

Full Length Research Paper

## Diversity of soil macrofauna under sugarcane monoculture and two different natural vegetation types

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Received 3 April, 2016; Accepted 8 June, 2016

Soil macrofauna organisms are recognized as ecological indicators of soil management practices. Sugarcane monoculture can have negative impacts on soil, including biodiversity loss, which should be evaluated. In that sense, the aim of this was to determine the diversity macrofauna under sugarcane (*Saccharum* spp.) annual growth cycle (2012-2013) comparing two different natural vegetation areas (Sandbank and Atlantic forest). The study areas are located at Usina Santa Teresa in Goiana municipality, in Zona Mata Norte of the Pernambuco State (Brazil). Soil macrofauna samples were collected in January, April and August 2013. In order to collect soil macrofauna samples, 5 pitfall traps were placed in the field for 7 days. Descriptive statistics and biodiversity indices were used to carry out data analysis. The presence and biodiversity indices were affected by the hydrological regime. Sugarcane harvest with straw burning initially promoted soil macrofauna taxa better adapted to system drastic changes. Moreover, as sugarcane growth year went by, soil macrofauna biodiversity indices similar to those reported at natural vegetation areas (Sandbank and Atlantic Forest) were observed.

**Key words:** Bioindicator, burnt sugarcane, functional groups, soil macrofauna.

### INTRODUCTION

Brazil is the largest producer of sugarcane in the world (Cerri et al., 2011). The main product of sugarcane is sucrose which is used as raw material in human food

industries or is fermented to produce ethanol (Mello et al., 2014; Siqueira et al., 2015). Despite its economic importance, the intensive cultivation and processing of

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sugar has negative environmental impacts. According to Rossetto et al. (2010), sugarcane monoculture leads to biodiversity loss and affects local and regional fauna and flora. Furthermore, soil tillage is traditionally with use of various agricultural machinery mainly made with disc plows, dish harrows and subsoilers (Portilho et al., 2011; Tavares et al., 2015; Surendran et al., 2016) that negatively affect soil aggregation and reduce biological activity (Benito et al., 2008). In addition to modifying soil physico-chemical characteristics, sugarcane cultivation also produces environmental chemical contamination and soil compaction (Iwai et al., 2008; Nurhidayati et al., 2012; Siqueira et al., 2013).

Soil is the habitat of different organisms that constantly interact and move thus influencing physic, chemical and biological properties of soil (Siqueira et al., 2014, Frouz et al., 2015). Soil macrofauna includes a great variety of edaphic organisms larger than 2 mm in size (Baretta, 2007; Bardgett and van der Putten, 2014) that contribute to soil homogenization, soil structure improvement (Siqueira et al., 2014) and therefore increase root penetration and air and water internal fluxes (Brussaard et al., 2007; Oliveira, 2008; Moura et al., 2015).

Edaphic macrofauna components include the following taxonomic groups: termites (*Isoptera*), woodlice (*Isopoda*), spiders (*Arachnida*), centipedes (*Chilopoda*), millipedes (*Diplopoda*), earthworms (*Oligochaeta*), slugs and snails (*Mollusca*), and ants (*Hymenoptera*) (Baretta, 2007; Bardgett and van der Putten, 2014). As those organisms have a large influence on soil physical, chemical and biological properties they are considered as "ecosystem engineers" (Lavelle et al., 2006; Kampichler and Bruckner, 2009; Garcia-Palacios et al., 2013). Some groups, like earthworms, have a key role in plant growth, nutrient cycling, productivity, soil properties improvement and clay transfer to soil surface (Baretta, 2007, Lubbers et al., 2013; Oliveira et al., 2014, Wagg et al., 2014). Furthermore, because of their strong interaction with soil, macrofauna communities are also profoundly affected by agricultural practices, such as land-use change, tillage or fertilizers. Since soil macrofauna is very sensitive to both chemical and physical soil parameters, it may be used as ecological indicators of agricultural practices (Merlim 2005; Siqueira et al., 2014). According to Schmidt et al. (2005), ants are good ecological indicators due to their vast abundance and species richness, large geographic distribution, sensitivity to environmental changes, ease to rear and perform morpho species identification (Siqueira et al., 2014; Cordeiro et al., 2004).

Soil macrofauna abundance depends on management practices, fertilization, liming, soil compaction, soil porosity, nutrient and minerals availability and osmotic pressure, among others (Baretta, 2007; Cividanes et al., 2009). Compacted soil becomes anaerobe, with reduced air and water circulation, being unsuitable for some

organisms (Siqueira et al., 2014). Thus agricultural practices that promote soil compaction lead to soil macrofauna decrease.

The study of soil macrofauna communities in each habitat fraction contributes to understanding the role of those organisms in the soil. Their response to soil management practices, environmental interactions or habitat changes occurs quickly (Correia and Oliveira, 2000). In that sense, their abundance, diversity and spatial variability allow the comprehension of their dynamics, the development of biodiversity indicators and therefore the adoption of agricultural practices in accordance with soil macrofauna ecological function.

Despite the essential role of soil macrofauna in soil management, only few studies relating to soil macrofauna and sugarcane culture have been conducted (Pasqualin et al., 2012; Benazzi et al., 2013). Thus, the present study aims to determine diversity of soil macrofauna under sugarcane (*Saccharum* spp.) annual growth cycle (2012-2013) and two different natural vegetation areas (Sandbank and Atlantic Forest).

## MATERIALS AND METHODS

### Study area

In the present study, soil macrofauna biodiversity was evaluated under different land uses: sugarcane monoculture (*Saccharum* spp.) and natural vegetations (Sandbank and Atlantic Forest). The study area is located in Usina Santa Teresa in Goiana municipality, in Zona Mata Norte of the Pernambuco State (Brazil) (Figure 1), whose geographic coordinates are 07°33'39"S and 35°00'10"W.

In this study, the area under sugarcane monoculture has 6.5 ha, a mean altitude of 8.5 m and has been cultivated with sugarcane for at least 24 years. The sugarcane management practices include burning of harvest residues. In 2010-2011, soil was ploughed and power harrowed, and sugarcane was replanted. Adjacent to the sugarcane area, there is the Sandbank area, with 260 ha, virtually unchanged due to its intrinsic characteristics. Most of the time, the water table is above the surface and during high tide periods, the Sandbank area is affected by saline waters. The Atlantic forest area belongs to a natural reserve in Usina Santa Teresa in Goiana, and in the present study 448 ha of it were used.

### Soil and climate characterization

The soils in the study area region is derived from "Barreiras group", comprising final tertiary sediments from continental origin and presenting sandy to clay texture (Brazil 1969,1972). In the lowland study areas, Spodosols (Soil Survey Staff 2010) with sugarcane plantations are found and in the Sandbank area, there are clay Gleysoils (Soil Survey Staff 2010). This lowland study area, located 10 km in land from the Atlantic Ocean, is representative of a regional lowland landscape whose soils are affected by seawater salinity and where sugarcane plantations are the main economic activity. On the other hand, in the upland study area (altitude above 55.7 m – Figure 1), cohesive Ultisols and Oxisol soils exist (Soil Survey Staff 2010). Specifically in the Atlantic forest area Oxisol soils are dominant, having a good structure and homogeneity along

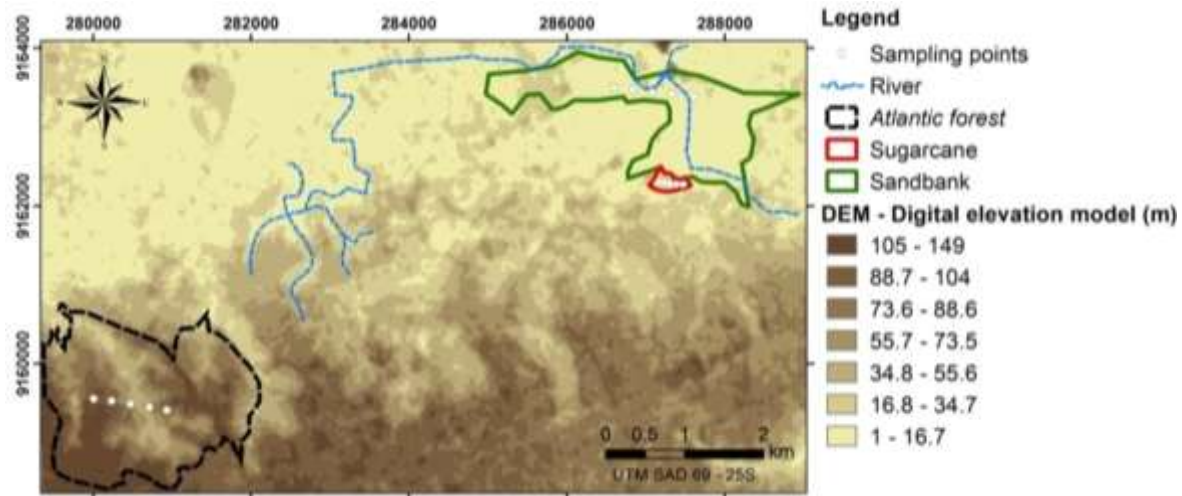


Figure 1. Geographic location of the study areas.

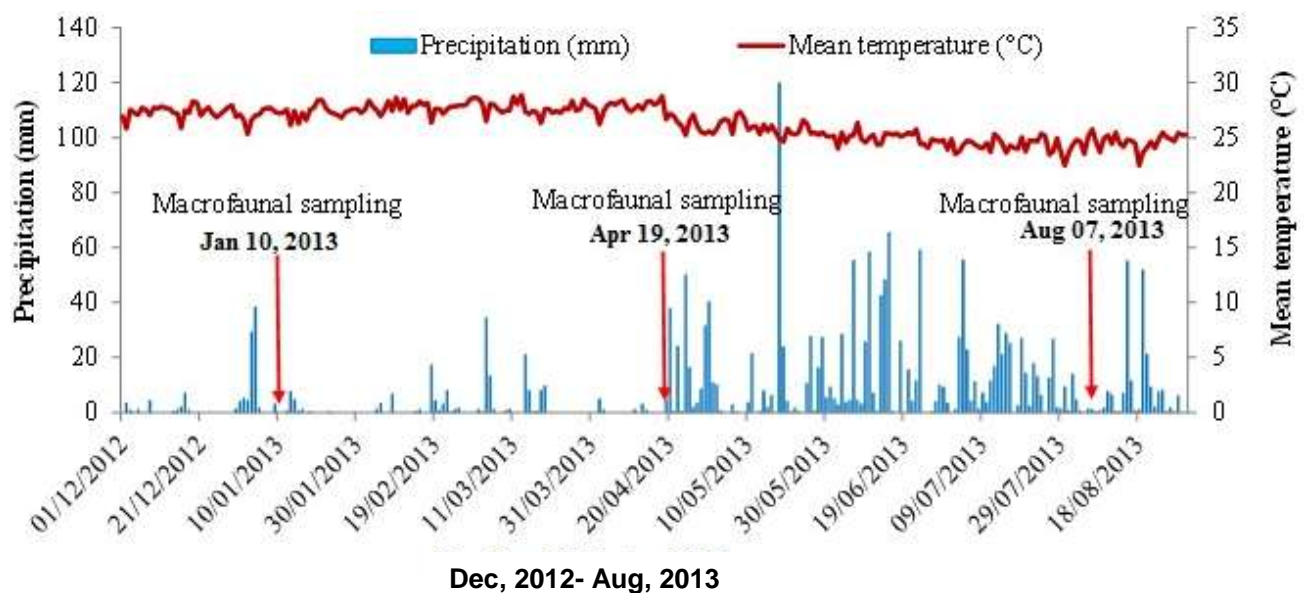


Figure 2. Rainfall and mean temperature during sugarcane growth year.

soil profile.

The climate in the study area region is pseudo tropical or humid tropical As type according to Koppen Climate Classification, with a rainy period during fall/winter and a mean annual temperature of 24°C (Figure 2).

#### Soil macrofauna sampling

Soil macrofauna sampling took place during the third sugarcane growth year (2012-2013) on the following dates: January 10, 2013; April 19, 2013 and August 07, 2013. At the same time, soil

macrofauna samples were collected in the natural vegetation areas.

In each area and sampling time, 5 pitfall traps were installed for 7 days in order to collect soil macrofauna samples (Siqueira et al., 2014). A pitfall trap is a plastic pot (9 cm high and 8 cm in diameter) placed at soil level and filled with 200 ml of 4% formolin to preserve collected individuals (Aquino et al., 2008; Siqueira et al., 2014). To reduce rain and surface flow damages, a plastic cover with a plastic dish was used and rails were made around the trap.

After 7 days, the traps were collected and voucher individuals were preserved in 70% alcohol. At the laboratory, individuals were identified with binocular lens into upper taxonomic levels (class/order/family) using taxonomic keys. After the individuals were

identified, they were stored and separated into functional groups.

### Data analysis

Initially, the data concerning soil macrofauna communities was analyzed using statistical descriptors to determine the main statistical moments to the total number of taxa in each area [number of taxa, minimum value, maximum value, mean, variance, standard deviation, coefficient of variation (%), skewness, kurtosis and Kolmogorov-Smirnov test ( $p < 0.05$ )].

Then, abundance (individuals trap<sup>-1</sup> day<sup>-1</sup>), Shannon index, total richness, mean richness and Pielou index were determined (Magurran, 2004).

Species abundance and diversity are expressed in biodiversity indices. Abundance refers to how common or rare a species is relative to other species in a defined location or community. Diversity takes into account both species richness (number of different species from the same community) and species evenness (individuals' distribution in each species) (Siqueira et al., 2014). Shannon index is represented in Equation 1:

$$H' = - \sum p_i \cdot \log p_i \quad (1)$$

Where  $p_i$  is the taxa  $i$  relative frequency.

Total richness (S) corresponds to the number of taxa present in the different land use areas. Mean richness is the mean number of taxa present in each land use. Pielou index indicates soil macrofauna community evenness and is calculated as follows (Equation 2):

$$U = \frac{H'}{\log 2S} \quad (2)$$

where  $H'$  is the Shannon index result and S is the total richness in every land use area. Pielou index varies between 0 (a taxonomic group is dominant) and 1 (relative abundance is similar between taxonomic groups).

Finally, in order to relate biodiversity parameters and to identify biodiversity patterns or dominant taxa, bar graphics were made.

## RESULTS AND DISCUSSION

Since sugarcane management practices included straw burning, a lower biodiversity was expected in that area (Pasqualin et al., 2012; Benazzi et al., 2013). Indeed, the sugarcane area presented the lowest number of taxa at every sampling time (Table 1). In turn, the Sandbank area presented the highest number of taxa (Table 1). That was also expected because this area is situated in the lowland (Figure 1) where water table is very close to the surface allowing the preservation of organic matter contents, thus contributing to epigenic soil fauna feeding. This fact was also reported by Leite-Rossi and Trivinho-Strixino (2012) at riverbanks areas in São Paulo state (Brazil). At the beginning of this study, the Atlantic forest area presented a number of taxa with values in between the other land use areas (Table 1).

The natural vegetation areas (Sandbank and Atlantic forest) presented the same number of taxa at the time of the second and third sampling (Table 1). Moreover, the taxa present in each land use area differed according to

the intrinsic characteristic of each area that result from differences in decomposition material, land cover type and macrofauna species dominance (Leite-Rossi and Trivinho-Strixino, 2012; Abbas et al., 2013).

The taxa richness at the sugarcane and the Atlantic forest areas increased over time (Table 1), probably reflecting a climatic impact on soil macrofauna. The Climograph drawn during the sugarcane growth season has confirmed that the first sampling took place during the dry season, a period of low rainfall (Figure 2). At the sugarcane area, the negative effect on taxa diversity was worse due to the recent crop harvest with burning of harvest residues (Portilho et al., 2011; Nurhidayati, 2012). Soil macrofauna communities at the Atlantic forest area, situated in the upland part of the study area, were more affected by climatic conditions than the Sandbank ones. In that area, soil organisms showed a seasonal behaviour with lower activity during the dry period (Menezes et al., 2009).

Table 2 represents statistical descriptors and measures of central tendency for the total abundance of individuals in different land use areas at every sampling time. Each time sampling took place, the data concerning soil macrofauna communities presented a lognormal distribution, according to Kolmogorov-Smirnov test, and great differences between skewness and kurtosis values (Table 2). The similar fitting of lognormal distribution observed at both the sugarcane area and the natural vegetation areas could indicate that sugarcane cultivation did not have a severe negative impact on the communities assessed in this study. At the time of the first sampling, the abundance of individuals was very low in the Sandbank area (Table 2). In the Atlantic forest and the sugarcane areas, greater data dispersion was observed (Table 2). This could be a sign of a lower biological stability in those areas (some taxa were favoured depending on the ecological context).

At the time of the last sampling, the number of individuals decreased in all land use area (Table 2). The highest values were recorded at the Sandbank area (Table 2). This could indicate a greater biological stability in that area. In turn, at the sugarcane and the Atlantic forest areas the soil macrofauna taxa, affected by the lack of rainfall, presented a quick development, possibly reflecting an ecosystem response to drought conditions attenuation (Souto et al., 2008; Siqueira et al., 2014) reported that soil macrofauna individuals able to survive during drought periods are better adapted to extrinsic environmental processes. Moreover, this disorderly increase in soil macrofauna individuals at the sugarcane and the Atlantic forest areas had perhaps promoted competition among trophic groups.

Considering the daily abundance of individuals per trap, the sugarcane and the Atlantic forest areas had a great number of individuals on the first sampling time, with

**Table 1.** Taxa richness of soil macrofauna communities in different land use areas at every sampling time.

Sampling time	Sugarcane	Sandbank	Atlantic Forest
Jan 10, 2013		Acari	
		Araneae	Araneae
	Acari	Coleoptera	Coleoptera
	Araneae	Diplura	Diplopoda
	Diplura	Entomobryomorpha	Diptera
	Entomobryomorpha	Formicidae	Entomobryomorpha
	Formicidae	Isoptera	Formicidae
	Isoptera	Poduromorpha	Isoptera
Number of taxa	6	12	8
		Sternorrhyncha	Orthoptera
		Symphyla	
		Thysanoptera	
		Anura	
Apr 19, 2013	Acari	Acari	Acari
	Araneae	Araneae	Araneae
	Coleoptera	Blattodea	Chilopoda
	Diplura	Coleoptera	Coleoptera
	Formicidae	Formicidae	Diplura
	Isoptera	Gastropoda	Formicidae
	Orthoptera	Isopoda	Heteroptera
	Poduromorpha	Isoptera	Isoptera
Number of taxa	9	11	11
		Orthoptera	Orthoptera
		Poduromorpha	Poduromorpha
		Thysanoptera	Anura
Aug 07, 2013	Araneae	Acari	Acari
	Coleoptera	Araneae	Araneae
	Diplopoda	Blattodea	Coleoptera
	Diptera	Chilopoda	Diplura
	Entomobryomorpha	Coleoptera	Diptera
	Formicidae	Dermaptera	Entomobryomorpha
	Hymenoptera	Diptera	Formicidae
	Orthoptera	Entomobryomorpha	Heteroptera
Number of taxa	8	12	12
		Formicidae	Isoptera
		Isopoda	Larva neuroptera
		Orthoptera	Orthoptera
		Poduromorpha	Thysanoptera

4.457 and 12.429 individuals, respectively (Table 3). This agrees with the greater mean standard deviation and variance recorded in Table 2. In those areas, soil macrofauna individuals reacted to drought conditions by long-distance travelling looking for feed, enhancing the probability of being captured by traps. At the Sandbank area, this could not have occurred due to permanent good feeding conditions.

At the time of the second sampling, daily abundance per trap was similar between all land uses. This could be related to the disorderly increase in soil macrofauna individuals less adapted to drought conditions in the sugarcane and the Atlantic forest areas (Souto et al.,

2008), as previously discussed. On the last sampling day, the Sandbank area presented the highest daily number of individuals per trap (10.914), probably reflecting better ecological stability during the rainy season. In this area, soil macrofauna individuals were well adapted to the usual water table fluctuations and to stable feed availability.

Shannon index indicates species abundance distribution, highlighting less common species (Magurran, 2004). The lower the value of this Shannon index, the higher dominance can one particular species have on the study community (Magurran, 2004). The lower value at the sugarcane (1.641) and the Atlantic forest (1.582)

**Table 2.** Statistical descriptors of the total abundance of individuals in different land use areas at every sampling time.

	Jan 10, 2013			Apr 19, 2013			Aug 07, 2013		
	Sugarcane	Sandbank	Atlantic forest	Sugarcane	Sandbank	Atlantic forest	Sugarcane	Sandbank	Atlantic forest
Minimum	1	1	3	3	3	3	1	2	1
Maximum	87	11	193	185	214	355	10	297	99
Mean	26.167	3.917	55.250	54.778	46.818	55.182	4.875	31.833	24.500
Variance	1116.567	15.356	6930.214	3933.694	5025.164	11012.164	11.554	7005.788	1023.545
Standard deviation	33.415	3.919	83.248	62.719	70.888	104.939	3.399	83.701	31.993
Coefficient of variation	127.701	100.051	150.675	114.497	151.412	190.169	69.724	262.934	130.583
Skew	1.546	1.162	1.305	1.292	1.844	2.768	0.87	3.436	1.567
Kurtosis	1.957	-0.222	-0.229	0.976	2.535	8.121	-0.567	11.855	1.731
Kolmogorov-Smirnov test	0.275Ln	0.271Ln	0.356Ln	0.247Ln	0.288Ln	0.329Ln	0.235Ln	0.468Ln	0.231Ln

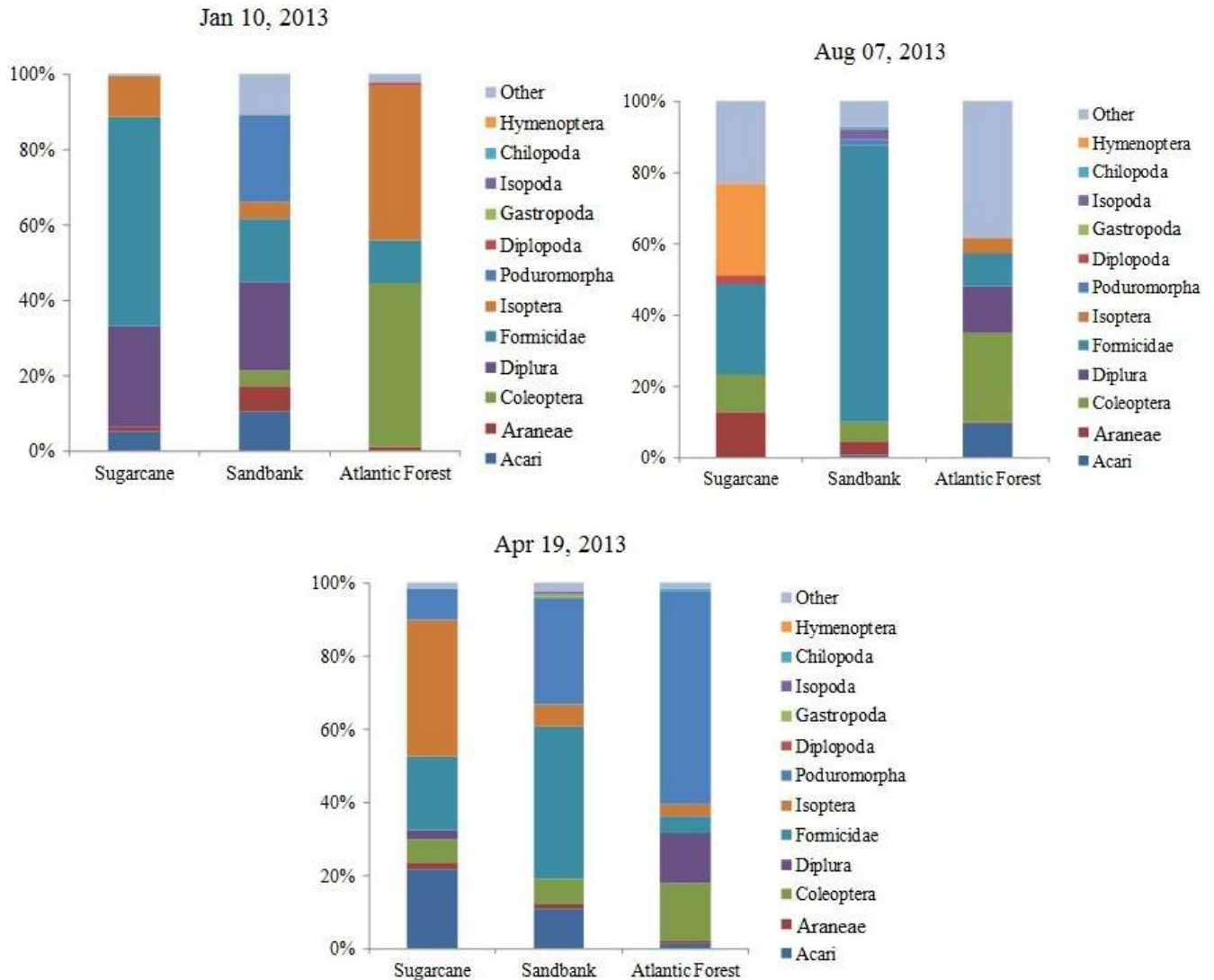
**Table 3.** Daily abundance, taxa richness and biodiversity indices of soil macrofauna communities in different land use areas at every sampling time.

Sampling time	Land use	Individuals.trap <sup>-1</sup> .day <sup>-1</sup>	Standard deviation	Shannon	Total richness	Mean richness	Pielou
Jan 10, 2013	Sugarcane	4.457	2.071	1.641	6	2.4	0.635
	Sandbank	1.343	1.883	2.991	12	3.0	0.834
	Atlantic Forest	12.429	6.999	1.582	8	4.4	0.527
Apr 19, 2013	Sugarcane	14.714	4.898	2.514	11	5.20	0.727
	Sandbank	14.429	8.321	2.148	11	5.00	0.621
	Atlantic Forest	17.114	7.403	1.832	11	6.00	0.530
Aug 07, 2013	Sugarcane	1.114	0.566	2.744	8	3.8	0.915
	Sandbank	10.914	6.304	1.453	12	8.2	0.405
	Atlantic Forest	8.400	10.954	2.581	12	5.2	0.720

areas on the first sampling time (dry season) confirms the dominance of a few numbers of taxa, better adapted to drought conditions (Table 3). At

the Sandbank area (2.991), a great contribution and interconnection between present taxa could have taken place, not highlighting any dominant

taxa. On the last sampling time, the opposite pattern occurred, revealing a great evenness in taxa abundances at the sugarcane (2.744) and



**Figure 3.** Proportional specimen distribution among taxa in different land use areas at every sampling time.

the Atlantic forest (2.581) areas (Table 3).

Pielou's index is constrained between 0 and 1 with the larger index value indicating a more even community (Magurán, 2004). As for Shannon index, its values were lower in the sugarcane (0.635) and the Atlantic forest (0.527) areas at the first sampling time (dry season), but the opposite occurred at the time of the last sampling (Table 3).

In fact, the sugarcane area presented the highest values of biodiversity indices at the end of this study. This result suggests that at the beginning of the sugarcane growth year, soil macrofauna communities undergo an initial selection and only individuals better adapted to sugarcane management practices and climatic conditions persist (Portilho et al., 2011; Moura et al., 2015).

Regarding proportional specimen distribution it's evident that, initially, no dominant taxa existed in the Sandbank area (Figure 3). In turn, Formicidae (55%), general predators of less frequent taxa, were dominant in the sugarcane area. Ants play important functions in maintaining soil health (Del Toro et al., 2012; Ribeiro et al., 2016). And it has been used as soil quality bioindicators in areas with anthropogenic interference and in this situation they could act as less frequent taxa predators (Andersen and Majer, 2004; Schmidt et al., 2005). Similar results were also reported by Pasqualin et al. (2012) at sugarcane areas under different crop management practices. Coleoptera (43%) and Isoptera (41%) were dominant in the Atlantic forest areas; the flying individuals can travel over longer distances looking

for feed.

On the second sampling time, Isoptera (37%) were dominant at the sugarcane area; soil cover with plant residues promoted organic matter decomposers. Formicidae were dominant at the Sandbank area (42%). Poduromorpha were dominant at the Atlantic forest area (58%). These last taxa have a key role in organic matter decomposition and are an excellent soil quality indicator (Rovedder et al., 2009). The abundance of this order rose in the Atlantic forest area with the improvement in hydrological conditions.

Finally, at the end of the study, individuals were more evenly distributed among taxa in the sugarcane area (Figure 3) corroborating the biodiversity indices values (Table 3). Even so, the predators (Formicidae - 26% and Aranae - 13%) had great abundances, probably revealing that ecological equilibrium had been achieved under the intensive cultivation of sugarcane. In the Sandbank area, Formicidae were dominant (78%), probably reflecting the great feed availability in that area, and not an ecological adaptation as described by Schmidt et al. (2005). These results agree with the lowest observed values of Shannon and Pielou indices (Table 3).

## Conclusions

Soil macrofauna communities under different land uses were affected by the hydrological regime in the study area. Sugarcane cultivation with straw burning initially promoted those taxa better adapted to drastic changes in the system (such as *Formicidae*). Moreover, as the sugarcane growth year went by, a biological equilibrium as compared to that of the natural vegetation areas was achieved. Biodiversity indices showed that every land use presented dominant patterns with different relevance degrees to the ecosystem. The biodiversity increase at the sugarcane area during its growth year has allowed the description of a food chain setting: *Formicidae* dominance at the beginning, followed by predators emergence, until finally an evenly distributed community was reached.

## Conflict of Interests

The authors have not declared any conflict of interests.

## ACKNOWLEDGEMENTS

The authors thank Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) and Fundação de Amparo a Pesquisa do Estado de Pernambuco – Brazil (FACEPE) by a DCR-Desenvolvimento Científico Regional grant awarded to

the first author. They also thank Fundação de Amparo à Pesquisa e ao Desenvolvimento Científico e Tecnológico do Maranhão - Brazil (FAPEMA), for funding the publication of this paper (APCINTER 192415/2014, BATI 25407/2015 and BEPP 01301/15).

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