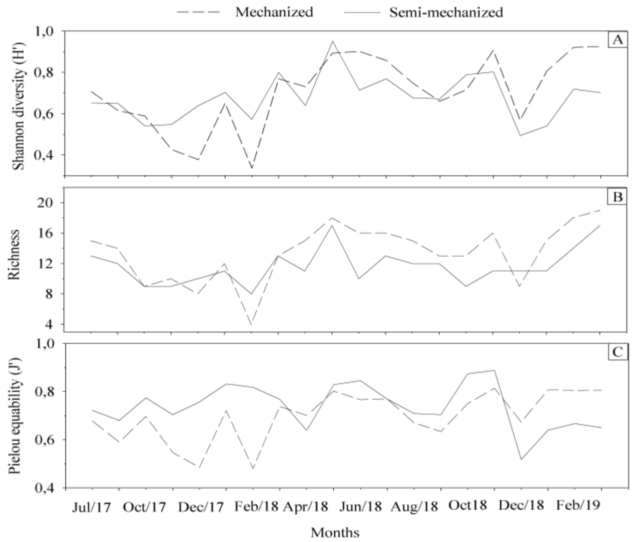

Fig. 4. Indices of diversity, richness and equability over 20 months of monitoring in an agroforestry system at the UFOPA Experimental Farm, Santarém, Pará

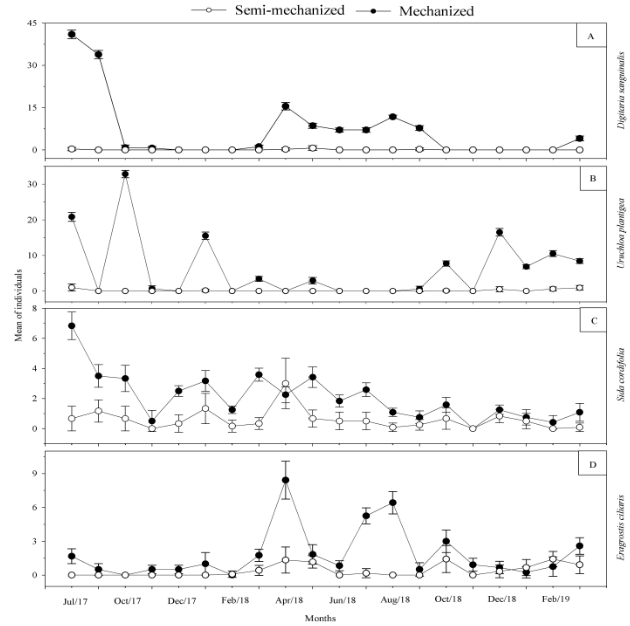

Fig. 5. Population dynamics of the species in the 20 months of monitoring in an agroforestry system at the Experimental Farm of UFOPA, municipality of Santarém, Pará state, Brazil

Table 1. Mean and distribution of species over the 20-month period

Taxon	MECBlock			SMECBlock		
	Median ± Standard Error	Fr (%)	Dr (%)	Median ± Standard Error	Fr (%)	Dr (%)
Borreriaverticillata L.	7.66 ± 0.18	18.85	25.35	2.11 ± 0.21	10.37	9.73
Clidemia hirta (L.) D.Don	0.17 ± 0.12	1.35	0.56	0.58 ± 0.17	4.20	2.72
Cyperus aggregatus (Willd.) Endl.	1.80 ± 0.26	4.69	4.00	0.50 ± 0.22	1.98	1.88
Cyperus esculentus L.	0.35 ± 0.43	0.81	0.67	0.06 ± 0.10	0.74	0.28
Cyperus sp.	0.63 ± 0.14	3.52	2.08	0.93 ± 0.18	5.56	5.13
Dalechampia scandens L.	0.48 ± 0.16	3.61	1.42	0.77 ± 0.12	9.38	3.48
Desmodium incanum (Sw.) DC.	0.93 ± 0.18	3.88	2.52	0.37 ± 0.20	2.59	1.24
Digitaria sanguinalis (L.) Scop.	6.97 ± 0.39	7.03	12.97	0.08 ± 0.15	0.49	0.36
Eragrostis ciliaris (L.) R. Br	1.87 ± 0.25	5.50	5.16	0.40 ± 0.19	2.22	1.99
*Hyptis atrorubens*Poit.	1.24 ± 0.36	2.89	2.15	0.07 ± 0.13	0.62	0.33
Ipomoea sp.	0.04 ± 0.08	0.63	0.09	0.17 ± 0.17	1.23	1.00
Mimosa pudica L.	0.75 ± 0.12	5.95	2.23	0.32 ± 0.11	3.70	1.85
Morphospecies 1	1.36 ± 0.26	3.07	3.03	0.01 ± 0.09	0.12	0.05
Morphospecies 2	0.79 ± 0.18	3.61	2.39	0.62 ± 0.33	1.85	3.39
Morphospecies 3	0.00 ± 0.06	0.09	0.01	0.02 ± 0.13	0.12	0.10
Morphospecies 4	0.18 ± 0.20	0.45	0.73	0.48 ± 0.19	2.10	1.19
Morphospecies 5	0.50 ± 0.46	0.27	0.56	0.03 ± 0.11	0.37	0.24
Morphospecies 6	0.02 ± 0.06	0.36	0.05	1.90 ± 0.35	5.06	6.30
Ocimum S	0.35 ± 0.16	2.07	0.87	0.14 ± 0.19	1.23	0.70
Oxalisdebilis Kunth	0.77 ± 0.30	1.08	2.03	0.02 ± 0.09	0.25	0.10
Panicum numidianum Lam.	2.49 ± 0.29	5.50	5.28	0.30 ± 0.17	2.10	1.51
Phyllanthusniruri L.	0.12 ± 0.15	0.90	0.35	0.10 ± 0.14	0.99	0.71
Rhynchospora nervosa (Vahl) Boeckeler	1.55 ± 0.23	4.78	4.35	0.19 ± 0.14	1.60	1.04
Sabiceaamazonensis Wernham	0.00 ± 0.00	0.00	0.00	7.24 ± 0.22	20.00	30.88
Scleriagaertneri Raddi	0.19 ± 0.14	1.08	0.73	4.56 ± 0.19	16.42	20.67
Sida cordifolia L.	2.08 ± 0.16	10.82	6.68	0.59 ± 0.23	3.70	2.54
Urochloaplantaginea (Link) R. D. Webster	6.34 ± 0.31	7.21	1.75	0.16 ± 0.17	0.99	0.59

Legend: MEC – mechanized block; SMEC – semi-mechanized block; Fr – relative frequency; Dr – relative density.

Table 2. Selection parameters chosenfor the SAS STEPDISC procedure for choosing the most important species

Nº	Species	R^2 Canonical	F-value	Pr > F	Wilks' λ	Pr<λ	Canonical Correlation	Pr> ASCC
1	*S.amazonensis*	0.24	154.70	<.0001	0.76	<.0001	0.24	<.0001
2	*S. gaertneri*	0.15	84.23	<.0001	0.64	<.0001	0.36	<.0001
3	*B. verticillata*	0.08	41.10	<.0001	0.59	<.0001	0.41	<.0001
4	*D. sanquinalis*	0.06	30.18	<.0001	0.56	<.0001	0.44	<.0001
5	*U. plantaginea*	0.04	21.63	<.0001	0.53	<.0001	0.47	<.0001
6	*E. ciliares*	0.01	6.02	0.01	0.52	<.0001	0.48	<.0001
7	*C. aggregatus.*	0.01	5.77	0.01	0.52	<.0001	0.48	<.0001
8	*S. cordifolia*	0.01	3.80	0.05	0.51	<.0001	0.49	<.0001
9	*P.numidianum*	0.00	2.22	0.14	0.51	<.0001	0.49	<.0001

Table 3. F and P values by species and treatment via repeated measure analysis

Species	Factor	F-value	P-value
BorrreriaVerticilata	Treatment	11.41	0.0062
	Block	0.27	0.98
	Time	2.49	0.0009
	Time*Treatment	0.68	0.83
	Time*Block	0.82	0.92
Cyperusaggregatus	Treatment	5.31	0.04
	Block	0.90	0.57
	Time	3.88	<.0001
	Time*Treatment	1.97	0.01
	Time*Block	1.38	0.01
Digitaria Sanguinalis	Treatment	34.41	0.0001
	Block	1.05	0.47
	Time	13.02	<.0001
	Time*Treatment	12.72	<.0001
	Time*Block	1.02	0.43
Eragrostis ciliares	Treatment	9.87	0.0094
	Block	0.70	0.72
	Time	2.55	0.0006
	Time*Treatment	1.86	0.02
	Time*Block	0.88	0.82
Scleriagaertneri Raddi	Treatment	39.64	<.0001
	Block	1.03	0.48
	Time	3.76	<.0001
	Time*Treatment	3.14	<.0001
	Time*Block	0.97	0.57
Morphospecies2	Treatment	26.51	0.0006
	Block	0.82	0.63
	Time	4.74	<.0001
	Time*Treatment	4.74	<.0001
	Time*Block	0.82	0.92
Panicum N	Treatment	15.91	0.0021
	Block	0.65	0.76
	Time	3.80	<.0001
	Time*Treatment	3.90	<.0001
	Time*Block	1.04	0.39
Sida cordifolia	Treatment	45.42	<.0001
	Block	1.94	0.14
	Time	2.35	0.0017
	Time*Treatment	1.44	0.11
	Time*Block	0.91	0.76
Uruchloaplantigea	Treatment	45.65	<.0001
	Block	1.03	0.48
	Time	14.23	<.0001
	Time*Treatment	13.31	<.0001
	Time*Block	0.99	0.53

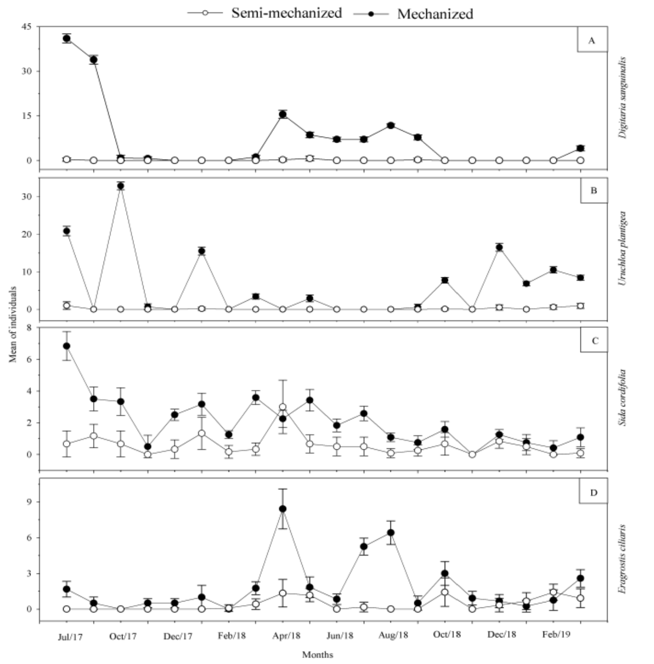

Fig. 5. Population dynamics of the species in the 20 months of monitoring in an agroforestry system at the Experimental Farm of UFOPA, municipality of Santarém, Pará state, Brazil

The low diversity at the beginning of the observations of theMEC regimewas associated with the soil tillage which occurred months before the start of monitoring. In this case, weeds and seed banks were displaced horizontally, about 10 to 15 cm below the soil surface (Pacheco *et al*., 2016). Of the twenty-seven species observed, nine were selected by the PROC STEPDISC step-by-step procedure as the best treatment discriminator (Table 2). By observing the density and frequency data it is noted that these species stood out for being more significant, as evidenced by the PROC STEPDISC procedure. For these species, the repeated measure analysis data allowed us to understand the dynamics of each selected species in relation to the impact generated by each treatment (Table 3). The values of F and by the p-value of table 3 indicate that the treatment factor was significant (pr<0.05) for the most important species in the area, thus demonstrating difference between treatments in relation to the influence on the species on the dynamics of the observed individuals.Among these species, the most affected by the SMEC system were *Digitaria s*. and *Uruchloa p*., which were either absent from treatment or showed very small populations (Fig. 5A and B). *Digitariasanguinalis*is most often encountered in areas that have been harrowed and plowed (Coelho *et al*., 2016), which explains its presence in the MEC regime. The genus Urochloa also has better development in these environments, and shows considerable competitiveness when living with other plants, which, according to Teixeira *et al*. (2017), causes growth losses and even production decline in some species. The species *Sidacordifolia*was also susceptible to the influence of the SMEC regimen, and presented higher number of individuals in MEC from the very beginning of the observations. The genus Sida is cited as having good representativeness in pasture areas, occurring, according to Ferreira *et al*. (2015), in high population levels in pasture areaswhere there is greater anthropic disturbance. *S. amazonenses* and *S. gaertneri* were the most scarce in the MEC system, andpresented few individuals or total absence (Fig.6A and B). The SMEC treatment provided a favorable environment for the establishment of these species, with a larger number of individuals, especially *S. amazonensis.* The species S. gaertneri infests pasture areas, but has a preference for more humid and shady environments (Silva *et al*., 2016). According to the same author, it is a spontaneous species that deserves attention when it appears in an area, due to its difficult control, which is related to its propagation characteristics, as it occurs both by seeds and by rhizome. *S. amazonensis*is described in the literature as occurring in disturbed areas, near shaded environments, such as clearings, forest edges and areas of regrowth, which are areas that are favorable habitats for the establishment of this species (Taylor *et al*., 2007). The occurrence of *B. verticillata*was observed in both control systems with greater presence of individuals of the species in the MEC system.This plant is reported to be quite aggressive and of great agricultural and livestock importance since it infests pastures and crop areas of perennial or agricultural species, and displays populations in the form of difficult-to-control and high density shoots (Silva *et al*., 2016).

CONCLUSION

The most important species, according to PROC STEPDISC, are D. sanguinalis and U. plantaginea for MEC and S. gaertneri and S. amazonensis for SMEC. Management regimes influenced weed dynamics, disfavoring some species and benefiting others. Privileged species may likely cause future problems for suppression and management due to the population increase offered by less competition between species. Finally, the adoption of different management regimes in agroforestry systems, implied the favoring of different species of weeds, indicating that a previous survey of the species occurring in the area, for later adoption of the control is necessary, aiming in this way the balance or eradication of weed populations.

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