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Effect of three different land use types on the temporal dynamics of microarthropod abundance in the high Guinean savanna of Ngaoundéré (Adamawa, Cameroon)

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Abstract

Soil degradation and desertification negatively affect agricultural productivity. It affects 46% of Africa's land area, where agriculture sustains over 50% of the economy in many countries. Microarthropod communities' abundance and composition are important components for soil health and quality assessment. Unfortunately, there is a dearth of information on microarthropods in central Africa in general and Cameroon in particular. We, thus, evaluated the population dynamics of Acari and Collembola as influenced by season, maize cultivation and fertilization in the high Guinean savanna agro-ecological zone (HGSAZ) of Cameroon. The abundances of Acari groups (Oribatida, Gamasina, Uropodina, Prostigmata, Astigmata) and Collembola were recorded. They were extracted from a field trial consisting of three plots of maize and one savanna plot that was established at Dang (Ngaoundéré 3, Adamawa region) in May of 2017 and 2018. The first plot received dead organic matter (DOM) while the second was treated with chemical fertilizer (NPK 20:10:10 at the rate of 8.75g/m^2). The third plot received no external input and served as a control. The adjacent grassy savanna was the out-of-field control. Results revealed that microarthropods were more abundant in the rainy than dry season. Overall, abundances of 16 tsd. ind./m^2 for Acari and 8 tsd. ind./m^2 for Collembola were recorded in the savanna control. In the experimental field with maize cultivation, the highest abundances of Acari (20 tsd. ind./m^2) and Collembola (7 tsd. ind./m^2) were recorded in the plot that received dead organic matter (DOM), while the control plot without DOM (10 tsd. ind./m^2 for Acari and 2 tsd. ind./m^2 for Collembola) and the plot with chemical fertilizer (8 tsd. ind./m^2 for Acari and 8 tsd. ind./m^2 for Collembola) had the lowest abundances. Therefore, application of NPK and removal of DOM from cultivated areas have negative effects on soil microarthropods, and could result in very high costs for farmers to maintain soil fertility. In contrast, mulches are safe, simple and easily accessible to local farmers, promote soil biota and have a positive influence on soil structure and microclimate. Further, knowledge from the present study may contribute to the improvement of soil health and quality and boost agricultural productivity in the HGSAZ of Cameroon.

Keywords Acari | Collembola | dead organic matter | NPK fertilizer | maize

1. Introduction

Soil degradation and desertification are of worldwide concern (UNCCD 1994). According to data released by the World Bank (2020), 2 billion people are poor, of whom 689 million live in absolute poverty and it is estimated that due to the COVID-19 pandemic, more than 100 million additional people could fall back in absolute poverty. Four of every five individuals living below the international poverty line reside in rural areas and depend

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on agriculture for their livelihoods and food security. The region where most of the world's poor are concentrated is Sub-Saharan Africa (World Bank 2020, FIDA 2021).

Land degradation affects 46 % of Africa's land area, with an estimated US$ 9.3 billion annual cost. The phenomenon is accelerated in agricultural regions with an annual loss of 30 to 60 kg of nutrients per hectare (Roy 2006, Chianu et al. 2008, Guedegbe & Sinsin 2020). Agriculture is one of the main economic activities in Africa and accounts for 15.8 % of Sub-Saharan African countries' GDP (Souhir 2019).

Considering this, it is undeniable that maintenance and restoration of soil quality are essential to ensure the needs of Africa's future generations. To achieve this goal, important research has focused on soil fauna, particularly microarthropods for the assessment of changes in soil quality in order to evaluate the sustainability of ecosystems (Aspetti et al. 2010, Menta 2012). Through their interactions in the soil, microarthropods are drivers for many ecosystem goods and services, namely decomposition and mineralization of dead organic matter, improvement of soil structure, regulation of microbial populations and nutrient cycling, thus improving the quality of the soil (Gbarakoro & Zabbey 2013, Begum et al. 2014, Sharma & Paewez 2017). Due to their abundance in soil and their sensitivity to ecological conditions, they are used as bioindicators of soil health and quality (Gardi et al. 2002, Gbarakoro & Zabbey 2013, N'Dri et al. 2016, Lakshmi & Joseph 2017, Manu et al. 2021, Koehler 1996). In soil ecosystems, microarthropods are influenced by complex factors, such as land use (forestry, agriculture, urbanization), pollution and other anthropogenic influences, seasons and climate change. Agricultural practices including heavy tillage machinery, chemical fertilizers, and pesticides, have profound impacts on soil biota (Begum et al. 2014). These impacts may lead to disturbances of within-soil interactions, resulting in soil degradation as a consequence of the loss of ecosystem goods and services (Zingore et al. 2010, Lal 2015) 7.3 billion in 2015 and projected to increase to 9.5 billion by 2050, necessitates an increase in agricultural production of ~70 % between 2005 and 2050. Soil degradation, characterized by decline in quality and decrease in ecosystem goods and services, is a major constraint to achieving the required increase in agricultural production. Soil is a non-renewable resource on human time scales with its vulnerability to degradation depending on complex interactions between processes, factors and causes occurring at a range of spatial and temporal scales. Among the major soil degradation processes are accelerated erosion, depletion of the soil organic carbon (SOC).

The variation in the abundance of microarthropods in landscapes, depending on the type of land use, is a well-documented contribution in Europe and the United States, numbers in annual cropping systems or perennial grasslands are typically in the range of 50–100 tsd. ind./m^2, compared to 200–250 tsd. ind./m^2 in undisturbed forest soils, in temperate climate (Blevins et al. 1983, Crossley et al. 1992). From 28.9 to 83.1 tsd. ind./m^2 were reported in soils of Georgia, USA (Blevins et al.

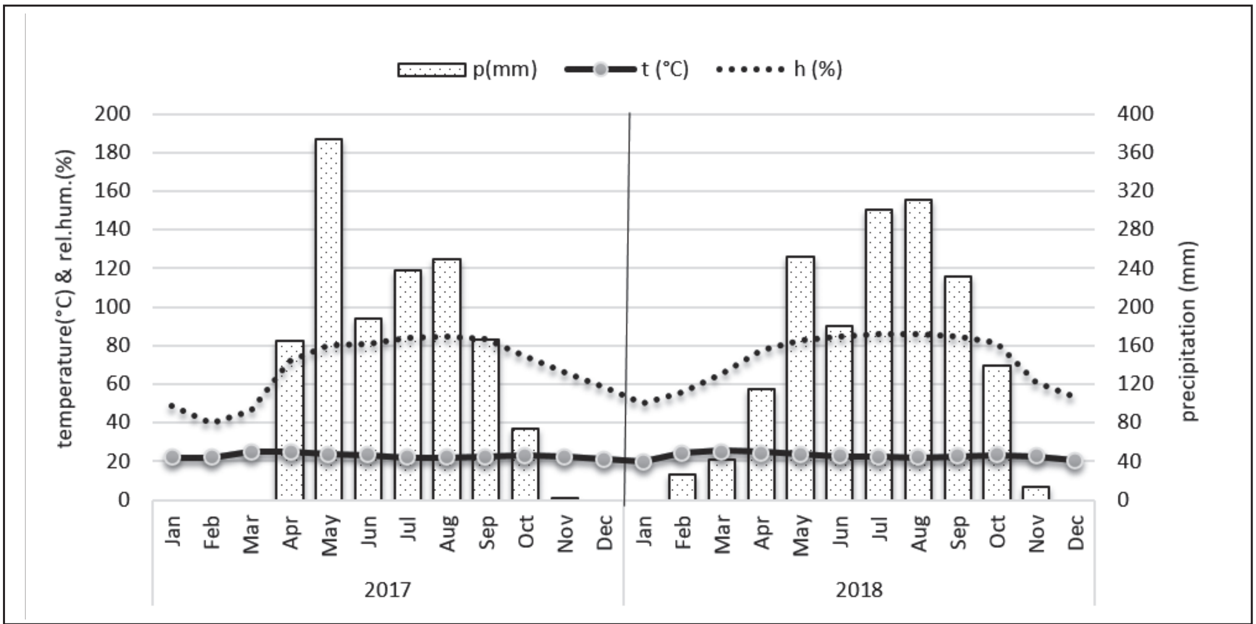

Figure 1. Weather data for the Ngaoundéré area, Jan. to Dec. 2017 and 2018, provided by Ngaoundéré airport meteorological station; t: temperature, p: precipitation, h: relative humidity; h: averages per month; p: sum per month.

1983). In Asia, a range of 3.7–26.7 tsd. ind./m^2 of Acari and 0.5–10.4 tsd. ind./m^2 of Collembola were reported by Banerjee et al. (2009) and Wang et al. (2015). One study from South America suggests that microarthropod abundance may be higher there than in Asia, but lower than in North America. This study from Argentina recorded a maximum of 31.7 tsd. ind./m^2 Acari (Bedano et al. 2005).

However, there are only a few publications on microarthropods in Sub-Saharan African soil ecosystems (for example: Block 1970, Iloba & Ekrakene 2008, N'Dri et al. 2011, Okiwelu et al. 2012, N'Dri et al. 2016). In this region, the range for Acari could be from 4.0 to 32.2 tsd. ind./m^2 and Collembola 0.5 to 3.4 tsd. ind./m^2 (Block 1970, N'Dri et al. 2011). For the Cameroonian savanna, knowledge on microarthropods is limited to that provided by Ermilov & Koehler (2017), Danra et al. (2018) and Danra et al. (2021). These publications contain information on abundance and diversity at the species level (Oribatida, Gamasina) and seasonal dynamics. Gamasina abundance of up to 22.0 tsd. ind./m^2 (Danra et al. 2018) and microarthropod populations ranging from 10.8 (savanna) to 74.9 tsd. ind./m^2 (ReviTec site) (Danra et al. 2021) were recorded in Cameroon. Own previous research revealed that microarthropods are present in the soil even in the dry season (Djoussi 2015) and that the variation of the microarthropod community is directly linked to season by abiotic parameters (rain, water content of soil) and vegetation development.

For the high Guinean savanna agro-ecological zone of Cameroon, the effect of agricultural management on soil microarthropods is yet to be elaborated. However, the inorganic fertiliser NPK 20:10:10 is widely used in maize crops compared to organic amendments (Agri-Stat 2012). To fill some of these knowledge gaps, we studied in rainy and dry season the impact of organic matter and chemical fertilizer (NPK) on the abundances of Acari (Oribatida, Gamasina, Uropodina, Prostigmata, Astigmata) and Collembola. Such knowledge on the abundance and dynamics of microarthropods as influenced by season, cropping and agricultural inputs may facilitate the improvement of soil health and quality and boost agricultural productivity in the high Guinean savanna agro-ecological zone of Cameroon.

In respect to microarthropod abundances under the influence of (1) seasonality, (2) maize cultivation, (3) chemical fertilizer and (4) organic matter, we hypothesize that:

1. Microarthropod abundances are lower in dry season compared to rainy season, due to low water content in soil which is the primary abiotic factors influencing population size (Huhta & Hänninen 2001, Djoussi 2015, Sharma & Paewez 2017).
2. Compared to the savanna control, abundance of microarthropods is low in conventional maize cultivation (maize control), which includes tillage and removal of organic matter (Menta et al. 2020, Gergócs et al. 2022).
3. Compared to maize control, inorganic NPK fertilizer has a negative impact on microarthropod abundance, as it makes the soil more acidic (Emmerson et al. 2016, Bolan et al. 2005).
4. Amendment of organic matter to conventional maize cultivation is expected to have a positive effect on microarthropod abundance due to the improvement of soil physical, chemical and biological conditions (Mensah & Frimpong 2018, Danra et al. 2021, Schnee et al. 2021, Badejo et al. 1995).

2. Sites and Methods

2.2 Climate and study site

The research was carried out in 2017 and 2018 at Dang, which is in the high Guinean savanna zone (Ngaoundéré 3 district, Adamawa region). The climate at Ngaoundéré is characterized by seven months of rain (April to October) and five months of drought (November to March; Fig. 1). Whereas the weather in 2017 is in agreement with this, some rain was experienced in February, March and November 2018, but only small amounts. So, we considered the dry season to last from November 2017 till March 2018.

According to the long-term climate data (https://en.climate-data.org/location/898011/, retrieved 2018), annual precipitation is 1523 mm and average temperature 22.0°C. In 2017, precipitation was less with 1455 mm and more in 2018 with 1611 mm. In both years, the mean annual temperature was higher than the long-term mean: 22.7°C in 2017 and 22.8°C in 2018.

The experimental field for the study was located behind the administrative building of the Faculty of Science of the University of Ngaoundéré (7°25'22.1" N; 13°32'20.6" E; Fig.2). Due to a relatively high sand content, the soil is permeable (silty clay loam). The texture is 35% sand, 25% silt and 40 % clay. It is composed mainly of brown or brownish-red laterites. Iron and aluminium content is high.

2.3 Experimental design, treatments

The investigations covered three consecutive seasons: the rainy season of 2017, the dry season of 2017/18 and the rainy season of 2018 (Fig. 1; details on sampling campaigns in 2.4). In early 2017, the site of roughly 1250 m^2

was cleared and hand ploughed with hoes to 5 cm depth. The management of the site followed strictly the same schedule in 2017 and 2018. The chronogram of agricultural activities and sampling dates of microarthropods for this study are shown in Table 1. On May 22, maize seeds were sown in 10 rows of 32 plants each per plot and harvested in October. Plant spacing within and between rows was 25 cm and 50 cm, respectively. Hand weeding with a hoe was done when necessary.

The dead organic material applied as mulch to the plots ‘maize mulch DOM (mmdom)’ consisted of dry leaves and twigs of *Annona senegalensis* (Annonaceae) and *Brachiaria* sp. (Poaceae), plants naturally and widely found in the region. The plant material was slightly crushed and placed on the ground as mulch for three weeks and then covered with soil one week before sowing. The NPK fertilizer (20:10:10) was surface broadcasted. An amount of 8.75 g/m^2 was applied five times from one week before sowing to harvest in October (Tab. 1), resulting in a total of 43.75 g/m^2, which corresponds to 437.5 kg NPK per ha and 87.5 kg/ha N per year. The application of chemical fertilizer in maize cultivation in high Guinean savanna is done either in two stages (at the time of sowing and at the earing) or fractionally for a good response (yield) (IFATI 2022).

For the treatment ‘maize bare (mb)’, all organic matter was removed from the soil surface before sowing, neither organic nor inorganic materials were added. Before inorganic NPK fertilizer was applied (‘maize bare NPK’ mbnpk), the respective plots were treated as described for mb.

The experimental plots were arranged in a completely randomized block design consisting of three treatments repeated three times each (Fig.2).

Grassy savanna (sav ctrl) adjacent to the experimental field was used as external control. To respect synergy and consistency in data collection, the replications applied in the savanna were pseudoreplications.

2.3 Soil parameters

Soil water content (WC %) was determined gravimetrically. For each sampling campaign, WC % was evaluated in each soil sample by the difference of the weight of the samples before (FM) and after extraction (DM).

With WC (g) = FM-DM.

FM = Fresh Mass, mass of soil before drying and DM = Dry Mass, mass of soil after drying by extraction process.

Soil pH was tested for each sample, in each sampling campaign with a digital compact pH meter (Oakton OK35423-00 EcoTestr pH1, Global Test Supply, UK). A mixture of 10 g of soil with 20 ml of distilled water in a 100 ml glass cup was shaken by hand for about 1 minute and left for about 2 minutes before the pH electrode was placed into the mixture. The result was read one minute later.

It is worth mentioning that in the dry season, the soil samples for the assessment of WC and pH were taken

Table 1. Chronogram of agricultural activities and sampling of microarthropods (numbers indicate dates).

	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	dry				rainy				dry	
ploughing			3							
sowing			22							
weeding				5 & 19		14 & 28				
DOM appl		24								
NPK appl			15	5	1	7	1			
harvesting								10		
sampling			17	15		15		15		15
2018			rainy							dry
ploughing			3							
sowing			22							
weeding				14 & 28		12 & 26				
DOM appl		24								
NPK appl			15	14	11	12	2			
harvesting								10		
sampling	15		17	15		15		15		

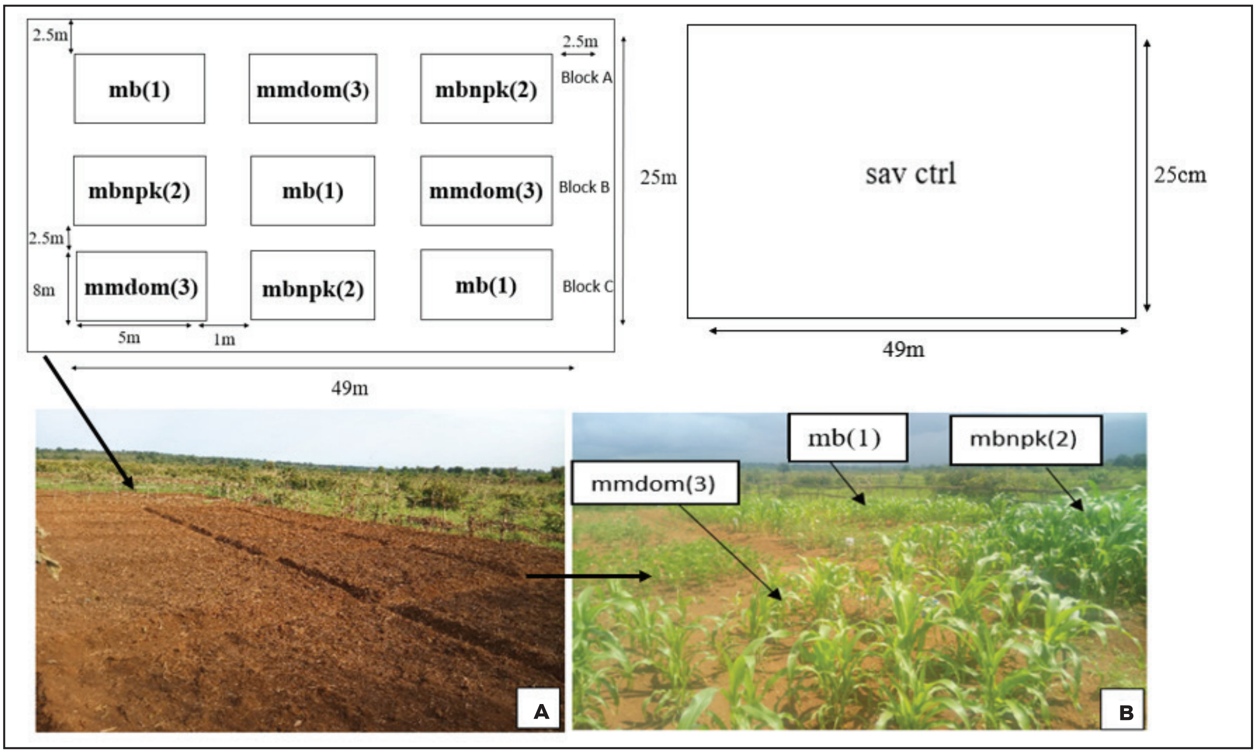

Figure 2. Completely randomized block design of the experimental field; experimental field before sowing (**A**: 08/05/17) and with maize crop (**B**: 28/06/17); sav ctrl: savanna untreated (outside). mb(1): maize bare = maize plot without mulch or NPK fertilizer; mbnpk(2): maize bare with NPK = Maize plot treated with NPK fertilizer only and mmdom(3): maize mulch = maize plot treated with mulch only.

before the watering of the plots, unlike those for the extraction of microarthropods which were collected after watering of the soil (See Section 2.4 below).

2.4 Sampling and extraction of soil microarthropods

Soil samples were collected using a steel soil corer with characteristics: diameter 6 cm and Area of cylinder 28.3 cm^2. The depth of the soil cores was 5 cm, giving soil core volumes of 141.4 cm^3. Dates of sample campaigns are shown in Tab. 1 (see 2.2 Experimental design, treatments). At each of the ten sampling campaigns, three samples were taken in each of the nine plots plus the three savanna plots, resulting in a total of 360 samples for the two years (180 samples/year). In the dry season, water from a borehole was used to wet the soil 30 minutes before sampling. For each plot 11 L of water were spread uniformly on the surface of the dry and rigid soil, using a watering can. The watering of the soil led to favourable conditions for an efficient extraction of the soil microarthropods (Koehler 1999).

The extraction was done with a Tullgren-type apparatus (dynamic extraction method), adapted from the third-generation extractor built by Danra and Djoussi (Danra et al. 2021). It was designed to hold 72 samples. In this study, 36 samples were extracted for each sampling campaign. The samples were heated and dried from topical electric bulbs (40 W) for 7 days. Ambient temperature serves as cooling. The heat creates a gradient of temperature and soil humidity, driving the microarthropods downwards from the samples via funnels into vials of 50 ml, filled with 25 ml of collecting and preservation fluid (4 parts 70% ethanol and 1 part glycerol).

2.5 Identification of soil microarthropods

Microarthropods were sorted under a stereomicroscope (ZEISS, 10 × 25) and identified up to the group level using Soil Biology Guide by Dindal (1990) and Manual of Acarology by Krantz (1978). The following groups were separated from other ‘Berlese fauna’: Acari (Oribatida, Gamasina, Uropodina, Prostigmata and Astigmata) and Collembola (Arthro- plus Symphypleona).

2.6 Abundances

The number of soil microarthropods extracted from each sample was counted. Abundances (ind./m^2) are calculated using the following formula:

ind./m^2 = n* 353.4

n = is the number of individuals counted from a sample, 353.4 is the multiplication factor to obtain individual numbers per m^2 from the sample area of 28.3 cm^2.

The abundances are given as thousand individuals per square meter (tsd. ind./m^2). The relative abundance (dominance D %) is calculated as the percentage of the abundance of a given group relative to the abundance of all microarthropods found (Acari + Collembola). Dominance classes are determined as follows: D > 10 % dominant, 1 % < D < 10 % common, D < 1 % rare (Gwiazdowicz et al. 2011, Manu et al. 2013). Seasonal abundances are calculated as arithmetic means from the abundances found in May, June, August, October, December 2017 and March, May, June, August, October 2018.

2.7 Statistical Analysis

To assess variations in the abundances of microarthropods over time, the data were subjected to repeated measures ANOVA (Friedman non-parametric test), followed by Pairwise posthoc Durbin test with Bonferroni correction, which compared the abundances among the sampling months. Kruskal-Wallis and Wilcoxon signed-rank tests were conducted to determine the variations and the differences, respectively, in microarthropod abundances among treatments. Linear relationship between water content and microarthropod abundance were assessed using regression analysis. Principal Component Analysis was used to determine relationships / interactions among the variables (abiotic and biotic).

3. Results

3.1 Soil parameters

Soil water content showed significant variations across time ($F = 5420.62$, df = 5, 234, $p = 2.2e^{-16}$) and treatments ($F = 3.76$, df = 3, 236, $p = 0.035$), and it ranged from 4.5 ± 0.4 % to 27.7 ± 2.1 %. The plots with DOM (sav ctrl, mmdom) had higher water content than those without. Reflecting the seasons, the lowest water content was recorded in December 2017 for mb, mbnpk and sav ctrl, while the highest was recorded in August 2018 for mmdom. In March 2018, early precipitation (Fig. 1) resulted in an increase of soil water content, with values close to those of May 2017/18 (start of rainy season).

The soil pH varied among treatments ($F = 26.99$, df = 3, 236, $p = 4.186e^{-15}$), but not over time ($F = 1.09$, df = 5,234, $p = 0.366$). Its range was between 4.1 and 5.6 (Tab. 2). The lowest pH of 4.1 was recorded for mb (DOM removed, 4.1 ± 0.6) and mbnpk (NPK-application, 4.1 ± 0.5). The plots with left or added DOM had higher pH than those without. The highest pH of 5.6 ± 0.2 was recorded in mmdom, June 2018. Similar high pH was recorded for the savanna in October 2017 (5.5 ± 0.1) and August 2018 (5.5 ± 0.2).

3.2 Microarthropods

3.2.1 Abundance

For the different plots, abundances of total microarthropods (annual means) showed distinct differences (Kruskal-Wallis test: $Chi^2 = 120.86$, df = 3, $p < 0.0001$) among groups, ranging from 3.4 to 14.0 tsd. ind./m^2 (Tab. 3). For the plots with left and added DOM (sav ctrl, mmdom), up to three times more individuals were recorded than for mb, where DOM was removed. The abundance for mmdom was even higher than that for sav ctrl. Compared to mb, NPK application (mbnpk) reduced abundances by a factor of 0.7 in both years and in respect to sav ctrl by even 0.4 (2017) and 0.3 (2018).

Acari made up for more than 70 % of the microarthropods retrieved. Within Acari, the Oribatida were most abundant, representing 50 % of the individuals, followed by Gamasina, which accounted for about 46 % in both years. Prostigmata, Astigmata and Uropodina accounted for less than 4 % in total and were not considered for further analyses. Consequently, results focused on the two Acari groups Oribatida and Gamasina.

For Collembola, Entomobryomorpha and Poduromorpha were not differentiated, although both groups were present. The ratio of Acari in respect to Collembola did not give a consistent pattern, being lowest in the NPK treatment in Aug. 2017 (0.7), and highest in the same treatment in Oct. 2017 (22.0).

3.2.2 Temporal dynamics of microarthropod abundances

Seasonal variation of Acari and Collembola abundances

Abundances for two rainy seasons were assessed by the campaigns in June, August and October of 2017 and 2018, those for one dry season in December of 2017 and March of 2018. Data pooled over plots and sampling campaigns

Table 2. Soil water content (WC %) and pH recorded in savanna (sav ctrl) and experimental plots (mean ± S.D).

	WC (%)				pH			
2017	sav ctrl	mb	mbnpk	mmdom	sav ctrl	mb	mbnpk	mmdom
May	11.0 ± 0.7	9.6 ± 1.0	9.6 ± 1.2	12.1 ± 0.7	4.9 ± 0.1	5.0 ± 0.6	5.0 ± 0.2	5.1 ± 0.3
Jun	17.1 ± 1.7	16.2 ± 1.3	16.0 ± 1.4	18.2 ± 1.0	5.3 ± 0.2	5.2 ± 0.4	4.6 ± 0.2	5.3 ± 0.2
Aug	26.6 ± 4.0	22.8 ± 4.8	22.4 ± 1.3	25.3 ± 2.1	5.3 ± 0.1	5.4 ± 0.2	4.8 ± 0.5	5.3 ± 0.2
Oct	15.8 ± 1.6	15.6 ± 1.3	14.7 ± 1.0	15.7 ± 1.9	5.5 ± 0.1	5.4 ± 0.2	4.6 ± 0.3	5.5 ± 0.2
Dec	4.5 ± 0.4	4.5 ± 0.6	4.5 ± 0.9	4.9 ± 1.1	5.4 ± 0.3	4.8 ± 0.6	4.7 ± 0.1	4.9 ± 0.3
Mean	15.0 ± 8.1	13.7 ± 6.9	13.4 ± 6.7	15.2 ± 7.5	5.3 ± 0.1	5.2 ± 0.2	4.7 ± 0.1	5.2 ± 0.2
Max	26.6	22.8	22.4	25.3	5.5	5.4	5.0	5.5
Min	4.5	4.5	4.5	4.9	4.9	4.8	4.6	4.9
Range	22.1	18.3	17.9	20.4	0.6	0.6	0.4	0.6
	WC (%)				pH			
2018	sav ctrl	mb	mbnpk	mmdom	sav ctrl	mb	mbnpk	mmdom
Mar	8.7 ± 0.2	8.4 ± 0.4	8.2 ± 0.3	8.8 ± 0.5	5.3 ± 0.2	5.3 ± 0.4	4.6 ± 0.2	5.5 ± 0.2
May	10.2 ± 0.7	9.2 ± 1.0	9.8 ± 1.4	10.8 ± 0.9	5.2 ± 0.1	5.1 ± 0.2	4.1 ± 0.5	5.3 ± 0.2
Jun	17.0 ± 1.6	16.1 ± 1.3	15.9 ± 1.4	18.3 ± 1.0	5.4 ± 0.1	5.4 ± 0.2	4.8 ± 0.3	5.6 ± 0.2
Aug	25.8 ± 3.4	24.3 ± 4.8	24.4 ± 1.3	27.7 ± 2.1	5.5 ± 0.2	4.9 ± 0.6	4.7 ± 0.1	5.1 ± 0.3
Oct	16.9 ± 1.2	14.1 ± 1.3	14.6 ± 1.0	17.4 ± 1.9	5.1 ± 0.1	4.1 ± 0.6	4.2 ± 0.2	4.7 ± 0.3
Mean	15.7 ± 6.7	14.4 ± 6.4	14.6 ± 6.3	16.6 ± 7.4	5.3 ± 0.1	5.0 ± 0.2	4.5 ± 0.1	5.2 ± 0.2
Max	25.8	24.3	24.4	27.7	5.5	5.4	4.8	5.6
Min	8.7	8.4	8.2	8.8	5.1	4.1	4.1	4.7
Range	17.1	15.9	16.2	18.9	0.4	1.3	0.7	0.9

WC: water content, sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dead organic matter.

Table 3. Microarthropod abundance (tsd. ind./m^2) and dominance (D %), recorded from the soil of savanna and the experimental plots (annual means of 5 campaigns).

year	Taxa	Treatments sav ctrl	mb	mbnpk	mmdom	D %
2017	**Microarthropod groups**					
	Collembola	1.9	0.9	1.2	2.8	**21.6**
	Acari	7.8	4.0	2.1	11.2	**78.4**
	total	9.7	4.9	3.4	14.0	**100**
	Acari groups					
	Oribatida	4.0	2.2	0.9	5.5	**50.0**
	Gamasina	3.3	1.6	1.0	5.6	**46.1**
	Uropodina	0.0	0.1	0.0	0.1	**1.1**
	Prostigmata	0.5	0.0	0.0	0.0	**2.0**
	Astigmata	0.0	0.1	0.1	0.0	**0.8**
	total	**7.8**	**4.0**	**2.1**	**11.2**	**100**
2018	**Microarthropod groups**					
	Collembola	3.5	1.2	0.6	3.1	**25.4**
	Acari	7.4	4.3	3.1	9.8	**74.6**
	total	10.9	5.5	3.6	12.9	**100**
	Acari groups					
	Oribatida	3.8	1.7	1.6	5.3	**50.2**
	Gamasina	3.2	2.4	1.4	4.4	**46.6**
	Uropodina	0.1	0.1	0.0	0.1	**1.5**
	Prostigmata	0.3	0.0	0.0	0.0	**1.4**
	Astigmata	0.0	0.0	0.0	0.0	**0.2**
	Total	**7.4**	**4.3**	**3.1**	**9.8**	**100**

With D > 10% dominant, 1% < D < 10% common, D < 1% rare.
sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dead organic matter.

showed that Acari and Collembola were present in the dry season but with much lower abundances than in the rainy seasons (Figs 3 and 4), regardless of time(Kruskal-Wallis test: $Chi^2 = 43.265$, df = 5, $p < 0.0001$) and treatments (Kruskal-Wallis test: $Chi^2 = 122.19$, d.f. = 3, $p < 0.0001$).With the rains, abundances of Acari increased more than three times as compared to the dry season, particularly in plots with DOM added (mmdom). This phenomenon was similar for Collembola, but in 2017 the effect of rainy season was small in sav ctrl (Fig. 3). For data pooled over sampling campaigns, the decline in abundance from the rainy toward the dry seasons was 40 % for Acari, 51 % for Collembola, 50 % for Oribatida and 33 % for Gamasina.

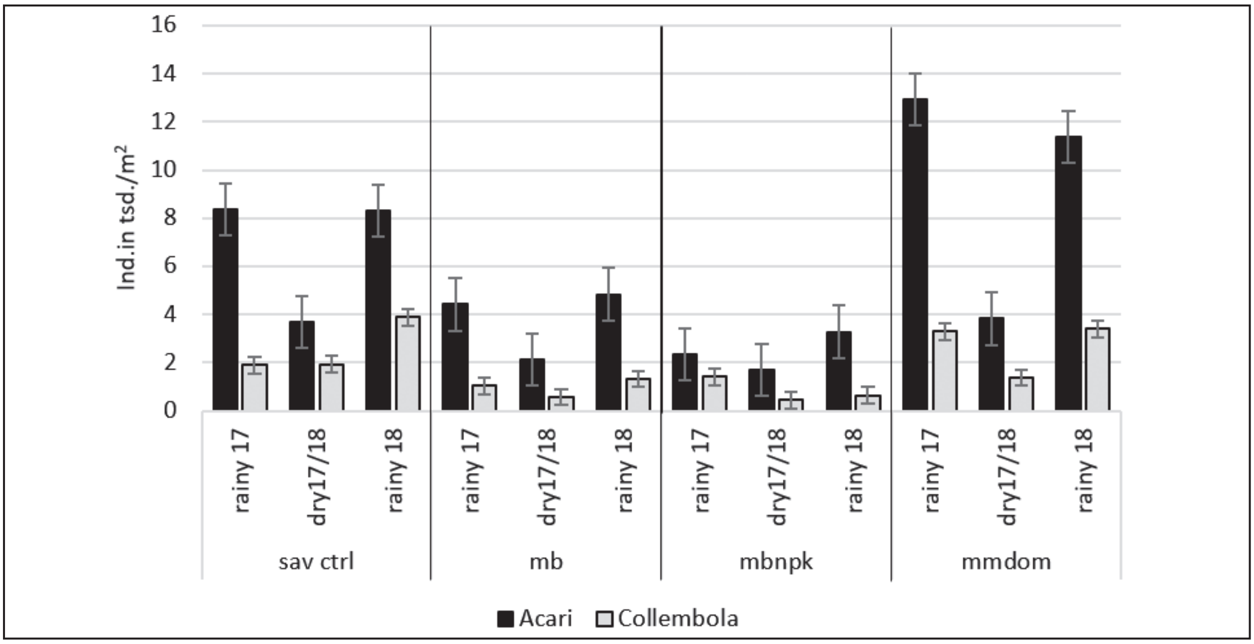

Figure 3. Abundances (mean ± S.E.) of Acari and Collembola for the rainy seasons of 2017 (*n* = 4) and 2018 (*n* = 4) as well as for the dry season of 2017/18 (*n* = 2). *n* sampling campaigns with 9 samples per plot [sav ctrl: savanna; mb: maize bare; mbnpk: maize with chemical NPK fertilizer; mmdom: maize with dead organic matter (DOM)].

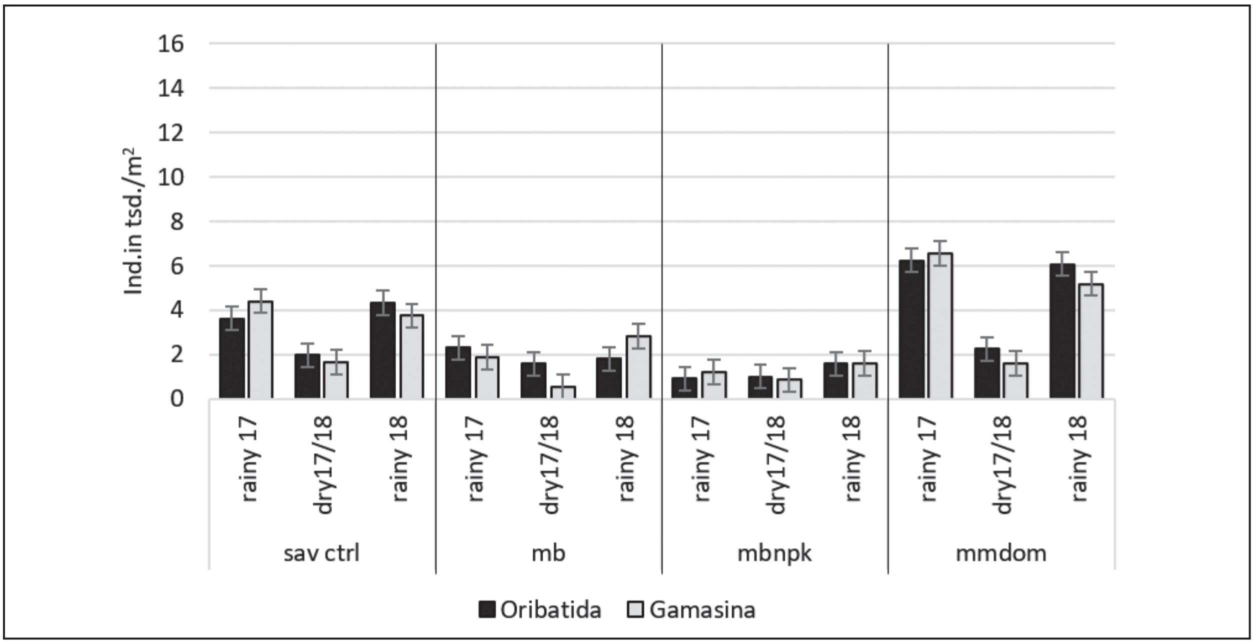

Figure 4. Abundances (mean ± S.E.) of Oribatida and Gamasina for the rainy seasons of 2017 (n = 4) and 2018 (n = 4) as well as for the dry season of 2017/18 (n = 2). n sampling campaigns with 9 samples per plot [sav ctrl: savanna; mb: maize bare; mbnpk: maize with chemical NPK fertilizer; mmdom: maize with dead organic matter (DOM)].

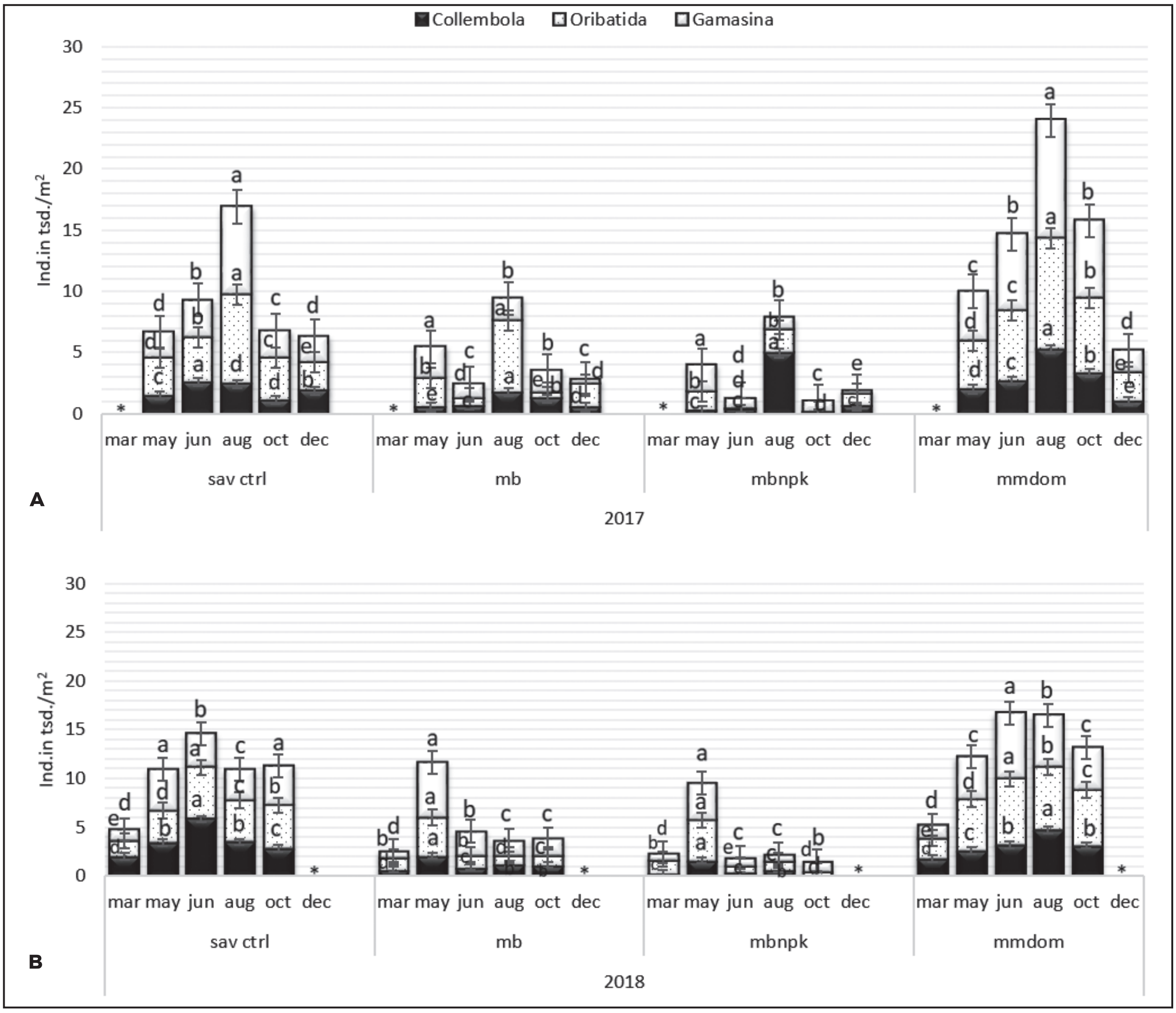

Figure 5. Temporal variation of Collembola, Oribatida and Gamasina abundance (tsd. ind./m2) in savanna and experimental field in (**A**) 2017 and (**B**) 2018. Abundance being significantly different from each other in time per treatment are marked by different letters for each microarthropod group (Wilcoxon signed-rank test [p < 0.05]). Months not sampled are marked by asterisks. Error bars = standard error. sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dry organic matter (DOM).

Monthly variation of Acari and Collembola abundances

As expected, for data pooled over treatments, Collembola (Friedman $\chi^2 = 34.79$, df = 9, $p < 0.0001$), Acari (Friedman $\chi^2 = 45.309$, df = 9, $p < 0.0001$), Oribatida (Friedman $\chi^2 = 32.27$, df = 9, $p < 0.001$) and Gamasina (Friedman $\chi^2 = 43.61$, df = 9, $p < 00001$) abundances varied significantly across sampling months. The differences in the abundances of microarthropods across sampling months are represented in Table 4, with p-values in bold. Generally, the abundance of Acari (27 pairs) differed more among sampling dates than Collembola (13 pairs). For Acari, differences in abundance among sampling dates were much higher for Gamasina (25 pairs) compared with Oribatida (10 pairs).

The temporal trends of abundances of Collembola in the DOM plots were similar to those of the two mite groups (Figs 5A and 5B), as they showed a clear relation to the rains in the plots with DOM. In contrast to the mites, these trends were more pronounced in 2018 than in 2017. Peaks became evident for sav ctrl in June and August 2017 and June 2018, for mmdom in August 2017 and 2018. Surprisingly, the abundances of Collembola for sav ctrl and mbnpk increased in 2017 from October (rainy) to December (dry season). In the mb plots, decrease of abundance was documented after a peak in May in the rainy season of 2018.

The trends in the abundances of Oribatida across months were similar for the DOM plots (sav ctrl and mmdom) and for the plots without DOM (mb and

Table 4. Differences in the abundances of microarthropods across sampling months according to Durbin test with Bonferroni correction.

	Aug 2017	Aug 2018	Dec 2017	Jun 2017	Jun 2018	Mar 2018	May 2017	May 2018	Oct 2017
Collembola									
Aug 2018	1.0000	-	-	-	-	-	-	-	-
Dec 2017	**0.0007**	**0.0000**	-	-	-	-	-	-	-
Jun 2017	0.0873	**0.0031**	1.0000	-	-	-	-	-	-
Jun 2018	1.0000	1.0000	**0.0003**	0.0461	-	-	-	-	-
Mar. 2018	**0.0062**	**0.0002**	1.0000	1.0000	**0.0030**	-	-	-	-
May 2017	0.2412	**0.0098**	1.0000	1.0000	0.1320	1.0000	-	-	-
May 2018	1.0000	1.0000	**0.0002**	**0.0298**	1.0000	**0.0019**	0.0873	-	-
Oct 2017	0.1075	**0.0039**	1.0000	1.0000	0.0572	1.0000	1.0000	**0.0371**	-
Oct 2018	1.0000	0.5192	0.0873	1.0000	1.0000	0.5192	1.0000	1.0000	1.0000
Acari									
Aug 2018	**0.0025**	-	-	-	-	-	-	-	-
Dec 2017	**0.0000**	**0.0003**	-	-	-	-	-	-	-
Jun 2017	**0.0000**	0.0708	0.9544	-	-	-	-	-	-
Jun 2018	**0.0017**	1.0000	**0.0000**	0.0967	-	-	-	-	-
Mar 2018	**0.0000**	**0.0000**	1.0000	**0.0271**	**0.0000**	-	-	-	-
May 2017	**0.0000**	1.0000	**0.0035**	1.0000	1.0000	**0.0000**	-	-	-
May 2018	1.0000	**0.0375**	**0.0000**	**0.0000**	**0.0271**	**0.0000**	**0.0004**	-	-
Oct 2017	**0.0000**	1.0000	**0.0035**	1.0000	1.0000	**0.0000**	1.0000	**0.0004**	-
Oct 2018	**0.0001**	1.0000	**0.0006**	0.7325	1.0000	**0.0000**	1.0000	**0.0025**	1.0000
Oribatida									
Aug 2018	0.4636	-	-	-	-	-	-	-	-
Dec 2017	**0.0003**	0.9193	-	-	-	-	-	-	-
Jun 2017	**0.0137**	1.0000	1.0000	-	-	-	-	-	-
Jun 2018	0.0580	1.0000	1.0000	1.0000	-	-	-	-	-
Mar 2018	**0.0000**	**0.0257**	1.0000	0.7778	0.2246	-	-	-	-
May 2017	**0.0208**	1.0000	1.0000	1.0000	1.0000	0.5523	-	-	-
May 2018	1.0000	1.0000	**0.0012**	**0.0474**	0.1863	**0.0001**	0.0708	-	-
Oct 2017	**0.0110**	1.0000	1.0000	1.0000	1.0000	0.9193	1.0000	**0.0387**	-
Oct 2018	0.0863	1.0000	1.0000	1.0000	1.0000	0.1542	1.0000	0.2702	1.0000
Gamasina									
Aug 2018	**0.0000**	-	-	-	-	-	-	-	-
Dec 2017	**0.0000**	**0.0113**	-	-	-	-	-	-	-
Jun 2017	**0.0000**	1.0000	0.0679	-	-	-	-	-	-
Jun 2018	0.2715	0.5887	**0.0000**	0.1198	-	-	-	-	-
Mar 2018	**0.0000**	**0.0032**	1.0000	**0.0208**	**0.0000**	-	-	-	-
May 2017	**0.0032**	1.0000	**0.0003**	1.0000	1.0000	**0.0000**	-	-	-
May 2018	1.0000	**0.0004**	**0.0000**	**0.0000**	0.9603	**0.0000**	**0.0154**	-	-
Oct 2017	**0.0003**	1.0000	**0.0032**	1.0000	1.0000	**0.0008**	1.0000	**0.0017**	-
Oct 2018	**0.0003**	1.0000	**0.0032**	1.0000	1.0000	**0.0008**	1.0000	**0.0017**	1.0000

mbnpk), respectively, but different for the two plots. Considering the DOM plots, the increase of abundance was progressive in the rainy seasons, peaking in August 2017 and June 2018, and declined towards the dry season. For the plots without DOM, no clear trends in abundances were documented, with peaks in August and May for the years 2017 and 2018, respectively.

With maxima in August, the abundances of Gamasina reflected the rainy seasons in 2017 in particular for mmdom, less for sav ctrl. For the plots with DOM removed, even a declining trend after the May peaks may be speculated. For Oribatida, maxima appeared earlier in 2018 (May, June). Apart from mmdom, temporal trends were less clear in this year.

Treatments modify effect of soil water content on abundances

The changing season (dry and rainy season) are reflected by the water content in the soil (WC %, Tab. 2). The results of the regression of abundances on WC % was treatments-dependent (Tab. 5).

With thresholds set arbitrarily, the modification of a positive influence of water content on abundances by the treatments became evident. Removal of organic matter in the mb plots appeared to inhibit the positive effect of the rains and may even lead to a negative slope. For the two mite groups, addition of DOM was particularly beneficial (mmdom, slope $\geq$ 0.25). For all three microarthropod groups, R^2 was high in this treatment.

3.2.3 Effect of treatments on abundances of microarthropod groups

Maize cultivation

Conventional maize cultivation implies the removal of DOM before seeding. This affected the soil water content (WC %, Tab. 2). As compared to sav ctrl, the soil on mb contained up to 17 % less water (calculated from the means of all campaigns). With DOM added (mmdom), up to 26 % higher water content was documented, relative to mb. The influence of maize cultivation (mb) on microarthropod group abundances in comparison to the savanna control (sav ctrl) is illustrated in Fig. 6. Data pooled over months and years indicated that the abundance of microarthropods was higher for sav ctrl than for mb for Gamasina ($V = 0$, $p = 0.005$) and Collembola ($V = 10$, $p = 0.013$), but similar for Oribatida ($V = 62$, $p = 0.007$). However, considering the temporal fluctuations as shown in the graphs, the abundances of Oribatida were higher in sav crtl as compared to mb, except for August 2017. For Gamasina and Collembola, monthly abundances were higher in sav ctrl than in mb, except for May 2018 and October 2017.

Effect of chemical fertilizer NPK on microarthropod group abundances

When data were pooled over months and years, Oribatida ($V = 136$, $p = 0.005$), Gamasina ($V = 132$, $p = 0.001$) and Collembola ($V = 96$, $p = 0.001$) were more abundant in the mb plots (maize without any substrate) compared with the mbnpk plots (maize cultivated with chemical fertilizer NPK). Monthly variations in the microarthropod abundance showed the same trend, but for Oribatida in May 2018, when the trend was reversed (Fig. 7). The addition of NPK to the bare soil (mb) reduced abundances of Collembola in all campaigns. Data pooled over months revealed that the abundances of microarthropods were reduced by the NPK application by up to 50 % in comparison to mb.

Effect of DOM on microarthropod group abundances

For the data averaged across months and years, the abundances of Oribatida ($V = 0$, $p = 0.003$), Gamasina ($V = 0$, $p = 0.001$) and Collembola ($V = 0$, $p = 0.001$) in the plot with DOM (mmdom) was by far superior to those in the plot without DOM (mb). The monthly abundances of the three microarthropods followed the same trends (Fig. 8), except for Gamasina in May 2018, when mb appeared to be superior to mmdom for that parameter. The abundances of Oribatida, Gamasina and Collembola in the mmdom relative to the mb plots were 3-fold, 2.5-fold and 2.8-fold.

Effect of treatments on community structure of soil microarthropods

Simple ratios of the microarthropod groups revealed distinct differences of the community structure (Tab. 6). The Acari/Collembola ratio of NPK was clearly higher than on the other plots and showed a remarkable range of the means of the five campaigns in 2017/18, respectively. Collembola were particularly affected by the NPK treatment. Within the Acari, Oribatida and Gamasina had surprisingly similar abundances (see also Tab. 3). Although the means did not show clear trends for the OR/GA ratio, the range was very small in the plots with DOM remaining or added and considerably higher in the plots with DOM removed. This was an indication for relatively higher abundances of Oribatida in these plots. As indicated by the range, the OR/GA ratio in particular did not vary much over time in the plots with left or added DOM, indicating a stable community structure in the mites.

Table 5. Results for Pearson linear correlations of water content (WC %) and abundances.

	Oribatida		Gamasina		Collembola	
	equation	R^2	equation	R^2	equation	R^2
sav ctrl	**y=0.16x+1.48**	**R^2 =0.47***	y=0.14x+1.10	R^2 =0.36ns	y=0.04x+2.08	R^2 =0.04ns
mb	y=0.03x+1.60	R^2 =0.00ns	y=-0.01x+2.17	R^2 =0.00ns	y=0.03x+0.60	R^2 =0.15ns
mbnpk	y=-0.04x+1.81	R^2 =0.04ns	y=- 0.01x+1.72	R^2 =0.04ns	y=0.10x-0.47	R^2 =0.17ns
mmdom	**y=0.25x+1.35**	**R^2 =0.73****	**y=0.27x+0.77**	**R^2 =0.60****	**y=0.17x+0.23**	**R^2 =0.89*****

df = 8, R2 < 0.399, ns = non-significant , R2 ≥ 0.399, * = significant at the 5% probability level , R2 ≥ 0.585; ** = significant at the 1% probability level, R2 ≥ 0.761; *** = significant at the 0.1% probability level. sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dead organic matter.

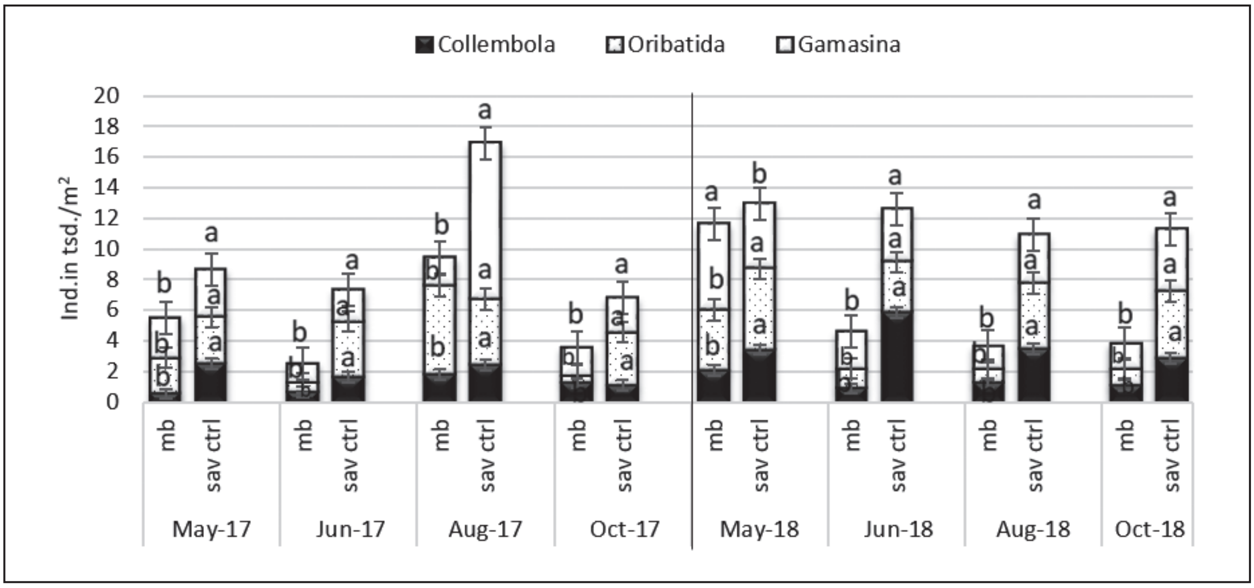

Figure 6. Effect of Maize cultivation on Collembola, Oribatida and Gamasina in control plots (sav ctrl: savanna, mb: maize bare). Abundances being significantly different from each other are marked by different letters for each microarthropod group (Wilcoxon signed-rank test [p < 0.05]). Error bars = standard error.

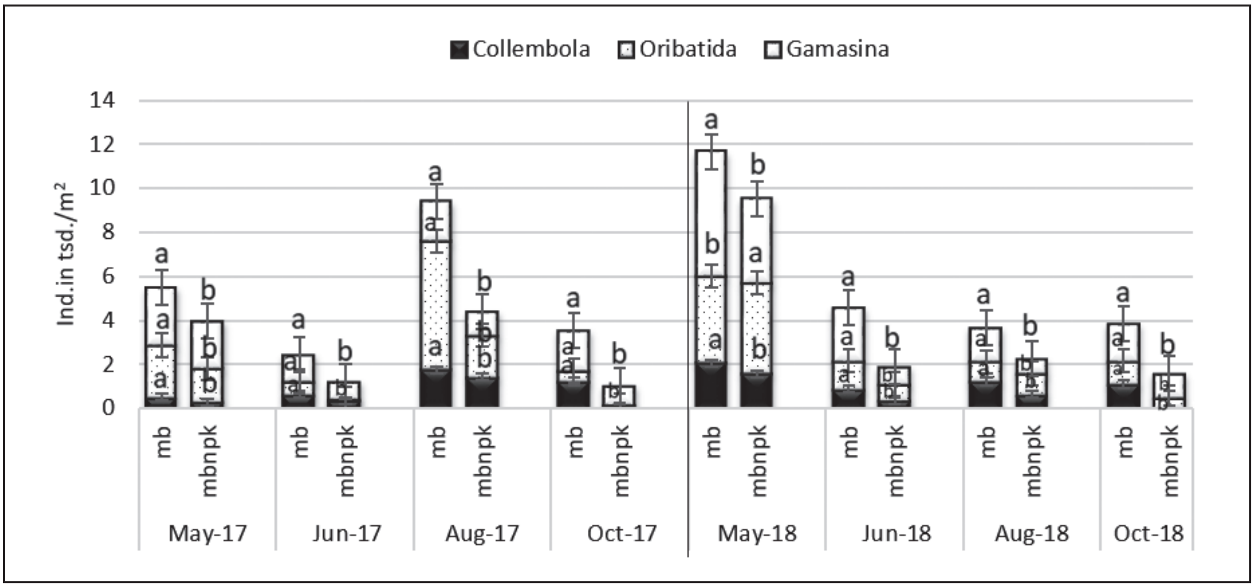

Figure 7. Collembola, Oribatida and Gamasina abundance (tsd. ind./m^2) in plots (mb: maize bare, mbnpk: maize with chemical NPK). Abundances being significantly different from each other are marked by different letters (Wilcoxon signed rank test [p < 0.05]). Error bars = standard error.

Principal Component Analysis

The PCA showed that the abundance of soil microarthropods was positively correlated with environmental factors (pH and WC), but the pH was negatively correlated with the WC. The microarthropods most affected by the pH were Collembolan (Fig. 9), meanwhile, Gamasina seemed to prefer high WC. The analysis per treatment did not reveal a clear segregation between treatments. However, the PCA plot showed that treatment with low pH and WC (i.e. mbnpk and mb) recorded low abundances of soil microarthropods.

Six variables were considered for the PCA biplot pH, WC, Collembola, Acari, Oibatida and Gamasina with Eigenvalues (3.214020057, 0.918969828, 0.865244815, 0.550981892, 0.443301563, 0.007481845, respectively) (Fig.10). Correlation circles showed that soil microarthropods were more correlated with DOM. The rainy season months had larger correlation circles than the dry season months. August 2017 had the largest correlation circle, while December 2017 and March 2018 (dry season months) had the smallest correlation circle and recorded a lower abundance of soil microarthropods compared to other months.

4. Discussion

4.1 Soil parameters

In the present study, water contents tended to be higher in soils with DOM left (sav ctrl) or added (mmdom) compared to the treatments without DOM. Gruda (2008) demonstrated that mulching reduced the rate of

Table 6. Ratios of microarthropod groups on the plots.

		mean		range	
		2017	**2018**	**2017**	**2018**
AC/COL	sav ctrl	4.1	2.2	4.5	2.0
	mb	4.7	3.4	7.3	2.5
	mbnpk	8.0	4.9	21.3	4.1
	mmdom	4.0	3.2	1.0	2.3
OR/GA	sav ctrl	1.3	1.2	0.4	0.8
	mb	1.9	0.9	**1.5**	**4.3**
	mbnpk	1.2	1.2	**1.5**	**3.3**
	mmdom	1.0	1.3	0.6	0.4

sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dead organic matter. Bold numbers indicate a strong variation in the communities highlighted.

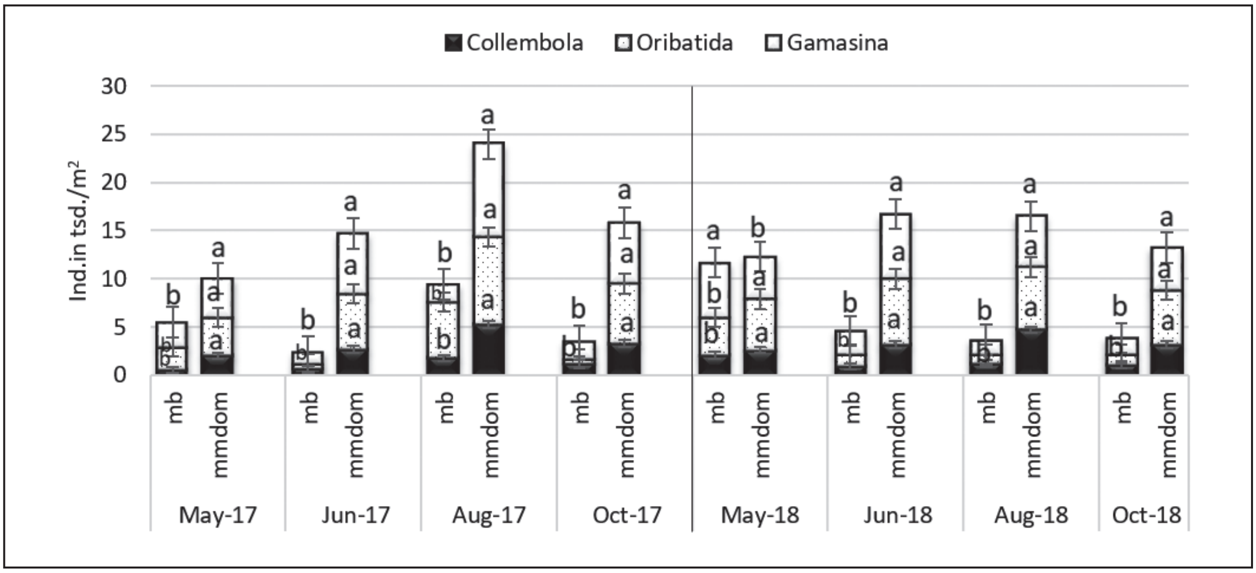

Figure 8. Oribatida and Gamasina abundance (tsd. ind./m2) in plots (mb: maize bare, mmdom: maize with DOM). Abundances being significantly different from each other are marked by different letters for each microarthropod group (Wilcoxon signed rank test [p < 0.05]). Error bars = standard error.

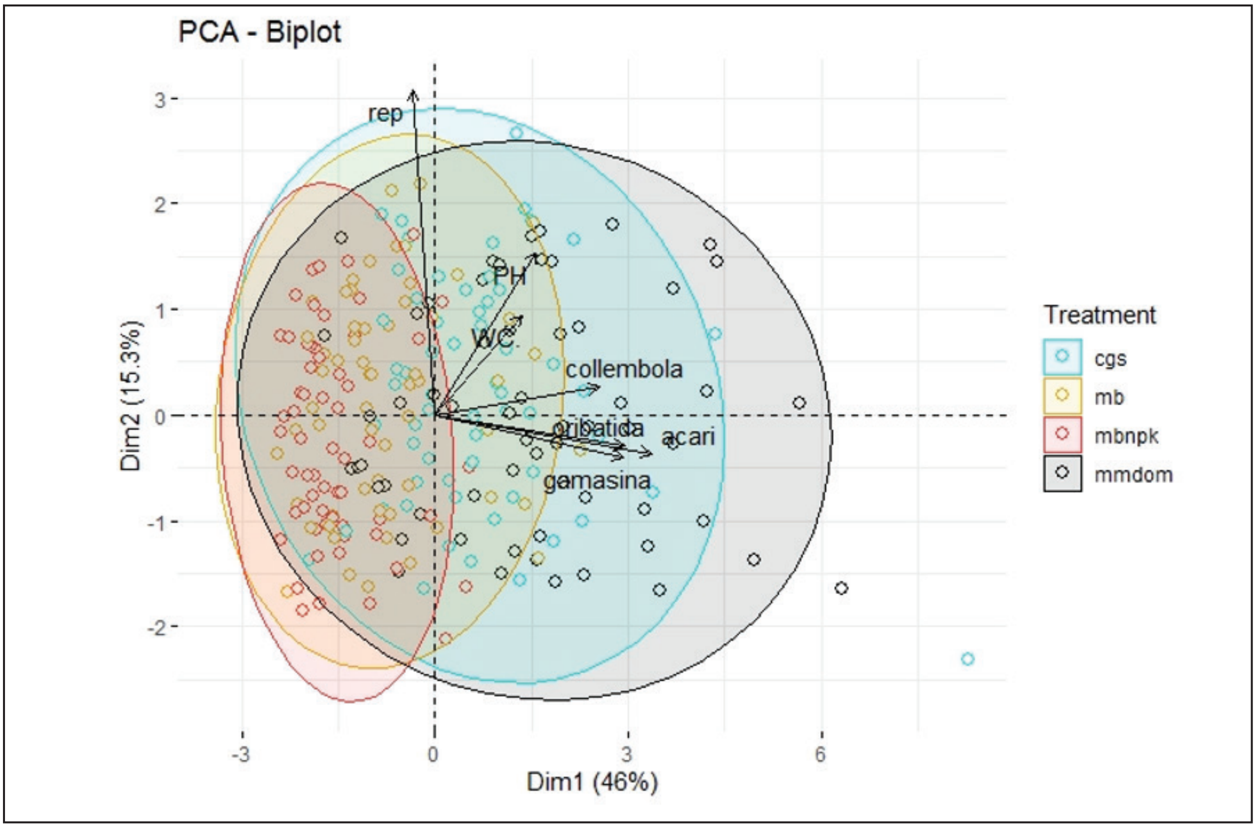

Figure 9. PCA biplot of environmental parameters and abundance of microarthropods with treatment as grouping factor. sav ctrl: savanna, mb: maize bare, mbnpk: maize with chemical NPK fertilizer, mmdom: maize with dead organic matter.

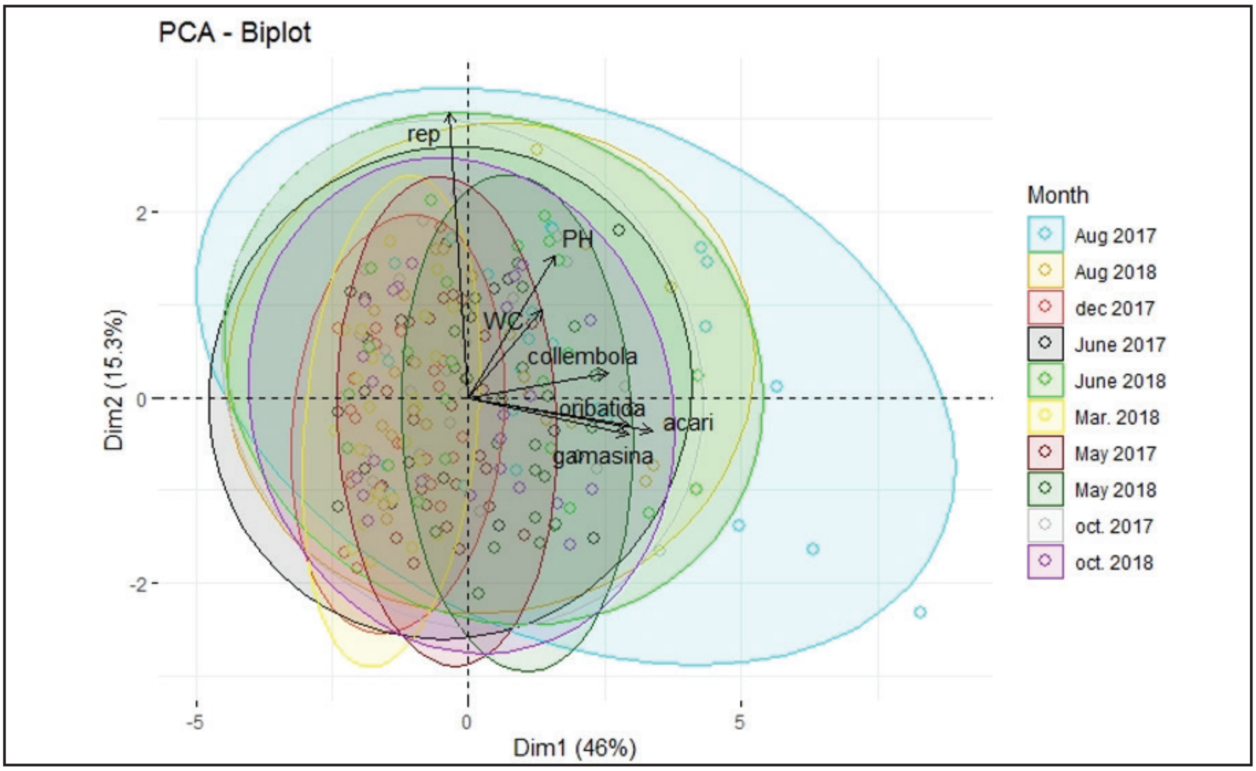

Figure 10: PCA biplot of environmental parameters and abundance of microarthropods with month as grouping factor. sav ctrl: savanna; mb: maize bare; mbnpk: maize with chemical NPK fertilizer; mmdom: maize with dead organic matter.

water evaporation from the soil and thus increased the water holding capacity of the soil, probably by retaining humidity. Our study indicated that soil water contents were higher in soils with DOM left (sav ctrl) or added (mmdom), thus; corroborating the findings of Gruda (2008). In addition to the high-water holding capacity of DOM, its degradation processes produced water vapour. This water is trapped in the soil matrix for a well-defined period due to porosity, which has the effect of an attempered soil moisture (Gruda 2008, Demir et al. 2009). Several studies around the world have supported the increase in soil water contents in the presence of dead organic matter or organic by products. Didier et al. (2018) showed that the mulch from virgin sugar cane harvest retained soil moisture compared to plots with no mulch both for irrigated and rainfed plots at Ferké 1 in northern Côte d'Ivoire. Similarly, three organic wastes, shredded date palm leaves, cereal straw and pine bark used as mulch in two soils with different textures (loam and silty loam) in a greenhouse in Spain had very low levels of evaporation compared with the soils without mulch, although significant differences were observed among organic waste (Rico Hernández et al. 2016). In a soybean field trial involving straw, grass, plastic and paper mulch and bare soil versus soil water retention at Gifu University Farm in Japan, the plastic and straw mulching stored the highest quantity of soil moisture, whereas the bare soil stored the lowest (Kader et al. 2017). In the present study, although DOM was not added to the savanna control (sav ctrl), the soil was covered with dead leaves from the plants and dry grass, providing considerable quantities of mulch to the soil. Therefore, it was not surprising that the soils with this treatment retained more moisture than the treatments without DOM, as clearly announced above that mulch retains soil water. The shading of the soil surface by the herbaceous vegetation of the savanna may have reduced the evaporation of water from the soil, the transpiration of water through the plants notwithstanding. This contention might have contributed also to the higher soil water content of the sav ctrl plots.

Soil acidification is a widespread natural phenomenon in regions with medium to high rainfall, and agricultural production systems can accelerate soil acidification processes through perturbation of the natural cycles of nitrogen (N), phosphorus (P) and sulfur (S) in soil, through removal of agricultural produce from the land, and through addition of fertilizers and soil amendments that can either acidify soil or make it more alkaline (Kennedy 1986). Changes in soil pH may be advantageous or detrimental depending on the starting pH of the soil and the direction and speed of pH change – for example decreases in soil pH in alkaline soils may be advantageous for crop production due to benefits in terms of the availability of P and micronutrients e.g. zinc (Zn) (Mitchell et al. 1952). On the other hand, decreases in soil pH for a highly acidic soil may be detrimental in terms of increasing crop susceptibility to toxicity induced by increased solubility of aluminum (Al) or manganese (Mn) as soil pH falls (Guinto 2015). In the present study, the soil was acidic and the addition of NPK fertilizer reduced the pH (4.7 and 4.5 in 2017 and 2018, respectively), which could be detrimental to crop productivity. Other studies have reported that the application of NPK results in an expected acidification (Bolan et al. 2005). However, the presence of dead organic matter in the soil tended to increase the pH (5.3 in both 2017 and 2018) in this study. Celik et al. (2004) and Valarini et al. (2009) have reported that dead organic matter as compost or mulch may render acid soil more alkaline. According to Agri-Stat (2012), NPK fertilizer is the most applied fertilisation method in crop production in the HGSZ of Cameroon. The non-rational application of this fertiliser could lead to soil acidification by the accumulation of H+ protons, which could have a deleterious effect on plants (Lükewille & Alewell 2008).

4.2 Microarthropods

Acari and Collembola abundances and group dominance

The findings of the present study document considerable abundances of 16 tsd. ind./m^2 Acari and 8 tsd ind./m^2 Collembola in savanna area, which is close to the findings of Danra et al. (2021) who recorded 23 tsd. ind./m^2 Acari and 6 tsd ind./m^2 Collembola, indicating the reliability of the method used and the results obtained. However, Danra et al. (2021) demonstrated up to 228 tsd. ind./m^2 Acari and 37 tsd ind./m^2 Collembola for composed amended substrates which was much higher compared with 20 tsd. ind./m^2 Acari and 7 tsd. ind./m^2 Collembola for DOM in the present study. In Danra et al. (2021) results of other studies on microarthropod abundances are listed, documenting a considerable presence of soil microarthropods in the savanna system investigated in the Ngaoundéré studies.

The Acari to Collembola ratio in our study ranges from 2.2 to 8.0 - which is higher than findings from sites in the vicinity of Bremen (Northern Germany, grassland; 2.4-3.8, unpublished data). For the climate of Ngaoundéré region, a high sensitivity of Collembola to drought may be speculated due to their delicate sclerotization (Pflug & Wolters 2001). Also Sheikh et al. (2017) discusses for his findings from an orchard soil in Kashmir (India) the sclerotization of Gamasina and Oribatida as a protection against drought, when compared to Collembola. However, it must be considered that Acari and Collembola as groups are very diverse in their biology and life history, so that the AC/COLL ratio is quite variable and should be considered with caution (e.g., Miller et al. 2014).

The generally very small size of the Gamasina and Oribatida found in the Ngaoundéré savanna allows the colonization of relatively fine soil pores and deeper soil being probably a key element of their survival in soils (Danra et al. 2021). The abundances of Oribatida and Gamasina are remarkably similar in range (OR/GA from 0.9-1.9). In temperate soils, Oribatida by far outnumber Gamasina. This contrast opens areas of research on their food sources and on their role in the savanna system in general. Studies on the abundance of soil microarthropods in different plots reveal that the use of mulches in cultivated fields has a much greater benefit for microarthropods than uncultivated savanna soils. The impact of no tillage on soil microarthropods has not been observed in the savanna, which opens the way for the presence of other negative impacts such as bush fires and grazing.

Temporal dynamics of abundances

In our study, we observed high variation of microarthropod abundances. Since temperatures do not fluctuate too much over the year, this is at first sight related to soil humidity and plant productivity as a consequence of dry and rainy seasons.

The lowest abundances are recorded in the dry season (Nov-Mar; Fig.1). Desiccation and shrinking of argillaceous soil may account for low microarthropod abundances in the dry season (Okiwelu et al. 2012, Shakir & Ahmed 2014, Danra et al. 2018, Danra et al. 2021). For the reasons indicated above, Collembola are most affected by the dry season.

With the onset of the rains, microarthropod abundances increase considerably which seems to be related to a fast population development in warm, but humid soils with an increasingly developed vegetation. This could provide a microclimate that better conserves humidity, being indispensable for soil microarthropod population development. Immigration from humid 'islands' is unlikely but survival of drought in deeper soil layers should be investigated by sampling below 20 cm depth (Danra et al. 2021).

However, the positive effect of the rains on microarthropod abundances becomes not evident in the plots with DOM removed, but only in the plots with left or added DOM (sav ctrl, mmdom). As estimated by eye, maize development on mbnpk is lush (Fig. 2) with all its generally positive effects on microclimate and food resource, but abundances are lowest. This is an indication that mulch not only improves microclimate, but also resources different from those provided by freshly grown maize.The comparatively early maxima n 2018 may be attributed to the early rains in this year, which also becomes plausible from the May abundances which are higher in 2018 than in 2017.

It is confirmed that dynamic extraction documents presence of microarthropods in the soil in the dry season. With the start of the rainy seasons, abundances increase considerably. However, this is strongly influenced by treatment. Removal of DOM results in a strong reduction of abundances of microarthropods and irregular temporal trends. The trends for the abundances of saprophagous Oribatida and predatory Gamasina are even more consistent than those of Acari and Collembola, suggesting that trophic level may not so much affect the reaction to drought as sclerotization (weak in Collembola).

Based on these findings, hypothesis 1 is accepted as far as the governing role of soil humidity is concerned.

Effect of maize cultivation on microarthropod group abundances

Maize cultivation is a profound disturbance of the soil environment. It includes tillage modifying the structure and pore-space, which is the living space for microarthropods. Tillage also removes DOM from the surface affecting the food resources for decomposers and exposes the soil fauna to unbuffered temperature and desiccation (Bachelier 1971, Bedano et al. 2006). On the other hand, in the course of the growing season the vegetation mitigates microclimate and provides resources.

In temperate soils, many studies document the negative effect of tillage on soil microarthropods. Dubie et al. (2011), for example, found greater abundances of six microarthropod groups including Oribatida and Collembola in no-till than in conventionally tilled plots at Stillwater, Oklahoma, U.S.A. Badejo et al. (1995) document very low abundances in bare fallow in a bimodal rainfall system in Ibadan (Nigeria). In savanna systems with pronounced dry and rainy seasons (unimodal rainfall), tillage - usually at the beginning of the rainy season – has a similarly severe impact. This may at least in parts be responsible for the lower microarthropod group abundance in mb (conventionally tilled) as compared to the savanna (no-till) plots.

In view of this, hypothesis 2 is accepted in respect to the effect of tillage.

Effect of NPK application on microarthropod group abundances

NPK fertilizer is a widely used component of conventional intensive agriculture to promote higher yields, also in Sub-Saharan Africa (Nyembo et al. 2012). However, intensification and expansion of agriculture are the first causes of degradation. On the other hand, intensive agriculture is an effort to feed the growing population, a vicious circle.

We applied in the growing season an amount of 437,5 kg/ha NPK, which is higher than the recommended dose of 2-300 kg/ha of NPK in the high savanna (IFATI 2022). However, with 87,5 kg/ha N, it is half the annual dose permitted in the European Union.

In the rainy season H^+ protons are released from the NPK, causing acidification of the soil. As expected, the soil of mbnpk is slightly more acidic. Apart from its effect on soil biota, the leaching of nitrogen is a risk for human health via contaminated ground waters

In a study involving microcosms containing known weights of humus with varying levels of pH, Hågvar (1990) demonstrated that the population growth of some species of Oribatida and Collembola diminished with increasing acidity (see also Emmerson et al. 2016). In accordance with this, the abundances of Acari and Collembola in mbnpk are low. This impedes the soil food web, leading to the inhibition of interactions in the soil ecosystem and may particularly in the long run negatively impact ecosystem goods and services, which in turn leads to soil degradation (Zingore et al. 2010, Begum et al. 2014, Lal 2015). However, Gergócs et al. (2022) found in a study in Hungary, that soil microarthropod communities are more affected by crop than by NPK fertilizer.

In our study, NPK application aggravates the detrimental effects of conventional maize cultivation (DOM removal, tillage) for soil microarthropods. In the course of the growing season, the lush development of the crop (Fig. 2) with its positive influence on microclimate and resources does not buffer the negative effect of the chemicals. Hypothesis 3 is accepted.

Effect of DOM amendment on microarthropod group abundances

Organic matter is a key element of soil functioning as it provides food for many microarthropods, which accelerate and control nutrient fluxes by influencing decomposition processes directly and indirectly (Seastedt & Crossley 1981, Hedde 2010). Mulch not only modifies the microclimate and preserves soil humidity but also is food for saprophages and detritivores. It has been shown that organic farming which includes mulching has positive effects on soil animal abundances (Bengtsson et al. 2005, Peredo et al. 2009). Badejo et al. (1995) report strong positive effects of mulch on soil microarthropods as compared to bare plots in their study near Ibadan (Nigeria). They also document an influence of the type of plant residues used.

It is the plots with DOM remaining or added (sav ctrl, mmdom), where the positive influence of WC% on abundances becomes evident. The absence of this on the plots with DOM removed is an indication that resource availability constraints the effect of soil water content.

Our investigation reveals clearly that DOM is favourable for soil microarthropods (sav ctrl, mmdom) in the savanna environment studied. Hypothesis 4 is accepted.

5. Conclusion

Our work documents considerable abundances for soil microarthropods, making them an important component of the soil ecosystem of the high Guinean Savanna zone. The seasonal fluctuations of microarthropods as a response to distinct dry seasons and unimodal rainfall are now somewhat understood. This has implications for the understanding of the functioning of these systems in general. They may serve as model systems for the understanding of effects of climate change which includes more hot and dry periods and torrential rains.

In this study, we showed that adding DOM to maize cultivation plots can increase microarthropod abundance on average by 46%, this effect is even more pronounced during the rainy seasons (up to 63%). By contrast, adding NPK detrimentally affects microarthropods, resulting in average abundance decline of 50% in comparison to maize control. Removal of DOM and application of NPK have negative effects on soil microarthropods. Conversely, mulches are beneficial for the microarthropods by providing a complex resource for soil biota as a whole and having a positive influence on soil structure and microclimate.In contrast to NPK fertilizers with its risks and high cost particularly for sub-Sahara farmers (Nyembo et al. 2012), mulch is safe, simple and easily accessible to local farmers. By avoiding chemicals and supporting soil biota and carbon sequestration, mulching regimes are a key element of sustainable agriculture (Mhlanga et al. 2021).

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7. References

Agri-Stat (2012): Annuaire des statistiques du secteur agricole campagnes 2009 et 2010. – MINADER Cameroun/Direction des enquêtes et des statistiques agricoles **17**: 123.

Aspetti, G. P., R. Boccelli., D. Ampollini, A. A. M. Del Re & E. Capri (2010): Assessment of soil-quality index based on microarthropods in corn cultivation in Northern Italy. –Ecological Indicators **10**(2): 129–135 [https://doi.org/10.1016/j.ecolind.2009.03.012].

Bachelier, G. (1971): La vie animale dans les sols. – La Vie Dans Les Sols: Aspects Nouveaux, Études Expérimentales : 1–82.

Badejo, M. A., G. Tian & L. Brussaard (1995): Effect of various mulches on soil microarthropods under a maize crop. – Biology and Fertility of Soils **20**: 294–298 [https://doi.org/10.1007/BF00336093].

Bedano, J. C., M. P. Cantú & M. E. Doucet (2005): Abundance of soil mites (arachnida: Acari) in a natural soil of Central Argentina. – Zoological Studies **44**(4): 505–512.

Bedano, J. C., M. P. Cantú & M. E. Doucet (2006): Influence of three different land management practices on soil mite (Arachnida: Acari) densities in relation to a natural soil. – Applied Soil Ecology **32**: 293–304 [https://doi.org/10.1016/j.apsoil.2005.07.009].

Banerjee, S., A. K. Sanyal & A. K. Bhaduri (2009): Studies on Soil Microarthropod Population in Three Different Garden Plots of 24 Parganas. West Bengal-A Preliminary Report. – Records of the Zoological Survey of India **109**: 1–9 [https://doi.org/10.26515/rzsi/v109/i4/2009/158971].

Begum, F., R. M. Bajracharya, B. K. Sitaula, S. Sharma, S. Ali & H. Ali (2014): Seasonal dynamics and land use effect on soil microarthropod communities in the Mid-hills of Nepal. – International Journal of Agronomy and Agricultural Research **5**(2): 114 –123.

Bengtsson, J., J. Ahnström & A. C. Weibull (2005): The effects of organic agriculture on biodiversity and abundance: A meta-analysis. – Journal of Applied Ecology **42**: 261–269 [https://doi.org/10.1111/j.1365-2664.2005.01005.x].

Blevins, R. L., G. W. Thomas, M. S. Smith, W. W. Frye & P. L. Cornelius (1983): Changes in soil properties after 10 years continuous non-tilled and conventionally tilled corn. – Soil and Tillage Research **3**: 135–146 [https://doi.org/10.1016/0167-1987(83)90004-1].

Block, W. C. (1970): Micro-arthropods in some Uganda soils. – In: Philippson, J. (ed.), Proceedings of a UNESCO/IBP Symposium on Methods of Study in Soil Ecology. UNESCO, Paris: 195–202.

Bolan, N. S., D. Curtin & D. C. Adriano (2005): Acidity. – In: Hillel, D. (ed.): Encyclopedia of Soils in the Environment. – Elsevier, Oxford: 11–17.

Celik, I., I. Ortas & S. Kilic (2004): Effects of compost, mycorrhiza, manure and fertilizer on some physical properties of a chromoxerert soil. – Soil & Tillage Research **78**: 59–67 [https://doi.org/10.1016/j.still.2004.02.012].

Chianu, J. N., A. Adesina, P. Sanginga, A. Bationo J. Chianu & N. Sanginga (2008): Structural change in fertilizer procurement method: assessment of impact in Sub-Saharan Africa. – African Journal of Business Management **2**: 065–071.

Crossley, D. A., B. R. Mueller & J. C. Perdue (1992): Biodiversity of microarthropods in agricultural soils: relations to processes. – Agriculture, Ecosystems and Environment **40**: 37–46 [https://doi.org/10.1016/0167-8809(92)90082-M].

Danra, D. D., E. N. Nukenine & H. Koehler (2018): Soil Gamasina from savanna and ReviTec site of Ngaoundéré (Adamawa, Cameroon): abundance and species diversity. – Soil Organisms **90**(3): 187–198 [https://doi.org/10.25674/8fsw-6t13].

Danra, D. D., H. Koehler & E. N. Nukenine (2021): Assessing a ReviTec Measure to Combat Soil Degradation by studying Acari and Collembola from Ngaoundéré, Adamawa, Cameroon. – Soil organisms **93**(3): 161–180 [https:// doi.org/10.25674/so93iss3id165].

Demir, Z., O. Yildiz & B. Toprak (2009): Water retention ratios of mulching material consisting primarily of pine bark over different soil types. – Pakistan Journal of Botany **41**: 1851–1859.

Didier, K. K., K. K. F. Jean-martial & K. K. Gaston (2018): Soil moisture management and mulch impact on sugarcane yields under irrigated and rainfed conditions in Côte d'Ivoire University Féli. – Journal of Biodiversity and Environmental Sciences **12**: 381–390.

Dindal, D. L., (1990): Soil Biology Guide. 2. – Wiley-Interscience publication, Syracuse, New York: 1349.

Djoussi, N. L. R. (2015): Seasonal dynamics of soil microarthropod communities in two experimental sites: an agricultural soil and the ReviTec of Ngaoundere (Cameroon). (Master Thesis). – University of Ngaoundéré, Adamaoua, Cameroon.

Dubie, T. R., C. M. Greenwood, C. Godsey. & M. E. Payton (2011): Effects of tillage on soil microarthropods in winter wheat. – Southwestern Entomologist **36**(1): 11–20 [https://doi.org/10.3958/059.036.0102].

Emmerson, M., M. B. Morales, J. J. Oñate, P. Batáry, F. Berendse, J. Liira, T. Aavik, I. Guerrero, R. Bommarco, S. Eggers & et al. (2016): How Agricultural Intensification Affects Biodiversity and Ecosystem Services. – Advances in Ecological Research **55**: 43–97 [https://doi.org/10.1016/bs.aecr.2016.08.005].

Ermilov, S. G. & H. Koehler (2017): New data on oribatid mites (Acari, Oribatida) of Cameroon: Results of the Joint German-Cameroonian scientific expedition (April 2016). – Systematic and Applied Acarology **22**: 2233–2244 [https://doi.org/10.11158/saa.22.12.13].

FIDA (2021): Rapport sur le développement rural 2021 vue d'ensemble. – Fonds international de développement agricole Via Paolo di Dono, **44** - 00142 Rome, Italie: 52.

Gardi, C., C. Menta & V. Parisi (2002): Use of microarthropods as biological indicators of soil quality: the BSQ sinthetic indicator. – In: Options Méditerranéennes, Série A n. **50**: 297–304.

Gbarakoro, T. N. & N. Zabbey (2013): Soil Mesofauna Diversity and Responses to Agro-Herbicide Toxicities in Rainforest Zone of the Niger Delta, Nigeria. – Applied Journal of Hygiene **2**: 1–7 [https://doi.org/10.5829/idosi.ajh.2013.2.1.81205].

Gergócs, V., N. Flórián, Z. Tóth, T. Szili-Kovács, M. Mucsi & M. Dombos (2022): Crop species and year affect soil-dwelling Collembola and Acari more strongly than fertilisation regime in an arable field. – Applied Soil Ecology **173**: 104390 [https://doi.org/10.1016/j.apsoil.2022.104390].

Gruda, N. (2008): The effect of wood fiber mulch on water retention, soil temperature and growth of vegetable plants. – Journal of Sustainable Agriculture **32**: 629–643 [https://doi.org/10.1080/10440040802395049].

Guedegbe, T. & T. Sinsin (2020): Is Land Degradation Neutrality in Africa Possible? – In: OCP Policy Brief: 10.

Guinto, D. F., S. Lauga, L. Dauara, E. Walasi & D. Autufuga (2015): SOIL HEALTH ASSESSMENT OF TARO (*Colocasia esculenta*) FARMS IN SAMOA. – Wright **1963**: 1–7.

Gwiazdowicz, D. J., J. Kamczyc & R. Rakowsk (2011): Mesostigmatid mites in four classes of wood decay. – Experimental and Applied Acarology **55**: 155–165.

Hågvar, S. (1990): Reactions to soil acidification in microarthropods: Is competition a key factor? – Biology and Fertility of Soils **9**(1): 178–181[https://doi.org/10.1007/BF00335804].

Hedde, M. (2010): Etude de la relation entre la diversité des macro-invertébrés et la dynamique de la matière organique des sols limoneux de Haute-Normandie. – Ecologie, Environnement. These de doctorat, Université de Rouen, France: 209.

Huhta, V. & S. M. Hänninen (2001): Effects of temperature and moisture fluctuations on an experimental soil microarthropod community. – Pedobiologia **45**: 279–286 [https://doi.org/10.1078/0031-4056-00085].

IFATI (2022): Manuel en agriculture culture du Maïs. – Institut de formation en agriculture et technologies innovantes arrete ministeriel n o 086 / minefop / sg / dfop / sdgsf / sacd 1. (n.d.): 13.

Iloba, B. N. & T. Ekrakene (2008): Soil micro arthropods recovery rates from 5-10 cm depth within 5 months period following Entozoan (organochlorine pesticide) treatment in designated plots in Benin city, Nigeria. – Journal of Entomology and Nematology **1**: 43–49.

Kader, M. A., M. Senge, M. A. Mojid & K. Nakamura (2017): Mulching type-induced soil moisture and temperature regimes and water use efficiency of soybean under rain-fed condition in central Japan. – International Soil and Water Conservation Research **5**: 302–308 [https://doi.org/10.1016/j.iswcr.2017.08.001].

Kennedy (1986): Acid soils and acid rain. – Research Studies Press, John Wiley, New York. IR Ed.

Koehler, H. (1996): Soil animals and bioindication. – In: van Straalen, N. M. & D. A. Krivolutski (ed.), Bioindicator Systems for Soil Pollution. – Kluwer acad. publ., Dordrecht, the Netherlands: 179–188.

Koehler, H. (1999): Predatory mites (Gamasina, Mesostigmata). – Agriculture Ecosystems Environment **74**: 395–410.

Krantz, G. W. (1978): A Manual of Acarology, 2nd ed. Oregon State University Book Stores, Corvallis, USA: 509.

Lakshmi, G. & A. Joseph (2017): Soil microarthropods as indicators of soil quality of tropical home gardens in a village in Kerala, India. – Agroforestry Systems **91**: 439–450 [https://doi.org/10.1007/s10457-016-9941-z].

Lal, R. (2015): Restoring soil quality to mitigate soil degradation. – Sustainability (Switzerland) **7**: 5875–5895 [https://doi.org/10.3390/su7055875].

Lükewille, A. & C. Alewell (2018): Acidification. – Encyclopedia of Ecology **2**: 233–241 [https://doi.org/10.1016/B978-0-444-63768-0.00251-1].

Manu, M., R. I. Băncilă & M. Onete (2013): Soil mite communities (Acari: Gamasina) from different ecosystem types from Romania. – Belgian Journal of Zoology **143**: 30–41.

Manu, M., R. I. Băncilă, Bîrsan, C. C. O. Mountford & M. Onete (2021): Soil mite communities (Acari: Mesostigmata) as indicators of urban ecosystems in Bucharest, Romania. – Scientific reports **11**: 1–14 [https://doi:10.1038/s41598-021-83417-4].

Mensah, A. K. & K. A. Frimpong (2018): Biochar and/ or Compost Applications Improve Soil Properties, Growth, and Yield of Maize Grown in Acidic Rainforest and Coastal Savannah Soils in Ghana. – International Journal of Agronomy **68**: 1–8 [https://doi. org/10.1155/2018/6837404].

Menta, C. (2012): Soil Fauna Diversity – Function, Soil Degradation, Biological Indices, Soil Restoration. – Biodiversity Conservation and Utilization in a Diverse World 284 [https://doi.org/http://dx.doi.org/10.5772/51091].

Menta, C., F. D. Conti, F. Lozano, C. Staffilani & F. S. Remelli (2020): Soil arthropod responses in agroecosystem: implications of different management and cropping systems. – Agronomy **10**: 982 [https://doi.org/10.3390/agronomy10070982].

Mhlanga, B., L. Ercoli, E. Pellegrino, A. Onofri & C. Thierfelder (2021): The crucial role of mulch to enhance the stability and resilience of cropping systems in southern Africa. –Agronomy for Sustainable Development **41**: 1–14.

Miller, J. J., J. P. Battigelli & W. D. Willms (2014): Grazing protection influences soil mesofauna in ungrazed and grazed riparian and upland pastures. – Rangeland Ecology & Management **67**:429–434.

Mitchell, J., J. E. Dehm & H. G. Dion (1952): The effect of small additions of elemental sulphur on the availability of phosphate fertilizers. – Scientific Agriculture [Ottawa] **32**:311–316.

N'Dri, J. K., H. M. André & T. Hance (2011): Soil mite diversity from Ivory Coast. – European Journal of Scientific Research **64**: 263–276.

N'Dri, K. J., T. Hance, H. M. Ande, J. Lagerlof & J. E. Tondoh (2016): Microarthropod use as bioindicators of the environmental state: case of soil mites (Acari) from Côte d'Ivoire. –Journal of Animal and Plant Sciences **29**(2): 4622–4637.

Nyembo, K. L., S. Y. Useni, M. M. Mpundu, M. D. Bugeme, L. E. Kasongo & L. L. Baboy (2012): Effets des apports des doses variées de fertilisants inorganiques (NPKS et Urée) sur le rendement et la rentabilité économique de nouvelles variétés de Zea mays L. à Lubumbashi, Sud Est de la RD Congo. – Journal of Applied Biosciences **59**: 4286–4296.

Okiwelu, S., N. T. Gbarakoro, O. C. Umeozor & M. A. Badejo (2012): Soil Microarthropods in a Secondary Rainforest, Rivers State, Nigeria - IV - The Impact of Oil Pollution on Their Vertical Distribution. – Resources and Environment **2**: 14–19 [https://doi.org/10.5923/j.re.20120202.03].

Peredo, S. F. P., P. Z. Esperanza, V. C. Marcela & P. B. S. Claudia (2009): Edaphic mesofauna community structure in organic and conventional management of cranberry (Vaccinium sp.) plantations: An agroecological approach. – Revista de La Ciencia Del Suelo y Nutricion Vegetal **9**:236–244 [https://doi.org/10.4067/S0718-27912009000300006].

Pflug, A. & V. Wolters (2001): Influence of drought and litter age on Collembola communities. – European Journal of Soil Biology **37**: 305–308. [https://doi.org/10.1016/S1164-5563(01)01101-3].

Rico Hernández, J. R., J. Navarro Pedreño & I. Gómez Lucas (2016): Avaliação de resíduos de plantas utilizadas como cobertura morta ("mulch") sobre a retenção de umidade do solo. – Spanish Journal of Soil Science **6**(2): 133–144. [https://doi.org/10.3232/SJSS.2016.V6.N2.05].

Roy, A. (2006): Africa Fertilizer Crisis: Summit Background and Process. Presented at the – Technical Session: High-level dialogue, Africa Fertilizer summit, Abuja, Nigeria, June 9th.

Schnee, L. S., H. Koehler, A. Ngakou & T. Eickhorst (2021): Long-term impact of single biochar and compost application on soil aggregation. – IOP IOP Conference Series: Earth and Environmental Science **264**: 012160 [https://doi.org/10.1088/1755-1315/648/1/012160].

Seastedt,T.R. & D.A. Crossley (1981): Microarthropod response following cable logging and clear-cutting in the southern Appalachians. Ecology **62**: 126–135.

Shakir, M. M. & S. Ahmed (2014): Seasonal abundance of soil arthropods in relation to meteorological and edaphic factors in the agroecosystems of Faisalabad, Punjab, Pakistan. – International Journal of Biometeorology **59**: 605–616 [https://doi.org/10.1007/s00484-014-0874-9].

Sharma, N. & H. Paewez (2017): Seasonal Dynamics and Land use Effect on Soil Microarthropod Communities in the Northern Indian State of Uttar Pradesh (India). – International Journal of Applied Agricultural Research **3**: 371–379.

Sheikh, A. A., N. Rehman, T. A. Bhat, M. A. Sofi, M. A. Bhat, S. Un Nabi, Aijaz, C., A. Sheikh, G. Lone & A. Sofi (2017):Vertical distribution of soil arthropods in apple ecosystem of Kashmir. – Journal of Entomology and Zoology Studies JEZS **843**: 843–846.

Souhir, M. (2019): The Agriculture in Africa 2019. – Africa-2019-special-report [https://oxfordbusinessgroup.com/blog/souhir-mzali/focus-reports/agriculture].

UNCCD (1994): Elaboration of an international convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa. – A/AC.241/27: 58.

Valarini, P. J., G. Curaqueo, A. Seguel, K. Manzano, R. Rubio, P. Cornejo & F. Borie (2009): Effect of compost application on some properties of a volcanic soil from Central South Chile. – Chilean Journal of Agricultural Research **69**: 416–425.

Wang, S., Y. Tan, H. Fan, H. Ruan & A. Zheng (2015): Responses of soil microarthropods to inorganic and organic fertilizers in a poplar plantation in a coastal area of eastern China. – Applied Soil Ecology **89**: 69–75 [https://doi.org/10.1016/j.apsoil.2015.01.004].

World Bank (2020): Reversals of fortune. Poverty and shared prosperity 2020. – Washington, DC: 201.

Zingore, S., J. Mutegi, B. Agesa, L. Tamene & J. Kihara (2010): Soil Degradation in Sub-Saharan Africa and Crop Production Options for Soil Rehabilitation. – Better Crops with Plant Food **99**: 24–26.