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Assessing a ReviTec Measure to Combat Soil Degradation by studying Acari and Collembola from Ngaoundéré, Adamawa, Cameroon

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Abstract

Acari and Collembola from a high Guinean savanna and an experimental ReviTec site were studied to assess the efficiency of compost and biochar amendments for the rehabilitation of degraded soil. The research sites are located in Dang (Ngaoundéré, Adamawa, Cameroon), which is subject to four months of dry season. Our study contributes to the suitability of microarthropods as bioindicators of a rehabilitation measure and to the general knowledge of soil mesofauna in dry sub-Sahara Africa savanna. Abundances of soil Acari and Collembola were assessed in four sampling campaigns during the rainy season (May, June, July, August 2017; 0–20 cm depth). Results from explorative sampling campaigns in the same months of 2016 are included to assess year-to-year development (0–10 cm depth). Soil water content, pH, N, C and soil temperature were monitored. Controls were savanna (adjacent to the experimental site) and ReviTec control (part of the experimental site). To assess the effect of compost and biochar soil amendments, we investigated compost + mycorrhiza (cpmy) and compost + biochar + bokashi (cpbcbo). We identified Acari groups (Gamasina, Uropodina, Prostigmata, Oribatida, Astigmata) and Collembola, extracted with a Tullgren-type apparatus. In the savanna, abundances of up to 23 tsd. Acari and 6 tsd. Collembola per m^2 were recorded. The corresponding findings for the compost-amended substrates of the ReviTec site are 228 tsd. Acari and 37 tsd. Collembola per m^2 (2017, means of five cores). The abundances increased gradually with the duration of the rainy season and reached their maximum in July/August. Abundances were higher at depths of 0–10 cm than at 10–20 cm, except in May. Abundances in May likely reflect the previous dry season, when animals seem to survive in deeper soil layers. Significantly higher abundances were recorded in the ReviTec substrates than in the control soils. The development of microarthropods indicates effective rehabilitation of ecosystem services of degraded soil after application of ReviTec.

Keywords Acari | Collembola | Cameroon | soil degradation | rehabilitation | biochar | bioindication | ReviTec

1. Introduction

Soil degradation is increasingly jeopardising the functionality of our life support systems, particularly in dry regions (UNCCD 1994, Barthlott et al. 2009). Various rehabilitation measures have been developed to counteract this threat. From an ecological perspective, they aim to accelerate secondary succession in order to achieve the rehabilitation of ecosystem services as a prerequisite for sustainable pastoralism, agriculture

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and forestry (UNCBD Guidelines, 2004, Millennium Ecosystem Assessment 2005, Prach & Walker 2011). The success of such attempts is mainly quantified by the direct measurement of vegetation development and by values derived from these measurements.

To rehabilitate degraded soil, amendments are used to improve soil physical, chemical and biological conditions. Compost and biochar have become prominent for this purpose (Glaser et al. 2004, Lehmann & Joseph 2015, Mensah & Frimpong 2018, Siedt et al. 2021, Schnee et al. 2021).

Highly abundant and diverse soil biota, with their complex interactions, contribute to various soil ecosystem services, e.g., by the alteration of soil structure, feeding activities and rate regulation in nutrient cycling (Whitford & Parker 1989, Begum et al. 2014, Sharma & Paewez 2017).

Acari and Collembola are the most prominent groups of soil microarthropods worldwide, exhibiting high abundance and biodiversity. Koehler (1984) found abundances of up to 189 and 80 thousand individuals per square meter (tsd. ind./m^2) for Acari and Collembola respectively in grassland sites in Bremen (Northern Germany). These values are in the upper range of those reviewed by Petersen & Luxton (1982). Acari and Collembola contribute to numerous ecosystem processes, though they are not involved in pore creation like earthworms, ants and termites. Predator-prey relationship of Gamasina and other Acari preying on Collembola and nematodes (Karg 1993, Schneider & Maraun 2009) contribute to the regulation of a related processes. Although an important component of soil biota, microarthropods are neglected in investigations of soil degradation and rehabilitation; however, there is ample evidence that soil microarthropods may give important information in this context (Koehler 2000, Koehler & Müller 2003, Parisi et al. 2005, Menta & Remelli 2020, Sanchez et al. 2021).

Abundance, diversity and community structure of soil microarthropods are influenced by quality and diversity of habitat, vegetation, availability and quality of organic matter, microclimate and land use history (e.g., Parisi et

Table 1. Microarthropod abundances recorded in various African forests and savannas (tsd. = thousand individuals, Total Acari in brackets are partial total for Gamasina + Oribatida)

Authors	Site location	Microarthropod groups					
		Oribatida	Gamasina	Prostigmata	Astigmata	Total Acari	Collembola
Block 1970	Bush	9.6 tsd./m^2	3.8 tsd./m^2	0.4 tsd./m^2	0.4 tsd./m^2	14.4 tsd./m^2	2.2 tsd./m^2
	Swamp forest	7.4 tsd./m^2	4.0 tsd./m^2	0.4 tsd./m^2	0.2 tsd./m^2	12.2 tsd./m^2	3.4 tsd./m^2
	Elephant grass	6.1 tsd./m^2	3.4 tsd./m^2	0.6 tsd./m^2	2.7 tsd./m^2	12.9 tsd./m^2	1.6 tsd./m^2
	Banana plantation	3.5 tsd./m^2	2.9 tsd./m^2	0.2 tsd./m^2	0.2 tsd./m^2	6.8 tsd./m^2	1.8 tsd./m^2
	Cofee plantation	4.9 tsd./m^2	3.1 tsd./m^2	0.3 tsd./m^2	7.7 tsd./m^2	16.1 tsd./m^2	2.1 tsd./m^2
	Pasture	2.6 tsd./m^2	0.9 tsd./m^2	0.4 tsd./m^2	0.0 tsd./m^2	4.0 tsd./m^2	0.5 tsd./m^2
	Arable soil	2.1 tsd./m^2	1.1 tsd./m^2	0.0 tsd./m^2	2.0 tsd./m^2	5.2 tsd./m^2	0.3 tsd./m^2
Mosadoluwa et al. 2000	Omo Biosphere reserve, Southwestern Nigeria	-	12.9 tsd./m^2	-	-	-	-
Gbarakoro et al. 2010	Secondary rainforest, River State, Nigeria	3.1 tsd./m^3	1.3 tsd./m^3	-	-	(4.4) tsd./m^3	-
N'Dri & Andre 2011	Lamto savanna (Ivory Coast)	4.5 tsd./m^2	14.3 tsd./m^2	-	-	(18.8) tsd./m^2	-
	Oume primary forest (Ivory coast)	15.7 tsd./m^2	16.5 tsd./m^2	-	-	(32.2) tsd./m^2	-
	Oume teak plantation (Ivory coast)	4.0 tsd./m^2	4.0 tsd./m^2	-	-	(8.0) tsd./m^2	-
	Tai primary forest (Ivory coast)	4.3 tsd./m^2	2.1 tsd./m^2			(6.4) tsd./m^2	

al. 2005, Callaham et al. 2008, Mohamedova & Lecheva 2013, Begum et al. 2014, N'Dri et al. 2016, Uthappa & Devakumar 2021, Wale & Yesuf 2021). Consequently, changes in these factors, including pollution and climate change, are reflected in soil microarthropod community parameters (Koehler 1992, 1994, 1996, George et al. 2017, Daghighi et al. 2017, Vladimirova et al. 2021, van Eekeren et al. 2021), qualifying them as bioindicators of the efficiency of rehabilitation measures and soil quality (Lehmann et al. 2011, Eo et al. 2012, Gopakumar & Joseph 2017, Manu et al. 2021, Todria et al 2021). Development of soil microarthropod communities is asynchronous and much slower than that of vegetation and aboveground biota, integrating effects over longer periods of time (Dunger 1975, Koehler & Müller 2003, Koehler & Melecis 2010). Even though it is generally accepted that soil microarthropods are important in assessing the state of soil ecosystems, the respective protocols and information are not well structured (Bünemann et al. 2018). Our research contributes to fill some respective gaps of knowledge for dry savanna.

There are few studies on the abundance, diversity and ecological roles of microarthropods in African soils (e.g., Block 1970, Lavelle 1983, Scholes & Walker 1993, Mosadoluwa & Buny 2000, Iloba & Odon 2006, Iloba & Ekrakene 2008, Gbarakoro et al. 2010, N'Dri & André 2011, Okiwelu et al. 2012, N'Dri et al. 2016, Mohammed et al. 2017, Wale & Yesuf 2021). Maximum abundances of Acari (Oribatida, Gamasina) and Collembola given in some of these publications are summarized in Tab. 1.

Despite not considering Prostigmata and Astigmata, the highest abundances for mites were reported from Oume primary forest with 32.2 tsd. Acari/m^2. The few data available for Collembola indicate very low abundances, probably due to drought susceptibility.

As reported previously, we found with our first-generation extractors of low efficiency, low abundances of Acari (1.7 tsd. ind./m^2) and Collembola (0.6 tsd. ind./m^2) in Adamawa soil (close to Ngaoundéré) and Far North soil (near Maroua), where abundances of 1.3 tsd. Acari and 0.5 tsd. ind./m^2 Collembola were documented. Even in the extended dry season (Ngaoundéré 4 months, Maroua 8 months) microarthropods were present (Danra 2014, Djoussi 2015, Ermilov & Koehler 2017, Danra et al. 2018). The improved third-generation extractors yielded the high abundances of this report, confirming the importance of an efficient extraction method.

The results displayed in Tab. 1 are part of assessing the efficiency of ReviTec in dry Cameroonian environments. ReviTec is an ecological rehabilitation approach developed by the Bremen-based partnership KeKo - Kesel, Koehler & Associates, Biologists, in co-operation with the Centre for Environmental Research and Technology (UFT) of the University of Bremen (Koehler et al. 2006, for more details see Danra et al. 2018). In Cameroon, four ReviTec sites were established for demonstration, teaching and research purposes in 2012/14: one on the premises of the University of Ngaoundéré (Adamawa region, high Guinean savanna) and three near Maroua (Far North; East Sudanian savanna) (Kesel 2012 unpublished report, Koehler et al. 2013). In this study, we evaluate findings from the Ngaoundéré ReviTec site and adjacent savanna.

A previous study (Danra et al. 2018) focused on the group of predatory soil mites (Acari, Gamasina) from samples taken in 2016. In this study, abundances and species diversity indicated that the rehabilitation measures effectively initiated and accelerated ecological succession, thus reflecting the efficiency of various soil amendments. The study of Danra et al. 2018 also highlighted the need of taxonomic expertise for the largely undescribed Gamasina species of the Adamawa savanna. In the present study, the samples from 2016 are evaluated for further microarthropod groups and those from the more extensive sampling campaigns in 2017 are presented.

With the findings on Acari groups and Collembola from this study, we contribute to the knowledge of soil microarthropods in high Guinean savannas and assess their potential to test the efficiency of a ReviTec rehabilitation measure. First, we provide baseline and reference data (controls); then, the effect of two ReviTec compost substrates is assessed, one with biochar amendment. We hypothesize that:

1. there are generally low abundances of Acari and Collembola in the savanna soil (control sav). Drought and the lack of a litter layer do not provide good living conditions for soil microarthropods.
2. abundances of Acari and Collembola are lower in dry season than in the rainy season. Vertical distribution is expected to change from a preference for deeper soil layers in the dry season to a more even distribution over the soil profile in rainy season. Microarthropods prefer a humid and cool habitat, which is why we expect them in the deeper soil layer in the dry season.
3. the two soil amendments tested on the ReviTec site will positively affect abundance of soil microarthropods, reflecting the improvement of the habitat quality for soil microarthropods.
4. potentially positive effects of biochar amendment are also long-lasting. Thus, the microarthropod abundances in the treatments with biochar (cpbcbo) are expected to be higher than those with compost alone (cpmy).
5. group-level assessment is suitable for the judgement of rehabilitation success.

2. Material and methods

The 2016 samples were previously evaluated on the species level for Gamasina in Danra et al. (2018). In the present paper, further microarthropod groups are evaluated, as well as additional samples from 2017. Below is a summary of the materials and methods detailed in Danra et al. (2018).

2.1 The study sites

The investigation was carried out on the ReviTec site of the University of Ngaoundéré at Dang, Adamawa region, Cameroon (7°25‘21”N, 13°32‘23“E) and on the adjacent high Guinean grassy shrub and tree savanna, affected by grazing and anthropogenic bushfire. The litter layer is almost non-existent in the dry season (Tchotsoua & Gonne 2010). The weather data for the two sampling years 2016/17 were provided by Ngaoundéré airport meteorological station, 7.5 km from the sites at similar elevation (Fig. 1).

2.2 The ReviTec site of Ngaoundéré

Field installation

An experimental ReviTec site was installed before the start of the rainy season in April 2012 on a 50×50 m^2 area by sod removal through grading and loamy sand application (approx. 30 cm layer; experimental degradation). Biodegradable bags were filled with 30 L of seven substrate mixtures; local seed was added. As a rehabilitation measure, the bags were arranged in groups (islands) of 2 x 2 bags per treatment in a Latin square design in part of the area, including controls, with five replicates per treatment (Fig. 2). The site was fenced as protection against cattle and vandalism.

The treatments selected to test the functionality of compost and biochar amendments with the study of soil microarthropods were compost-mycorrhiza (VAM; cpmy) and compost-biochar-bokashi (cpbcbo; Tab. 2). There were two controls: the savanna control (sav) and the ReviTec control (ctrl1, Fig. 2).

Compost from cow dung was prepared in an aerobic process by Prof. Ngakou, Ngaoundéré, who also provided the vesicular-arbuscular mycorrhizal fungi (VAM), *Glomus* sp. for the cpmy substrate. Since we could not observe an effect of the VAM on vegetation development and as ectomycorrhizal hyphae represent the bulk of below-ground fungal biomass (Brabcová et al. 2016), we assumed that the inoculation with VAM had no effect on microarthropods. The cpmy treatment represents compost amendment. The fermentation of the bokashi with effective microorganisms provided by Utamtsi-GIC Sondason (Fondjomekwet) was short (five days). Therefore, we do not assume it to be different from compost. The biochar

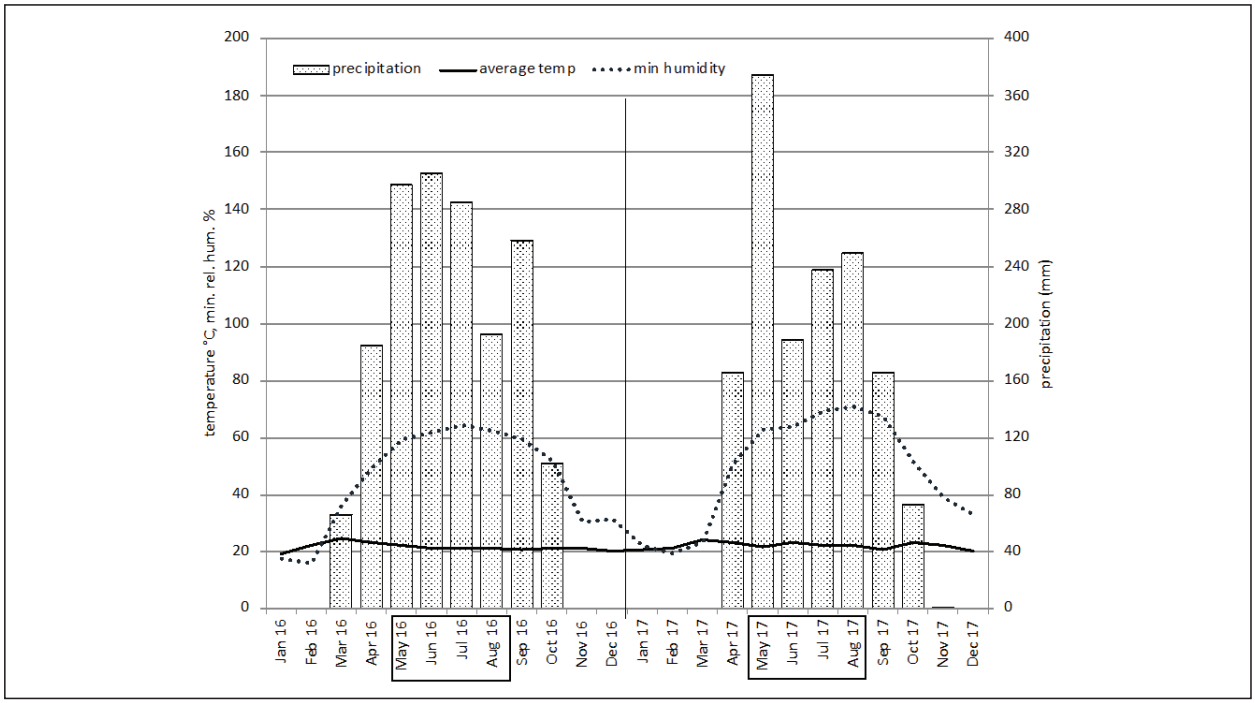

Figure 1. Weather data from Ngaoundéré airport, Jan. 2016 to Dec. 2017, 1105 m ASL. Total precipitation: 2016 = 1691 mm, 2017 = 1455 mm; temperature: mean/min/max 2016 = 22/19/25°C, 2017 = 22/21/24°C; min rel. hum: mean/min/max 2016 = 45/16/64%, 2017 = 48/20/71%. Months of sampling are enframed.

Table 2. Selected ReviTec treatments (ctrl = control, cp = compost, bc = biochar, my = mycorrhiza, bo = bokashi, inoc = inoculated). Percentages of substrates are by volume (v/v).

Plots	Code	Seed	Bag	Substrate				
				Loamy sand	compost cp (%)	Biochar bc (%)	Bokashi bo (%)	Mycorrhiza my
Savanna	sav							
Control	ctrl1							
Compost + mycorrhiza	cpmy	#	#	70	30			inoc
Compost + (Biochar+ Bokashi)	cpbcbo	#	#	70	10	10	10	

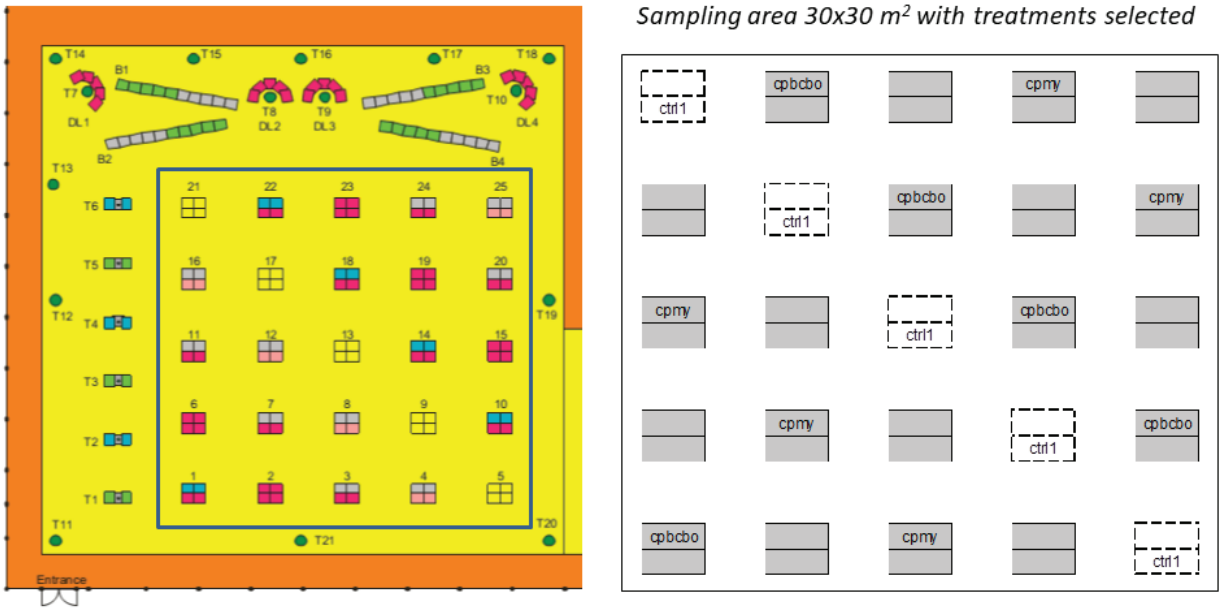

Figure 2. Left: the whole ReviTec site with various structures composed of bags. Treatments are indicated by colours, controls are arranged in central diagonal. Right: Sampling design for microarthropods from cpmy (compost-mycorrhiza), cpbcbo (compost-biochar-bokashi) and two controls (ctrl1 and sav [savanna outside the site not shown]). Samples were taken in 2016 (n = 2) and 2017 (n = 5); sampling dates see Fig. 1.

was provided by GIZ from (project SFID, Mbang) and crushed manually. We tested the bokashi-biochar mixture as used by Utamtsi in coffee and vegetable plantations, which represents a compost-biochar amendment.

2.3 Sampling

In both years, 2016/17, four sampling campaigns were carried out at thirty day intervals over the rainy season, from May to August. Due to limited extraction capacity of the second generation extractor, only two replicates per treatment could be processed in 2016 (n = 2 per depth per date; 0–5 cm and 5–10 cm depth). For the 2017 sampling campaign, the corer and extractor were optimized (third generation extractor). With an extraction capacity of 40 soil cores in one batch it was possible to sample soil cores to a depth of 20 cm (divided into 0–10 and 10–20 cm) and process 5 replicates per treatment (Tab. 3).

The findings from sav are intended to give baseline data for high Guinean savanna. By comparing sav with ctrl1 we assess the effect of artificial degradation caused by preparing the ReviTec site. Comparisons of treatments with ctrl1 allow a judgement of the effect of the respective ReviTec substrates.

2.4 Soil parameters

To estimate water content (WC%) in each soil sample for each sampling campaign, the fresh mass (FM) was obtained by weighing before microarthropod extraction and the dry mass (DM) by weighing directly after extraction (7 days, reaching 60°C at the end of the extraction period). The gravimetric water content is given by the following expression:

WC % =100 × WC (g)/ DM (g)

where WC (g)= FM-DM.

The pH of each soil sample at each sampling campaign was measured with a digital compact pH meter (WTW GmbH, 3310 IDS).

A digital insertion thermometer (Renkforce, -50 to +300°C) was used to measure soil temperatures in the field in each plot at each sampling date. The thermometer was inserted into the soil to a depth of 10 cm.

For the analysis of total C and N, we took five samples from each of the four plots in September 2017, from 0-10 cm soil depth. Air-dried soil samples (20–30 mg) were weighed into tin capsules and analysed by gas chromatography for C and N content using a Euro Analyzer coupled to a thermal conductivity detector (TCD). Samples were combusted for complete oxidation at > 1000°C. NOx were reduced to N_2 at 600°C and N_2 and CO_2 were quantified in the TCD. The analyses were done in the laboratory of Prof. Diekmann, University of Bremen.

2.5 Microarthropod extraction and identification

In a dynamic extraction process, the soil microarthropods were expelled from the broken-up soil cores in a heat and desiccation gradient. After two precursors, the first author developed the third-generation model with proven high efficiency, using the well-established Bremen apparatus as a blueprint. The extraction regime applied was also adapted from the Bremen experience (Koehler 1999). Starting with a humid phase and a temperature slightly above ambient, the final temperature of approx. 60°C at the upper side of the soil core was reached after 7 days. Heating was regulated by dimming the electric bulbs (40 W) placed above each soil core. The downward facing side of the soil core was cooled by ambient air. Specimens were collected in glass tubes filled with 95 % ethanol; 75 % proved to be unsuitable because high evaporation causes the ethanol to lose its preservation features. The specimen were sorted and counted with a stereoscope (ZEISS, mostly 10 x 25) at group level, after being identified mainly according to Dindal (1990).

2.6 Data analysis

The abundance of soil microarthropods was calculated by using the formula:

ind./m² = n × factor

Where:

- n is the numbers of individuals counted from a sample.
- factor is the scaling factor to calculate individual numbers per m^2. The surface area of the soil cores in 2016 and 2017 was 78.5 cm^2 and 18.3 cm^2, respectively, resulting in factors of 127 and 353 (Tab. 3).

The total microarthropod abundance in the entire soil core (0–20 cm) was calculated by adding the abundances from depth 1 and depth 2 (Tab. 3). Because the multiplication with the factor depends on the area of the corer, we prefer to present abundances as individuals in thousands per m^2 (tsd. ind./m^2).

The dominance D % gives the percentage of the population represented by a specific group in relation to all microarthropods found (also referred to as relative abundance).

We ran the statistics with ind./m^2 and did not apply any transformations. Significances were tested with Kruskal-Wallis tests and subsequent Mann-Whitney U-tests for pairs ($p < 0.05$; for 2017 only [n = 5] due to insufficient sample size in 2016 [n = 2]). Linear Pearson correlations were calculated with Excel for data from 2016 and 2017 with the abundances recorded at 0–10 cm soil depth.

3. Results

3.1 Response of soil parameters to the soil amendments

The soil temperature measured in 2017 ranged from 20.6°C to 24.6°C. The highest values were recorded in the savanna (sav), followed by ReviTec control (ctrl1) and the compost treatments (Tab. 4). The soil temperatures decreased from May to August by 2.0°C (cpbcbo) and 3.4°C (sav). Compared to Ngaoundéré airport weather records (Fig. 1), soil temperatures on sav and ReviTec site were higher in May (sav also in June) and lower from June to August. Particularly at the beginning of the rainy season (May/June), the temperatures of compost plots were 1.6 to 2.6°C below that of savanna.

With a mean of 18.3 %, gravimetric water content (0-10 cm) was generally higher in 2016 than in 2017 (15.9 %), reflecting the higher average precipitation (Fig. 1; Tab. 4). Over the four sampling months in 2016, water content was highest in savanna (sav 25 %), whereas in the compost amended treatments and the ReviTec control (ctrl1) water content was 8 to 9.6 % lower. In respect to the sampling campaigns, the highest water content was recorded in sav in May, reflecting the early start of rainy season.

In 2017, mean water content was highest in the compost treatments (21–24 %), whereas in ctrl1 and sav values on the order of 10 % were measured. In both of these plots, water content did not exceed 12 %. The highest water content was recorded in the cp treatments in June,

Table 3. Sample tools, sample dimensions, sampling depth and number of samples per plot.

date	**corer**		**soil cores**				**n**	**n per treatment**				**total**
year	diameter (cm)	area (cm^2) of soil cylinder	factor to calculate ind./m^2	depth1 (cm)	depth2 (cm)	volume (cm^3) per depth	per depth	sav	ctrl1	cpmy	cpbcbo	per depth
2016	10	78.5	127	0–5	5–10	392.5	2	2	2	2	2	64
2017	6	28.3	353	0–10	10–20	283.0	5	5	5	5	5	160

Table 4. Gravimetric soil water content, pH and temperature (°C) recorded in savanna and ReviTec site.

ttt	**month**	**depth**	**2016**		**2017**		
			WC%	pH	T°C	WC%	pH
sav	May	0–10	26.5	5.4	24.6	7.7	4.4
	May	10–20				7.7	4.9
ctrl1	May	0–10	17.5	5.3	24.0	7.8	5.1
	May	10–20				14.4	5.3
cpmy	May	0–10	20.9	5.8	23.2	14.8	5.0
	May	10–20				23.6	5.0
cpbcbo	May	0–10	21.1	6.0	23.0	13.2	5.6
	May	10–20				19.1	5.4
sav	Jun	0–10	24.5	5.9	24.6	7.7	4.4
	Jun	10–20				7.7	4.9
ctrl1	Jun	0–10	13.8	5.3	22.2	12.3	5.3
	Jun	10–20				19.4	5.1
cpmy	Jun	0–10	11.8	5.2	22.2	41.4	5.4
	Jun	10–20				39.9	5.2
cpbcbo	Jun	0–10	14.0	5.4	22.0	40.0	5.9
	Jun	10–20				38.6	5.8
sav	Jul	0–10	25.6	4.8	21.6	9.1	5.0
	Jul	10–20				16.8	5.0
ctrl1	Jul	0–10	15.8	4.7	21.2	10.0	5.1
	Jul	10–20				10.7	4.9
cpmy	Jul	0–10	15.9	5.3	21.0	13.1	5.5
	Jul	10–20				14.0	5.2
cpbcbo	Jul	0–10	17.8	5.4	21.0	25.6	5.3
	Jul	10–20				16.6	5.5
sav	Aug	0–10	23.3	4.4	21.2	10.8	5.0
	Aug	10–20				18.3	4.5
ctrl1	Aug	0–10	14.3	5.2	21.2	10.1	4.8
	Aug	10–20				14.4	4.8
cpmy	Aug	0–10	15.2	5.4	20.6	13.3	4.5
	Aug	10–20				17.1	4.8
cpbcbo	Aug	0–10	15.1	5.7	21.0	17.7	4.8
	Aug	10–20				15.3	5.0
mean (min/max)		**0–10**	**18.3 (11.8/26.5)**	**5.3 (4.4/6.0)**	**22.2 (20.6/24.6)**	**16.3 (7.7/41.4)**	**5.1 (4.4/5.9)**
10–20					**18.4 (7.7/40.0)**	**5.1 (4.5/5.8)**	

reflecting the rainy period in May 2017. In 10–20 cm the mean water content is higher than in 0–10 cm. The vertical gradient is particularly obvious in May 2017.

The pH values of 4.4 to 5.0 from savanna soil confirm the expected acidity for the prevailing Rhodic Ferralsol. For the sand cover of the ReviTec site (ctrl1), for compost and in particular for the biochar amendments, slightly higher pH values from 4.8 to 5.9 were measured. Inter-annual differences were minimal and there was no evidence for a vertical gradient (Tab. 4).

The sequence for total nitrogen (N) percentages recorded in September 2017 was sav >> cpmy > cpbcbo = ctrl1, that for C was sav >> cpbcbo > cpmy > ctrl1. The compost and biochar-bokashi amendment was not reflected in a strong increase of C. The C/N ratio was higher in savanna when compared to ctrl1 and cpmy, but lower compared to that of the cpbcbo substrate (Tab. 5), an indication of stable carbon in sav and particularly in cpbcbo.

3.2 Microarthropods

Microarthropod abundance and community structure

From the ReviTec site and the savanna soils we extracted a diverse 'Berlese fauna': in addition to Acari (Oribatida, Gamasina, Uropodina, Prostigmata, Astigmata) and Collembola (mainly Arthropleona), we recorded Protura, Diplura (among them Japygidae), Thysanoptera, Formicidae, Isoptera, Coleoptera, insect larva, Diplopoda (among them Polyxenidae), Isopoda, Pseudoscorpiones, and Araneae. In the following analyses we focus on the microarthropods Acari and Collembola, for which the sampling and extraction method is appropriate.

Generally, the specimens found were very small. Mites dominate the Collembola. Within mites, the Oribatida are most abundant (more than 70% of the Acari), followed by Gamasina. Prostigmata, Astigmata and Uropodina represent less than 5% of the mite population (Tab. 6). They were aggregated into one mite group, 'others', and were not included in the following analyses.

With 22 tsd. ind./m^2 (0–20 cm, overall mean; Tab. 6), soil microarthropods are abundant in the Adamawa savanna. However, on ctrl1 twice as many microarthropods were found. Abundances in the investigated ReviTec treatments were up to eight times as high as sav, and four times as high as ctrl1. Maximal abundances of 228 tsd. ind./m^2 Acari and 37 tsd. ind. /m^2 Collembola were recorded in August 2017 from cpmy (0–20 cm, mean from 5 samples).

Since Oribatida dominate the Acari (83/72%; 2016/2017), Oribatida and Acari abundances were strongly correlated ($R^2 = 0.96$). There was also a strong correlation ($R^2 = 0.78$) between the abundances of total Acari and Gamasina in 2017, although Gamasina made up of less than 1/4 of total Acari. No correlation was detected between abundances of Acari and Collembola and between Oribatida and Gamasina in 2016 or 2017.

No predator-prey relationship between Gamasina and Collembola was observed in 2016. However, in 2017 a slight indication for this interaction was revealed ($y = 1.4003x + 1.7158$; $R^2 = 0.55$).

Development of abundances of Acari and Collembola in time (0–10 cm soil depth)

Higher abundances were recorded in the artificially degraded ReviTec plot (ctrl1) than in the savanna (sav), with the exception of Gamasina in 2016 (Figs 3, 4). However, only Acari and Oribatida abundances of ctrl1 differed significantly from sav in June and August 2017 ($n = 5$, $p < 0.05$). Concerning the general patterns, abundances in the two consecutive years developed quite similarly. In sav and ctrl1, the abundances of Acari showed a clear relation to the start of the rainy season (March 2016/April 2017, Figs 1, 3). The correlation with the duration of the rainfall (months) was strong (0–10 cm; $R^2 = 0.9$). Lower abundances of Acari in May 2017 as compared to May 2016 were likely attributable to the late start of the rainy season in 2017 and the associated low water contents (Tab. 4). The corresponding findings for Collembola confirmed an even more pronounced positive effect of humid soil conditions on population development, particularly in sav (Fig. 3). However, the correlation of Collembola abundances with the duration of the rainfall was very weak, particularly in 2016 (0–10 cm; $R^2 = 0.2$).

Due to high Oribatid dominance, results for total Acari abundance were similar to those for Orbatida (Fig. 4). The 2016 dynamic of Gamasina abundance in sav, however, differed from that of total Acari and followed that of the Collembola. Since water content in sav soil remained well over 20% for all four sampling campaigns in 2016, these findings give some indication for predator-prey interaction, as mentioned above.

The differences in abundances of investigated taxa between the sampling campaigns were conspicuous ($p < 0.05$ in 2017), mainly in the early rainy season (May to July). Highest abundances were found primarily in the last sampling campaign in August.

To assess the substrate amendments, we focused solely on the results from the ReviTec site (Figs 5, 6). In both years, Acari and Collembola were more abundant in the compost treatments (cpmy, cpbcbo) than in the control (ctrl1), particularly in the early rainy season. Almost all abundances recorded in ctrl1 were lower than those of

Table 5. Total nitrogen (N), carbon (C) and C/N ratio, data are means (± standard errors; n = 5) recorded from 0–10 cm samples from savanna and ReviTec site in September 2017.

	savanna	**ReviTec substrates**		
	sav	ctrl1	cpmy	cpbcbo
N%	0.15 (± 0.01)	0.08 (± 0.00)	0.09 (± 0.01)	0.08 (± 0.01)
C%	2.44 (± 0.07)	1.13 (± 0.06)	1.26 (± 0.09)	1.49 (± 0.27)
C/N	15.86 (± 0.30)	14.56 (± 0.20)	13.61 (± 0.27)	18.57 (± 1.93)

Table 6. Microarthropod group diversity: abundance (all figures except D % tsd. ind./m²) and dominance (D %), recorded in the ReviTec and savanna sites in 2016 (0–10 cm) and 2017 (0–10 cm and 10–20 cm). Means over four sampling campaigns (May, June, July, and August) per year.

year	**taxa**	**savanna**		**ReviTec substrates**						**D %**	
		sav		ctrl1		cpmy		cpbcbo			
		0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20	0–10	10–20
2016	**Microarthropods groups**										
	Collembola	2.5		4.9		5.7		9.1		**14.0**	
	Acari	8.3		21.5		41.0		65.8		**86.0**	
	total	**10.8**		**26.4**		**46.6**		**74.9**		**100**	
	Acari groups										
	Oribatida	5.5		18.9		35.1		53.9		**83.0**	
	Gamasina	2.5		1.5		4.4		10.6		**13.9**	
	Uropodina	0.0		0.0		0.0		0.1		**0.1**	
	Prostigmata	0.2		0.3		0.4		0.5		**1.0**	
	Astigmata	0.1		0.8		1.0		0.8		**2.0**	
	total	**8.3**		**21.5**		**41.0**		**65.8**		**100**	
2017	**Microarthropods groups**										
	Collembola	2.9	2.0	3.7	2.3	11.3	7.2	15.8	5.6	**13.0**	**15.0**
	Acari	9.8	6.8	21.6	13.4	94.3	37.9	99.3	38.8	**87.0**	**85.0**
	total	**12.7**	**8.8**	**25.3**	**15.7**	**105.7**	**45.1**	**115.1**	**44.4**	**100**	**100**
	Acari groups										
	Oribatida	6.1	3.7	15.3	9.6	72.5	29.5	69.4	28.0	**72.6**	**73.1**
	Gamasina	2.8	2.7	4.6	2.9	18.6	7.3	28.1	9.7	**24.0**	**23.4**
	Uropodina	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.1	**0.2**	**0.1**
	Prostigmata	0.5	0.2	1.2	0.5	1.3	0.3	0.3	0.5	**1.4**	**1.6**
	Astigmata	0.5	0.2	0.5	0.4	1.6	0.7	1.4	0.5	**1.8**	**1.8**
	total	**9.9**	**6.9**	**21.6**	**13.4**	**94.3**	**37.9**	**99.3**	**38.8**	**100**	**100**

D > 10% dominant, 1 % < D < 10% common, D < 1% rare. Only dominant groups are used for the analyses.

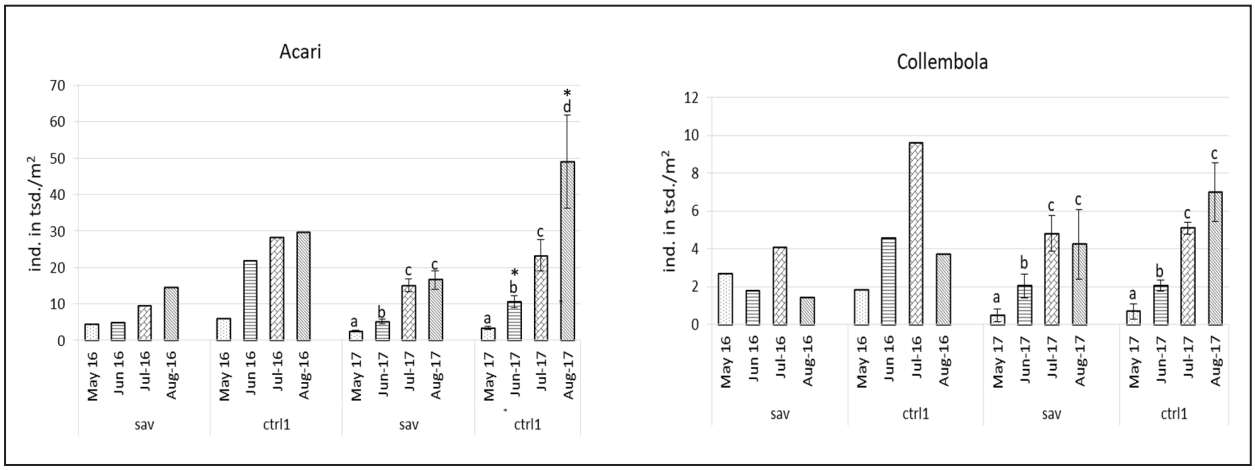

Figure 3. Temporal variation of total Acari and Collembola in control plots (sav: savanna; ctrl1: ReviTec control plot; tsd. ind./m², 0–10 cm). Significant differences between 2017 sampling campains are marked by different letters.(n = 5); Asterisk: Difference to sav significant (n = 5, $p < 0.05$). (Kruskal-Wallis test with subsequent Mann-Whitney U-test to test pairs [$p < 0.05$]). Error bars: standard error.

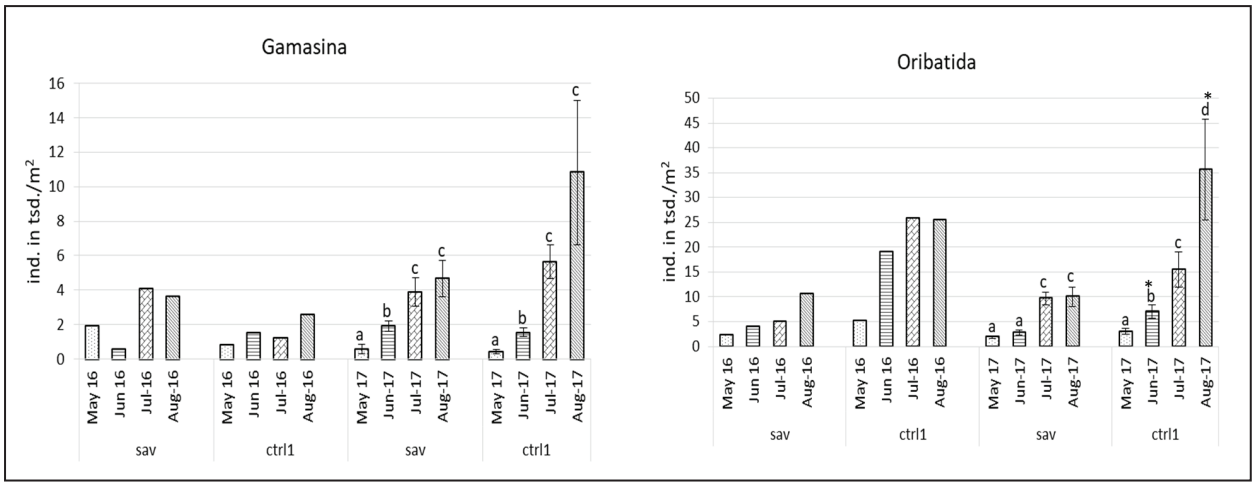

Figure 4. Temporal variation of Oribatida and Gamasina in control plots. Details as in Fig. 3.

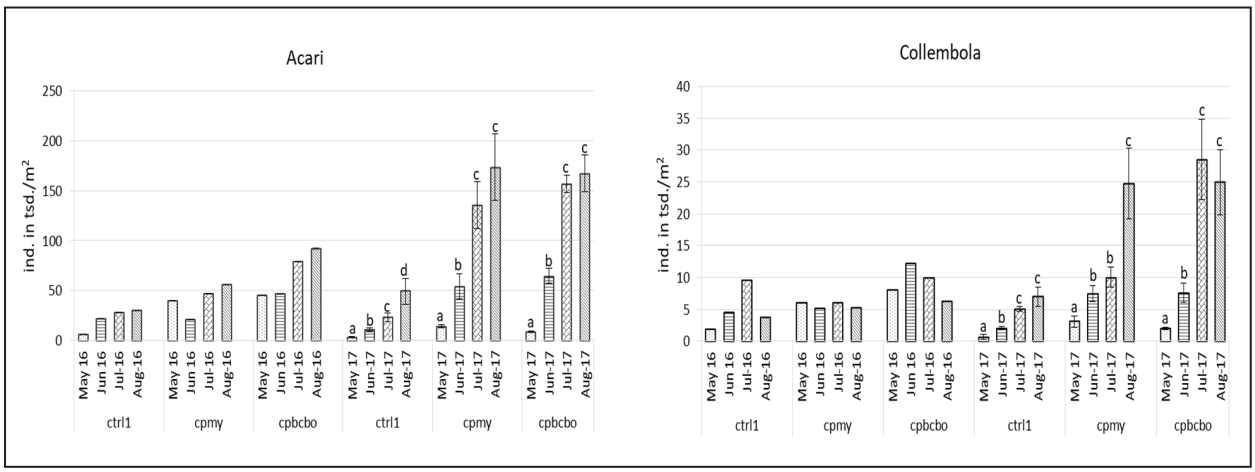

Figure 5. Temporal variation of total Acari and Collembola in the ReviTec plots (ctrl1: ReviTec control; cpmy: compost + mycorrhiza; cpbcbo: compost + biochar + bokashi). Details as in Fig. 3.

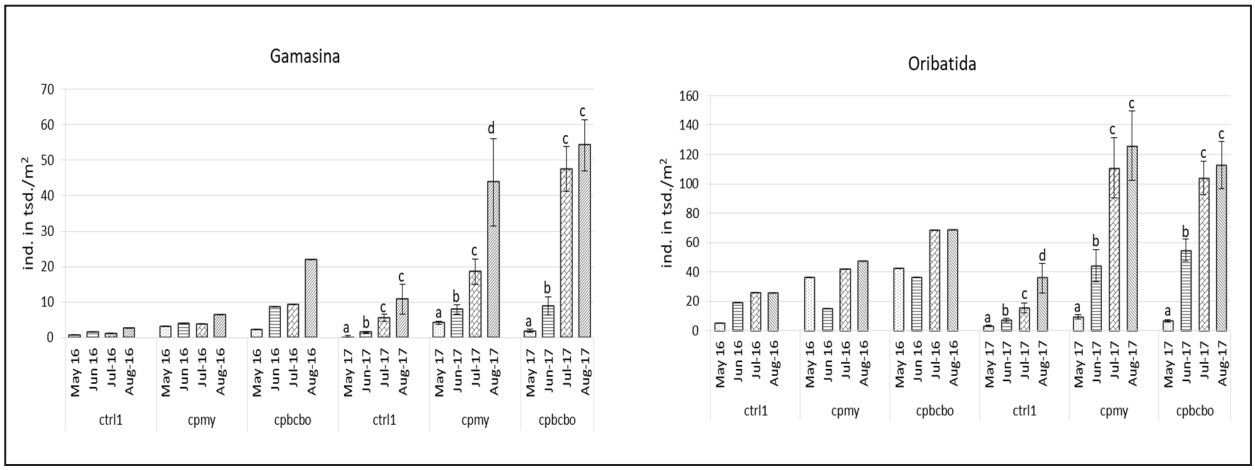

Figure 6. Temporal variation of Oribatida and Gamasina (tsd. ind./m^2) in the ReviTec plots (ctrl1: ReviTec control; cpmy: compost + mycorrhiza ; cpbcbo: compost + biochar + bokashi). Details as in Fig. 3.

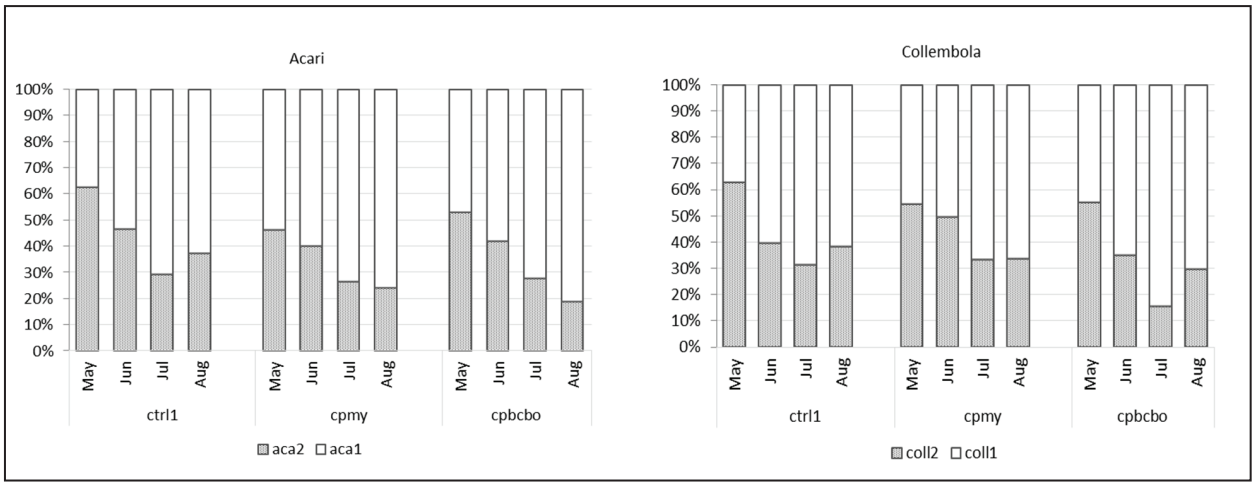

Figure 7. Vertical distribution of Acari (aca) and Collembola (coll) in the ReviTec site (2017). 1: 0–10 cm soil depth, 2: 10–20 cm soil depth; ctrl1: ReviTec control; cpmy: compost + mycorrhiza; cpbcbo: compost + biochar + bokashi.

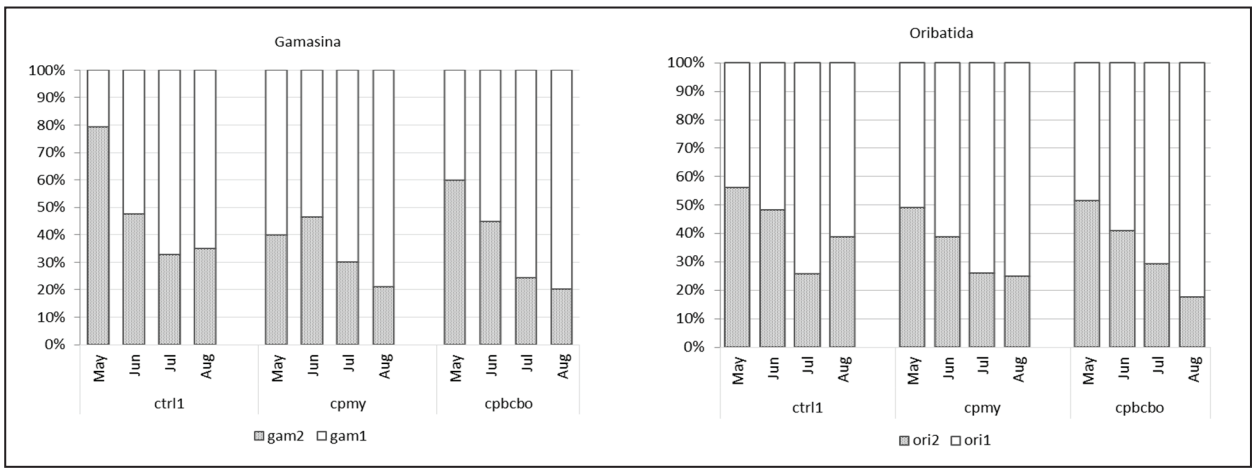

Figure 8. Vertical distribution of Oribatida (ori) and Gamasina (gam) in the ReviTec site (2017). For details see Fig. 7.

the compost treatments (significant in 2017, $p < 0.05$), with the exception of Collembola and Gamasina in cpmy in August.

Besides the differences in magnitude, the temporal development of abundances in the amended soil was similar to that found in the controls, particularly in 2017 (Fig. 5).

Increase rates are calculated by comparing the August abundances (n-Aug) to the May abundances (n-May) by calculating the ratio n-Aug/n-May (Figs 5, 6). The rates varied with the plots sampled and the groups considered. In 2016, the maximum rates ranged from 2.0 for Collembola on ctrl1 to 9.3 for Gamasina in substrate cpbcbo. An evesn higher increase of abundances was observed in 2017. The maximum rates ranged from 12.2 for Collembola to 28.4 for Gamasina, both also in cpbcbo. The microarthropods showed an enormous capability for population development triggered by the rains after the dry season and influenced by soil amendments.

Changes in the vertical distribution of Acari and Collembola over time

Changes of vertical distribution were analysed for 2017 samples (0–10 cm, 10–20 cm). Over the course of the rainy season, Acari and Collembola not only became more abundant, as described in the previous section, but also increasingly colonized the upper soil layer.

Apart from May, significantly higher abundances ($p < 0.05$) were recorded in the upper soil layer in all plots at all dates for all microarthropod groups investigated. In May, less than 40% of Acari and Collembola of the 0–20 cm soil core from ctrl1 were found in the upper soil layer (0–10 cm), whereas in the ReviTec treatments this value was a slightly higher (40–50%). From June to August, this percentage increased to 50–80% in the ReviTec control (ctrl1); the increase was even more dramatic in the ReviTec treatments (Fig. 7). Oribatida and Gamasina largely exhibited the same trends as total Acari (Fig. 8).

4. Discussion

4.1 Sampling

In 2012, the ReviTec Ngaoundéré site was set up in a factorial design on the premises of the University of Ngaoundéré, Dang. The first author and his colleague Lea-Rosine Djoussi pioneered the systematic study of soil microarthropods of Cameroonian dry savanna, including ReviTec sites (Danra 2014, Djoussi 2015). Our study took advantage of substantial methodological efforts by the first author, including the possibility to treat a higher sample size. These efforts notwithstanding, our project could only allow the evaluation of a limited number of treatments. We also had to accept the compromise of assuming that the inoculation with mycorrhizal fungi had no effect on microarthropods, and to consider it a compost treatment. The addition of biochar-bokashi to compost was assessed by the cpbcbo treatment.

4.2 Soil parameters

Site establishment in April 2012 initiated a vital secondary succession. In 2016/17, the vegetation cover was considerable, particularly on the ReviTec islands, though it was more sparse on ctrl1. Vegetation cover develops with the rainy season, becoming dry when the rainfall stops. The ReviTec site is fenced, whereas sav is affected by cattle grazing and has suffered from regular fires in the past, resulting in low vegetation. The high vegetation cover on the ReviTec islands mitigates soil temperatures in comparison to savanna and to ctrl1. The effect of vegetation varies depending on the season and the corresponding growth (structural development) and degree of greening. Interception of the torrential rains in the rainy season is likely to be influenced by the vegetation, depending on its development. With greening, evaporation by transpiration will increase; however, vegetation structure protects soil moisture, which is beneficial for soil biota (Koehler & Born 1989).

High water content in the savanna soil in May 2016 was attributed to the early start of the rainy season and to flooding caused by heavy rain and bad drainage, an indication of degradation. On the ReviTec site with its sandy loam layer, good drainage is assumed. Additionally, high activity of ant, termite and earthworm was reported (Neef 2014, Staffeldt 2014), which contributes to good drainage. Ants and termites are likely to have emigrated from the surrounding area. Earthworms are abundant in the surrounding savanna and probably survived the site implementation measures by estivating in deeper soil layers during the dry season. As expected, the amendment of compost and biochar increased soil water content and also slightly the pH. Celik et al. (2004) and Valarini et al. (2009) observed an increase of available soil water content by 56% and soil pH after compost application. Investigations by Laird et al. (2010) revealed that biochar-amended soils retained more water at gravity drained equilibrium (up to 15%) and had higher pH values (up to 1 pH unit), relative to the un-amended controls. Furthermore, Ekebafe et al. (2015) reported that substrates containing biochar, such as terra preta and biochar bokashi, could reduce runoff and increase soil pH.

The observed effects of the ReviTec applications on soil

temperature, soil water content and pH are supportive for soil biota development. However, a detailed study on microclimate and soil water conditions would be useful to enable more detailed discussion of the results shown in Tab. 4 and their implications for soil biota. First tests of an innovative monitoring device of soil moisture at the Ngaoundéré ReviTec site yielded promising results (Zaman et al. 2016).

It can be assumed that within the four to five years since site establishment, the compost amendments were subjected to decomposition processes whereas biochar remained largely unchanged (Kuzyakov et al. 2014). Compost amendments were reported to have effects not only on soil physical characteristics and pH, but also on other chemical properties (Celik et al. 2004, Sarwar et al. 2008), resulting in positive changes for soil biota. Biochar increases the stability of compost and has positive effects on aggregate formation (Jien et al. 2015). As expected, the compost treatments increased total C content compared to the ReviTec control (ctrl1). Compared to the savanna, this increase in the experimental soils was surprisingly small. More detailed studies on carbon in the Ngaoundéré savanna may be rewarding, including differentiation of pyrogenic carbon resulting from grassland fire (Saiz et al. 2015). Several studies have indicated that compost and bokashi amendments increase C and N contents (Valarini et al. 2009, Hernández et al. 2014, Devarajan et al. 2021). However, compared to ctrl1, total N was higher ony in the cpbcbo treatment. This increase of total N observed in cpbcbo treatment may be due to the sorption potential of biochar reducing N mineralisation and leaching, and thus significantly increasing total N content in soil, as in Laird et al. (2010) and Kuoppamäki et al. (2021).

The observed C/N ratio was generally favourable for mineralization processes in all plots, supporting the development of belowground biomass and of the interactive food web, including that of microarthropods. Since biochar is only slightly bioavailable, the C/N ratio is of limited importance for this amendment.

4.3 Extraction

As mentioned before, a major challenge of our project was to establish the methodology for sampling, extracting and counting soil microarthropods. Furthermore, the methodology had to be adapted to the Cameroonian environment and possibilities. An explorative extraction of soil cores with a highly efficient extractor in the Bremen lab showed that the efficiency of the first Ngaoundéré extractors (built by the first author in 2014) was inferior by a factor of 100. After the first author's experience in Bremen, considerable improvements of the extractors were effectuated resulting in an efficiency well comparable to that of Bremen and the literature. Still, underestimation of small and transparent Prostigmata and juveniles may be possible, as optical equipment was not as sophisticated as that in, for example, the Bremen laboratory.

The efficiency of dynamic extraction methods is influenced by the humidity of the soil (Vannier 1970). To ensure comparable extraction efficiencies for samples from dry and rainy season, the soil of each sampling spot was watered some hours prior to coring, as described by (Koehler 1999). An extraction regime starting with a humid phase by covering the samples to reduce desiccation was applied.

4.4 Soil microarthropods

The numbers of individuals expelled from the soil with the improved extraction methodology are considerable and close to those found in temperate zone soil; they are orders of magnitude higher than those reported in the literature reviewed from sub-Saharan African sites, which are even more humid than those in the dry savanna. Even the study of Danra (2014) at the Salak ReviTec site near Maroua (Far North), with 8 months of dry season and mean monthly temperature maxima close to 40°C, documented an abundant and diverse microarthropod community. The diversity of arthropod groups encountered at the Ngaoundéré site is remarkable, as is what we found previously on species level in the Gamasina and Oribatida (Acari) (Ermilov & Koehler 2017, Danra et al. 2018). Therefore, we reject hypothesis 1**.**

According to Lakshmi et al. (2021), drought as well as flooding may highly reduce soil microarthropod density. In this investigation, Acari were clearly more dominant than Collembola, which reflects the high susceptibility to drought of the delicately sclerotized latter group (Pflug & Wolters 2001). Sheikh et al. (2017) attributed the predominance of Acari to their morphological and physiological adaptations as well. Many mite taxa possess sclerotized exoskeletons, diverse feeding preferences and are long-lived. With maximal abundances of 29 tsd. ind./m^2, Collembola comprise on average less than 15% of total microarthropods. Mites, on the other hand, reach maximum abundances of 173 tsd. ind./m^2.

High dominance of Acari was also reported by Block (1970) from seven sites with various soil, vegetation and cultural practices in Uganda, East Africa, as well as in a secondary rainforest in Nigeria (River State) by Gbarakoro et al. (2010). The dominance of Oribatida was surprising, since their preferred habitat of the litter layer was virtually absent. Their high abundance is attributed

to their strong sclerotization protecting them from drought and to their small size, which allows them to live in finer soil pores. Predatory Gamasina were numerous, but there indications for a predator-prey relationship with Collembola were present only in sav 2016. This raises the question of Gamasina prey resources apart from microarthropods, such as nematodes.. Alternative prey may be present in greater numbers in the amended soils. The delicate Prostigmata and Astigmata were found in low individual numbers only; however, this may have methodological reasons as they are easily overlooked with the standard optical equipment at our disposal. Block (1970) also recorded a high abundance of Oribatida, followed by predatory Gamasina and mainly low abundances of Prostigmata and Astigmata.

Abundances in savanna soil (sav) were lower than those found on the ReviTec control (ctrl1), with only some exceptions. This does not necessarily mean that our experimental degradation by covering the site with loamy sand was unsuccessful. The partially higher abundances in ctrl1 as compared to sav may result from the successional processes on the ReviTec site since April 2012, which are associated with the dense vegetation cover on the islands nearby to the ctrl1 plots and offer some litter, cover and a more favourable microclimate. However, from the comparably low abundances on sav we also can conclude that the savanna is quite degraded from grazing and fire. On the species level of Gamasina and Oribatida, lowest diversity was found in ctrl1 (Danra et al. 2018, Ermilov and Koehler 2017) indicating a long-term effect of the experimental degradation and the importance of species level analyses for the assessment of rehabilitation measures.

With the change from dry to rainy season in April/May we observed strong population development, leading to the highest abundances in July/August. Although the general patterns of population developments are quite similar across the two years, indicating the overriding effect of the rains, differences are also obvious, which may be due to successional processes, year to year variability or methodological developments from 2016 to 2017 (Tab. 2). The last reason seems unlikely, however, since abundances in the controls sav and ctrl1 are a good reference with very similar abundances in both years (Tab. 5; 0–10 cm). This result justifies the comparison of the findings for the two consecutive years. On the compost-amended plots, abundances in 2017 are considerably higher than they were in 2016. To determine whether this is due to succession or year to year variability, longer-term investigation is necessary.

As shown by trends in 2016 and statistically in 2017, the increase rates from May to August were considerable and were particularly significant until June. This raises the question of how the intensive population growth is possible. Since the dry season strikes on a regional scale, immigration is unlikely. Population development from a few survivors in deeper soil layers, or from survival stages, is more realistic.

Our stratified sampling yielded some insight into the changes of vertical distribution of soil microarthropods in the dry savanna. In 2016, the 0–10 cm soil cores were divided into 0–5 cm and 5–10 cm; a vertical stratification of abundances did not become evident. Based on these findings, soil cores to a depth of 20 cm were taken in the following year and stratified into 0–10 cm and 10–20 cm. In May 2017, considerable abundances were found in the depth of 10–20 cm, making up more than 50% of the microarthropods in the core. After the rainfall, the proportion of microarthropods at 0–10 cm increased.

The dry season can be assumed to be the most prominent factor influencing soil microarthropod populations in the savanna. Drought in our Cameroonian savanna sites is more influential than low temperatures in winter season in the temperate zone, as can be seen from our study over 20 years of secondary succession at a site in Bremen (northern Germany; Koehler & Melecis 2010, Daghighi et al. 2017).

Drought, high soil temperature, and sparse and dry vegetation cover may provoke downward migration, estivation (dormancy), or death of microarthropods. Drought avoidance behaviour of mites and Collembola was reported by Urhan et al. (2008), Detsis (2014), and Vannier (1970). The generally small size of the microarthropods found in our study (< 500 µm) allows the colonization of relatively fine soil pores in the depth of the fine-textured savanna soil. Analyses on the species level of Gamasina and Oribatids have shown a high dominance of slender edaphic Rhodacaridae and small Oppiidae (Danra et al. 2018, Ermilov & Koehler 2017). An upward migration of Acari and Collembola in the wet season was observed by Price (1973). However, high abundances encountered in the course of rainy season cannot be attributed to vertical migration alone but are assumed to be a result of population growth. The prevailing high temperatures may support short generation times, assuming the microarthropods exhibit corresponding reproduction strategies. The species of the dominant families of Gamasina (Rhodacaridae) and Oribatids (Oppiidae) have this characteristic; however, respective biological knowledge is limited (Hassan et al. 2017, Wehner et al. 2014).

After the dry season, rainfall not only directly improves living conditions for microarthropods, but also affects vegetation development and prey populations which in turn influence the soil microarthropod populations indirectly. We observed that consideration of soil

humidity alone is insufficient to achieve an understanding of population dynamics;the other components of the soil ecosystem must also be included. However, the alternating seasons are a main factor (Flórián et al. 2019). Based on this reasoning, hypothesis 2 is accepted.

Tropical dry savanna ecosystems are under stress from firewood exploitation and overgrazing, aggravated by climate change. Due to high biotic activity in the rainy season with permanent high temperatures, high turnover of bioavailable organic matter restricts its accumulation. Pyrogenic carbon from fires in the dry season may be lost through erosion or may be incorporated into the soil by macrofauna in the rainy season, thus playing an important role in savanna ecology (Ansley et al. 2006, Forbes et al. 2006, Petter & Madari 2012, Reisser 2016). With compost amendments, the lack of bioavailable organic matter is alleviated, explaining the observed positive effects.

The bags filled with compost amended substrate have higher abundances and generally supported stronger population development as compared to the controls. As we discussed previously (Danra et al. 2018), it is unlikely that microarthropods were introduced with the compost. We see the observed abundances rather as an indication for an improvement of habitat quality for soil microarthropods by the respective amendments (hypothesis 3). Compost application is beneficial to soil biota not only by affecting soil chemical properties, but also by influencing physical soil properties such as bulk density, macro-porosity, oxygen diffusion rate, and pore space (Carter et al. 2004). An important indirect effect is the improvement of the food source, such as palatable soil organic matter, and prey for the predators, particularly nematodes. Muturi et al. (2011) and Leroy et al. (2007) demonstrated that compost application to agricultural fields would not only boost yields, but also increase the abundance of mites and Collembola due to direct and indirect effects.

Although the difference between the two compost treatments was not so conspicuous, the highest increase rates were documented in biochar amended soil (cpbcbo), ranging from factor 12 to almost 30 compared to the May abundances. Increase rates of Gamasina were higher than those of Oribatida and Collembola.

Application of charcoal in soil can increase soil microflora populations (Verheijen et al. (2009), Warnock et al. 2007). Although there was no significant difference of total Acari, Collembola and Oribatida abundance between the two ReviTec treatments, the Gamasina clearly preferred the cpbcbo amendment. Moreover, Kuoppamäki et al. (2021) recently reported that biochar application in soil may also increase Oribatids abundance. Accordingly, hypothesis 4 is accepted. This is supported by Danra et al. (2018), who reported higher species number of Gamasina in cpbcbo as compared to cpmy.

5. Conclusion

Since there is good indication from our data that the savanna site is degraded, we cannot provide baseline data for microarthropods in high Guinean grassy shrub and tree savanna. An undisturbed 'steady state' site has to be found. After the dry season with low microarthropod abundances, the rainy season triggers strong recovery and dynamics of soil microarthropod populations, in addition to those effects which are attributed to successional processes and year to year variability. Any sampling regime has to be adapted to these circumstances. Long-term studies have to be implemented to detect the effects of succession and climate change (Daghighi et al. 2017).

The positive effects of ReviTec application on soil parameters are interpreted as outcome of complex ecosystem processes including secondary succession and as an indication of successful rehabilitation of the ecosystem services, water holding capacity and drainage. Data are not sufficient to make conclusions regarding biogenic soil stabilization, and can provide only vague evidence for the establishment of nutrient retention and cycles.

The ecosystem engineering activities of ants, termites and earthworms in savanna have been described (Lavelle 1983, Decaëns et al. 2001, Jouquet et al. 2006, Lavelle et al. 2016) and proposed for soil rehabilitation (Mando et al. 1999). The unexpected high abundance and diversity of microarthropods we found in dry high Guinean grassy shrub and tree savanna (including findings not reported here from the Maroua region) qualify these measurements for inclusion in the toolbox of soil rehabilitation measures, bioindicators and assessors of success. Investigations of soil microarthropods in dry savannas have to consider the strong temporal dynamics triggered by rainfall and dry seasons. The pronounced changes in vertical distribution require sampling depths of 20 cm or even more.

More knowledge on the biology of the microarthropods of sub-Saharan dry savanna is needed to explain the strong seasonal population development and changes in vertical distribution. Understanding of the role of soil microarthropods in savanna soil subjected to a prolonged dry season has to complement the knowledge of the roles of termites, ants and anecic earthworms. Such an understanding of dry savanna ecology is mandatory to combat soil degradation and desertification and to understand the consequences of climate change.

Microarthropods have to be considered in addition to macrofauna to understand the functional processes of savanna soil, which deliver important ecosystem services. Dryland soil ecology may serve as a model for potentially increasing drought in temperate zones.

Our results demonstrate that the ReviTec approach is effectively reaching its initial objective of stimulating and accelerating the successional process, since the increase of the abundances of mites and Collembola was highly significant for ReviTec treatments compared to the controls. Thus, compost and biochar amendments are recommended for the rehabilitation of dry savanna soil.

The analysis of the efficiency of the ReviTec treatments for soil development proved to be quite convincing even at the group level. However, finer taxonomic resolution as documented for the Gamasina by Danra et al. (2018) differentiates more clearly between the controls (sav, ctrl1) as well as between the compost treatments (cpmy, cpbcbo). To improve the understanding of degradation and rehabilitation, the analysis on species level has to be developed for the sub-Saharan soil microarthropods. This also is critical for the consideration of any biodiversity issue. However, for a longer-term monitoring of rehabilitation measures and the assessment of their success, group level studies may give sufficient information (hypothesis 5).

With our study, we contribute evidence of a highly abundant and diverse microarthropod community, strongly influenced by rainy season and experimentally amended organic matter, to the common understanding of dry savanna ecology. The complex interactions of pyrogenic and detritus-based soil organic matter with the soil biota require intensive research of dry savanna ecosystems to provide the necessary knowledge for sustainable use and successful rehabilitation. The respective capacity building has to be established.

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