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Article *in* Applied Soil Ecology · November 2011

DOI: 10.1016/j.apsoil.2011.09.001

Applied Soil Ecology 51 (2011) 122–129

Contents lists available at SciVerse ScienceDirect

Applied Soil Ecology

journal homepage: www.elsevier.com/locate/apsoil

Termite and earthworm abundance and taxonomic richness under long-term conservation soil management in Saria, Burkina Faso, West Africa

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ARTICLE INFO

Article history:
Received 23 November 2010
Received in revised form 30 August 2011
Accepted 1 September 2011

Keywords:
Abundance
Taxonomy
Earthworm
Management Practices
Termite

ABSTRACT

Unsustainable crop and soil management practices are major causes of soil degradation and declining soil biodiversity in West Africa. Identifying soil management practices that favor macrofauna abundance is highly desirable for long-term soil health. This study investigates the effects of long-term conservation soil management on termite and earthworm abundance and taxonomic richness in the central plateau of Burkina Faso. Trials included rotations with 5 Mg ha^{-1} yr^{-2} of organic matter added (established in 1960), application of 10 Mg ha^{-1} yr^{-1}applied with additional organic (manure or straw) and mineral inputs (established in 1980) and different tillage systems (established in 1990) where 10 Mg ha^{-1} yr^{-1} of organic matter was also applied. Soil macrofauna was surveyed at the soil surface and in the upper 30 cm using transect and monolith sampling methods, eight weeks after sorghum crop planting. A total of five termite taxa: *Trinervitermes* sp., *Microtermes* sp., *Odontotermes magdalenae*, *Macrotermes* sp. and *Amitermes stephensoni*; belonging to the family of Termitidae, and two earthworm taxa: *Dichogaster affinis*, *Millsonia inermis*; from the family of Acanthodrilidae were found. Termite taxonomic richness per treatment ranged between 1 and 4, while earthworm taxa ranged from 0 to 2. Under rotation, one termite taxa and no earthworm taxa were identified. In the organic amendment plots, three termite and two earthworm taxa were found. And light tillage (animal or hand) resulted in four termite taxa and one earthworm taxa. The two types of fauna clearly responded differently to the different conservation soil management practices. Under rotation lower recorded macrofauna population was attributed to the lower rate of applied organic matter compared to levels applied in the organic amendment and tillage trials and where more macrofauna were found. Location of food stock (rooting depth of different crops in the rotation) also had a significant effect on termite presence. Effect of rooting depth on earthworms was not observable due to the absence of earthworms in the rotation trials (possibly due to insecticide application. Manure treatments favored earthworms, while sorghum straw treatments favored termites likely due to respective preference for easy versus difficult to digest organic sources. Animal plowing and hand hoeing had similar and significantly positive effects and both termite and earthworm biological components compared to tractor tillage. We conclude that termite and earthworm abundance and taxonomic richness are most significantly affected by the type and amount of organic matter applied and tillage regimes, with rooting depth of rotations crops also playing a significant role. To promote macrofauna abundance and taxonomic richness in soils, integrated conservation soil management practices with attention to the particular needs and preferences of termites and earthworms is needed.

1. Introduction

Soils in West Africa are prone to degradation and are characterized by low organic matter content, low water holding capacity and inherent low fertility (Fall and Faye, 1999; Breman and Bationo, 1999; Stroosnijder and Van Rheenen, 2001). Unsustainable land use and management involving changes in vegetation, intensive soil tillage and removal of biomass have led to decreased soil organic matter content, deterioration of important soil

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0929-1393/$ – see front matter
doi:10.1016/j.apsoil.2011.09.001

physical parameters, and consequently an increase in soil erosion (Wu and Tiessen, 2002; Ouédraogo et al., 2006). The decrease in soil organic matter furthermore affects soil fauna which has an important role in initiating and/or maintaining key soil processes, e.g. soil structure formation and decomposition of fresh organic material.

The potential beneficial effects of soil macrofauna on soil physical characteristics in general and soil aggregation in particular are well recognized (Kooistra, 1991; Kooistra and van Noordwijk, 1991; Droogers and Bouma, 1997; Mando and Midiema, 1997). Earthworms and termites in particular have a very strong impact on the soil environment and are therefore called “ecosystem engineers” (Lavelle et al., 1999; Jones and Eggleton, 2000). Earthworms can modify soil structure through burrowing and casting activities, both of which have significant effects on soil physical properties such as aeration, infiltration and hydrology (Marinissen, 1992; Sveistrup et al., 1997; Blanchart et al., 2004). Termites are one of the most important biological agents for reworking the soils. Their behavior in selecting, transporting, and manipulating soil particles and cementing them together with saliva brings some immediate changes in soil structure and properties (Lobry de Bruyn and Conacher, 1990; Logan et al., 1990; Wood, 1996; Mando, 1997). Providing conditions favorable to soil macrofauna settlement is desirable for long term soil health.

Land use and management as well as geographic location, soil type and climate all influence soil fauna populations (Lee, 1985; Binet et al., 1997; Paoletti et al., 1998; Chan, 2001). Termite diversity has been found to decrease under long-term cultivation (Kooyman and Onck, 1987). Earthworms are sensitive to extreme soil conditions such as very high or very low temperatures, low soil moisture, poor drainage, soil texture (very fine or very coarse), low organic matter content and low pH (Diaz Cosin et al., 1994). Their activity is also affected by management practices like manure and straw inputs, tillage and crop type (Berry and Karlen, 1993; Heimbach, 1997). However, data regarding the effect of long-term agricultural management practices on soil macrofauna diversity in general is very scarce. Establishing the effect of long-term management practices on soil fauna communities will help to define and further develop the sustainability of conservation soil management techniques.

To date, most studies on soil fauna have been focused on describing and quantifying the effects of soil invertebrates on soil processes, in particular soil structure formation (Brussaard and Juma, 1996; Pulleman et al., 2005a,b), and associated soil physical processes, soil organic matter decomposition (Lavelle et al., 1999; Brauman, 2000) and nutrient transformation (Mando, 1997; Lamandé et al., 2003; Ouédraogo et al., 2006). This study investigates the effects of selected long-term soil management trials with the aim of: (1) quantifying earthworm and termite abundance, biomass and taxonomic richness as influenced by crop rotation, tillage practices, nitrogen application, manure application and crop residue management; and (2) determining the management options which could promote sustainable agro-ecosystem by improving fauna biological component and their provision of ecological services in the Savannah zone of West Africa.

2. Materials and methods

2.1. Study site description

The research was carried out in the savannah zone of Saria in Burkina Faso (12°17.0′N, 02° 09.5′W and 300 m above sea level) where the mean annual rainfall is 800 mm and the average daily temperatures range from 30 °C in July–December to 45 °C in April–June. The soil is a *Ferric Lixisol* (WRB, 2006; FAO-UNESCO, 1994). The 15 cm topsoil is sandy loam, with an average bulk density of 1.7 Mg m^{-3}, and pH of 5.3 (Mando et al., 2005; Ouattara et al., 2006). Soil survey data indicate 3.9 (mg g^{-1}) total carbon, 0.3 mg g^{-1} total N, 0.09 cmol kg^{-1} exchangeable K and 67.3 mg kg^{-1} total phosphorus levels (Zougmoré, 2003; Ouattara, 1994).

2.2. Experimental design

The study is part of a long-term experiment involving three different trials. The first trial (Saria I), established in 1960, investigates the effect of crop rotation in combination with organic and mineral fertilizers on crop yield and soil fertility. The trial is arranged in a split plot design, with the full trial being comprised of six main treatments and three sub-treatments. All are replicated six times. The six main treatments are: T1– control without any fertilizer, T2 – low mineral fertilizer rate (100 kg ha^{-1} NPK + 50 kg ha^{-1} urea) + sorghum straw restitution,T3 – low mineral fertilizer rate + biannual farmyard manure input of 5 Mg ha^{-1} (C (22.5%), N (1.27%), P (0.28%)), T4 – low mineral fertilizer rate, T5 – high mineral fertilizer rate (100 kg ha^{-1} of NPK + 100 kg ha^{-1} urea + 50 kg ha^{-1} of KCl) + 40 Mg ha^{-1} of manure every 2 years, and T6 – high mineral fertilizer rate. The three sub-treatments are continuous sorghum, sorghum–cotton (*Gossypium hirsutum*) rotation and sorghum–cowpea (*Vigna unguiculata*) rotation. In this study sub-treatments were named S1–1 for continuous sorghum, S1–2 for sorghum–cotton (*Gossypium hirsutum*) and S1–3 for sorghum–cowpea (*Vigna unguiculata*). In this study, the low mineral fertilizer rate T3 in combination with the crop rotations was considered; and sampling was done in three of the six replicates in the full trial. During the cotton and cowpea rotation phase, pesticide i.e. decis (deltamethrine) was applied on cotton and on cowpea to prevent crop damage. Every year at the beginning of the cropping season the land was tractor-tilled to a depth of 20 cm and rotation occurred every two years. The individual plot size was 6 m × 8 m.

The second trial (Saria II) was established in 1980 and compares, in a factorial design, four types of organic amendments (sorghum straw, aerobic compost, anaerobic compost, and farmyard manure) at annual rates of 10 Mg ha^{-1}, with and without urea input (23 kg ha^{-1}) in six replicates. Each block contains ten treatments, and the fields are tractor-tilled to a depth of 20 cm every year. Sorghum straw (C (42.5%), N (0.60%), P (0.08%)) and farmyard manure are the organic amendments that were considered in this study. Therefore, six treatments replicated three times were selected: control plus (S2–1) or minus (S2–2) nitrogen, manure plus (S2–3) or minus (S2–4) nitrogen, straw plus (S2–5) or minus (S2–6) nitrogen. Each treatment was sown with sorghum; 31,250 plants per ha. Plot size was 5 m × 4.8 m.

The third trial (Saria III) was established in 1990 and studies, in a randomized block design, the effects of light tillage on physical and chemical soil properties. It consists of three blocks or replications. Each block contains four annual treatments: T1 – hand hoeing, T2 – hand hoeing + farmyard manure (10 Mg ha^{-1}), T3 – oxen plowing, T4 – oxen plowing + farmyard manure (10 Mg ha^{-1}). Treatments receive an annual input of 100 kg ha^{-1} NPK (15 kg ha^{-1} N, 23 kg ha^{-1} P and 15 kg ha^{-1} K) + 50 kg ha^{-1} urea. Two treatments were included in our study: oxen plow + manure as S3–1 and hand hoeing + manure as S3–2. The ox plowing depth is 15 cm and hand hoeing depth is 5 cm. The study was made on the whole bloc and sorghum was planted on each treatment at 31,250 seedling per ha. Plot size was 5 m × 15 m.

Saria I is at equal distance, 30 m with Saria II and Saria III; while Saria II and III are distant of 20 m apart.

2.3. Macrofauna sampling

Sampling was done approximately eight weeks after sowing for both termites and earthworms in September 2006, during the growing season. Termite assessment used the monolith and a semi-quantitative transect sampling method. Earthworms were collected through monolith sampling only.

Monolith sampling was carried out according to the standard Tropical Soil Biology and Fertility (TSBF) method (Anderson and Ingram, 1993; Swift and Bignell, 2001). One soil monolith of 25 × 25 × 30 cm was randomly sampled in each plot ($n = 3$). Termites and earthworms were then collected by hand-sorting on plastic trays.

Transect sampling for termites was done alongside the monolith sampling. In each sampling plot of Saria I and III, 5 × 4 m transects (or 5 × 2 m in Saria II) were randomly laid out. Each transect was sampled sequentially for 30 min by two people trained in the microhabitats which are common sites for termites (Jones and Eggleton, 2000; Swift and Bignell, 2001).

Based on visual observation notes taken while in the field, termites were classified into one of four feeding groups in line with the classification of Donovan et al. (2001) and Eggleton et al. (2002): feeding group I – lower termites (wood, wood litter and grass feeders); feeding group II – some higher termites (wood litter and grass feeders); feeding group III – all higher termites (very decayed wood or high organic content soil); feeding group IV – all higher termites (low organic content soil-true soil feeders).

Visual observations from the field were also used to place earthworms into the following functional groups from a classification based on habitat, food choice, feeding behavior and eco-physiology (Lavelle et al., 1999; Swift and Bignell, 2001): epigeics (those that live and feed on the soil surface); anecics (those transporting organic straw from the surface into vertical burrows and actively mixing it with soil), and endogeics (those foraging on soil organic matter and dead roots within the soil, largely forming horizontally orientated burrows).The mature worms, particularly those with observable clitella were considered for identification, while juveniles were ignored (because we do not know the species they belong to).

2.4. Calculation of macrofauna abundance, biomass and taxonomic richness

Biological assessment for both earthworm and termite abundance included: abundance, biomass and taxonomic richness at genus and species level. Abundance represents the number of individuals per m^2 and biomass was calculated as $g\,m^{-2}$. Taxonomic richness (S) was estimated as the number of taxa per monolith for earthworms and monolith and transect sample together for termites. Quantitative and statistical analyses were based on monolith data only for both termites and earthworms.

2.5. Soil and roots

The soil physical properties being considered, i.e. texture, available water and organic carbon, were determined from samples taken from the wall of a soil pit (80 cm × 50 cm × 80 cm), dug at the edge of each selected treatment. Three core samples were taken per soil layer. Two layers 0–15 and 15–30 cm were used. Soil particle size distribution was determined by the Robinson pipette method on sieved soil (<2 mm) dried at 105 °C (Mathieu and Pieltain, 1998). Available Water (AW) was calculated as follows: AW (mm) = [water content at pF2 (%vol) – water content at pF4.2 (%vol)] * depth (mm). Determination of pF2 and pF4.2 followed the procedures described by Wang and Benson (2004). Organic carbon was determined by the stable isotope method (UC Davis 2006) on 25 mg of ground soil. Soil temperatures measured at 10, 20 and 50 cm by the Saria meteorological station were used for the analysis.

Root studies were undertaken following the procedures described by Akinnifesi et al. (1999) and Vanlauwe et al. (2002).

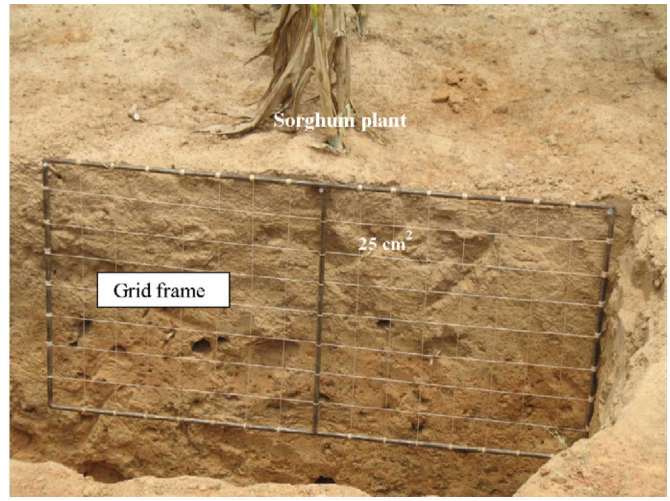

Fig. 1. Trenches were dug perpendicular to the Sorghum planting ridges to expose the rootzones. Roots were counted using a grid with 25 cm^2 grid cells hung on the wall of the trench/pit.

Trenches 100 cm long, 50 cm wide and 80 cm deep, were dug eight weeks after planting sorghum. The trenches were dug perpendicular to the ridges containing two sorghum planting rows at 5 cm from the sorghum plant. Roots were manually counted for each 25 cm^2 following a grid hung on the pit wall (Fig. 1).

2.6. Data analysis

Statistical analysis to test for significance of treatment effects was done for each individual trial according to the number of factors studied. Saria I studied the rotation effect hence a one way complete randomized block analysis of variance (ANOVA) was run for selected treatments using the 12th edition Genstat software (GenStat, 2009). Saria II studied organic amendment (+/–) nitrogen effects. Therefore, two kindsof ANOVA were run. The one way complete randomized block of selected treatments evaluated the full treatment effect, and the two way complete randomized ANOVA determined the significance of interaction effects. Saria III which studied the tillage effect was anlaysed using the one way complete randomized block ANOVA. When analysing the interactions, the student Newman–Keuls test was used for comparing mean values. Differences between treatments were then determined comparing the least significant difference (LSD) given by the ANOVAs.

3. Results

3.1. Soil physical properties

Within sites, differences between treatments, although sometimes significant (Table 1) are smalls. Soil texture in the rotation trial is mainly sandy loam in the 0–15 cm layer. Available water in the sorghum–cotton rotation was higher compared to continuous sorghum and sorghum–cowpea. But sorghum–cowpea had improved the rooting depth (80 cm) compared to continuous sorghum (55 cm) and sorghum–cotton (35 cm) rooting depths.

Manure and straw applications significantly improved carbon stock compared to control plots (Saria II). Soil texture is mainly sandy loam in the 0–15 cm layer and roots were developed to a depth of 30–45 cm. Control – N available water is higher compared to other treatment. The topsoil characteristics are homogeneous under two tillage practices. In general, the mean average daily temperature during the sampling period was 35 °C at a depth of 10 cm, and 31 °C at 50 cm depth. As such, general soil conditions were

Table 1
General topsoil characteristics at 0–15 cm depth and rooting depth of the studies sites Saria I, II and III.

Treatments	Carbon (g kg^{-1})	Clay <2 μm (%)	Silt 2–50 μm (%)	Sand 50–2000 μm (%)	AW (mm)	Rooting depth (cm)	Texture
Saria I							
S1–1	32.5a	13a	26b	61b	22b	55	S loam
S1–2	35.4a	11b	28a	61b	27a	35	S loam
S1–3	26.4b	12ab	26b	62a	21b	80	S loam
Saria II							
S2–1	17.3c	10a	29c	61a	26bc	35	S loam
S2–2	17.8c	8b	32b	59a	31a	30	S loam
S2–3	34.9a	11a	35a	54b	26bc	30	S loam
S2–4	24.5b	10a	29c	61a	27b	45	S loam
S2–5	26.4b	9ab	30bc	62a	23a	30	S loam
S2–6	27.6b	10a	30bc	61a	24cd	40	S loam
Saria III							
S3–1	24.4a	7a	30a	63a	29a	30	S loam
S3–2	22.4a	10a	30a	61b	23b	30	S loam

Classification base on the standard deviation value and the means followed by same lower case letter(s) are not significant per study site.

relatively uniform across treatments and appropriate for fauna (Brady and Weil, 1999).

3.2. Effects of crop rotation on termites and earthworms

Crop rotation had a significant impact on termite abundance (Table 2). Two distinct abundance groups were identified: group 1 (S1–1 – continuous sorghum) where abundance = 37 termites m^{-2} and group 2 (S1–2 and S1–3 sorghum–cotton and sorghum–cowpea respectively) which had a significantly lower abundance of 16 termites m^{-2}. The identified termite was *Trinervitermes* sp. belonging to the subfamily Termitidae–Nasutitermitinae which occurred across treatments. In terms of feeding behavior, this group of termites is known to be a leaf and dead grass feeder.

No differences in the earthworm biological component could be measured under the different rotations. In fact, not a single worm was identified under continuous sorghum and sorghum–cotton. In the sorghum–cowpea rotation only juvenile worms were found (11 m^{-2}). These were eliminated from the taxonomic classification. We learned that an insecticide was applied in the cotton and cowpea phase, which may have been a controlling factor for earthworm abundance in this trial.

3.3. Effects of organic and inorganic inputs on termites and earthworms

Organic amendment (+/−) N had a significant impact on termite abundance (Table 3). Two distinct groups were identified: group 1 (S2–6 – straw minus N) with an abundance of 1621 termites m^{-2} compared to the second group (remaining treatments) where abundance was below 272 termites m^{-2}. Earthworm abundance was relatively low and varied from 0 to 11 worms m^{-2}, with no differences observed between treatments.

Calculated biomass for both termites and earthworms was not statistically different than in the treatment were no fauna were identified. Termite biomass is related to abundance and the feeding possibilities allowed by the treatment (Table 3). Earthworm biomass follows the same principle with highest biomass 0.2 g m^{-2} under Manure − N versus 0.02 g m^{-2} under Manure + N where the same worm density (11 worm m^{-2}) was recorded.

Identified termites are from three termite taxa belonging to the family of Termitidae (Table 4). This major family was dominated by the subfamily Macrotermitinae with two taxa recorded, followed by subfamily Termitidae–Nasutitermitinae with one taxa. *Trinervitermes* sp. (Termitidae–Nasutitermitinae) occurred in all treatments with the exception of manure ± N treatments. Feeding capabilities under S2–1 (Control + N) may have allowed the presence of two taxa (*Trinervitermes* sp. and *Odontotermes magdalenae*) compared to S2–6 (Straw − N) where however the highest termite abundance was recorded. The same number of termite taxa was recorded because some of termites identified on the transect sampling were not considered in the quantitative calculation.

At treatment level, two earthworm taxa (epigeic and endogeic worms) from the family of Acanthodrilidae; *Dichogaster affinis and Millsonia inermis* were collected under the manure treatments. No earthworm taxa were identified in the other treatments. S2–1, S2–2 and S2–6 earthworm taxonomic richness is nil and under S2–3 (Manure + N), the identified juvenile worm was not classified into any taxonomic group.

An analysis of the individual factor effect (Table 5) shows that:

Table 2
Macrofauna abundance and biomass of Saria I, Burkina Faso. Classification of means based on the least significance difference given by the ANOVA.

Treatments	Abundance (number m^{-2})		Biomass (g m^{-2})	
	Termite	Earthworm	Termite	Earthworm
Sorghum-S (S1–1)	37a	0a	0.016a	0.00a
S-cotton (S1–2)	16b	0a	0.011a	0.00a
S-cowpea (S1–3)	16b	11a	0.005a	0.03a
p-Values	0.01*	0.44	0.44	0.44
Lsd	12	–	–	–
Std errors	4	9	0.01	0.03

* Significant difference, (−) *p*-values were not given by the analysis due to the identical value of indicated component.

Table 3
Macrofauna abundance and biomass of Saria II, Burkina Faso. Classification of means based on the least significance difference given by the ANOVA.

Treatments	Abundance (number m^{-2})		Biomass (g m^{-2})	
	Termite	Earthworm	Termite	Earthworm
Control + N (S2–1)	272b	0a	0.43a	0.00a
Control − N (S2–2)	101b	0a	0.04a	0.00a
Manure + N (S2–3)	0b	11a	0.00a	0.02a
Manure − N (S2–4)	0b	11a	0.00a	0.18a
Straw + N (S2–5)	155b	5a	0.05a	0.01a
Straw − N (S2–6)	1621a	0a	1.34a	0.00a
p-Values	0.03*	0.46	0.19	0.14
Lsd	967	–	–	–
Std errors	434.1	7	0.55	0.07

* Significant difference, (−) *p*-values were not given by the analysis due to the identical value of indicated component.

Table 4
Termite taxonomic richness and functional (feeding) groups based on monolith and transect methods in Saria II, Burkina Faso. F = fungus grower; G = dead/dry grass; L = leaf litter; S = soil; W = wood feeder. S2–3 and S2–4 termite taxonomic richness is nil.

Termites taxonomic group	Functional group[a]	Food type[b]	Possible pest[c]	S2–1	S2–2	S2–5	S2–6
Termitidae–Nasutitermitinae							
Trinervitermes sp.	II	LG	Yes	+	+	+	+
Termitidae–Macrotermitinae							
Microtermes sp.	II	FWLG	Yes	–	–	+	+
Odontotermes magdalenae	II	FWLG	Yes	+	–	–	–
Taxonomic richness per treatment	2	1	2	2			
Taxonomic richness under Saria II	3						

Treatments key: Control + N (S2–1); Control – N (S2–2); Manure + N (S2–3); Manure – N (S2–4); Straw + N (S2–5); Straw – N (S2–6).
[a] Based on classification by Bignell and Eggleton (2000); Donovan et al. (2001) and Eggleton et al. (2002).
[b] Based on field notes/observation.
[c] Based on observations by Kooyman and Onck (1987) and Jannette (2002). (+/–) denotes present or absent respectively.

Table 5
Effect of manure, straw and nitrogen applications on termite and earthworm abundance and biomass in Saria II, Burkina Faso.

	Abundance (number m^{-2})		Biomass (g m^{-2})	
	Termites	Earthworms	Termites	Earthworms
Manure (Mg ha^{-1})				
0	537a	1b	0.47a	0.001b
10	0a	11a	0.00a	0.10a
p-Values	0.164	0.05*	0.25	0.02*
Lsd	–	9.26	–	0.08
Std errors	363	4	0.4	0.04
Straw (Mg ha^{-1})				
Removed	93b	5.3a	0.12a	0.049a
Incorporated	888a	2.7a	0.7a	0.003a
p-Values	0.01*	0.60	0.09	0.36
Lsd	540	–	–	–
Std errors	248	5	0.3	0.05
Nitrogen (Mg ha^{-1})				
0	574a	3.6a	0.46a	0.059a
23	142a	5.3a	0.16a	0.009a
p-Values	0.23	0.67	0.43	0.19
Lsd	–	–	–	–
Std errors	342	4	0.4	0.04

* Significant difference, (–) *p*-values were not given by the analysis due to the identical value of indicated component.

(1) Manure application improved earthworm abundance ($p = 0.05$) and biomass ($p = 0.02$).
(2) Crop residue (straw) management had a significant effect only on termite abundance ($p = 0.01$). When residue is incorporated in the soil, termite abundance is about 888 m^{-2} and when the residue is removed the number decreases by 90%.
(3) The effect of nitrogen application alone (plus or minus N) was insignificant on both macrofauna.

As can be seen in Table 6, the interaction between manure and nitrogen was insignificant. However the residue and nitrogen interaction triggered termite biomass and abundance.

3.4. Effects of tillage on termites and earthworms

No effects from tillage were found on the termite and earthworm biological components of the soil (Table 7). In absolute values, more termites (1765 m^{-2}) were recorded with tillage by animal than by hand tillage. Regarding earthworms, fewer worms were recorded with animal tillage than with hand tillage (48 worms m^{-2} with animal tillage compared to 43 worms m^{-2} with hand tillage). Biomass for both fauna was related to the number of identified individuals, the more individuals, the higher the biomass.

Regarding the taxonomic richness aspect, a total of four termite taxa belonging to the family of Termitidae were identified (Table 8). This major family was dominated by subfamily Macrotermitinae with two taxa (*Macrotermes* sp.; *Microtermes* sp.), followed by subfamily Termitidae–Nasutitermitinae and Termitidae–Termitinae with respectively one taxa: *Trinervitermes* sp. and *Amitermes stephensoni*. Three of these taxonomic termite groups (*Trinervitermes* sp., *Macrotermes* sp., *Amitermes stephensoni*) were identified in the animal plowed treatment, while two taxa (*Macrotermes* sp.; *Microtermes* sp.) from the same subfamily were found in the hand hoeing treatment.

Regarding earthworms, just one epigeic worm (*Dichogaster affinis*) from the family of Acanthodrilidae was collected across the two tillage treatments.

4. Discussion

4.1. Termite and earthworm abundance and taxonomic richness under long-term crop rotation

The data show that termites were most abundant under continuous sorghum. It is has been noted in others literatures (Giller et al., 1997; Brady and Weil, 1999) that termite populations increase under monoculture conditions. Our findings support this. It appears that continuous sorghum farming, where sorghum straw is removed so that only the root biomass provides fresh organic input has provided the type of feeding environment

Table 6
Interactive (two levels) effect of straw and nitrogen applications rates on termite and earthworm abundance, biomass and diversity in Saria II, Burkina Faso.

Straw	Nitrogen (kg ha^{-1})	Abundance (number m^{-2})		Biomass (g m^{-2})	
		Termite	Earthworm	Termite	Earthworm
Removed	0	51b	5a	0.02b	0.09a
	23	136b	5a	0.22b	0.01a
Incorporated	0	1621a	0a	1.34a	0.00a
	23	155b	5a	0.05b	0.01a
	p-Values	0.01*	0.60	0.04*	0.41
	Lsd	764	–	0.98	–
	Std errors	350	7	0.4	0.07

* Significant difference, (–) *p*-values were not given by the analysis due to the identical value of indicated component.

Table 7
Macrofauna abundance and biomass of Saria III, Burkina Faso. Classification of means based on the least significance difference given by the ANOVA.

Treatments	Abundance (number m^{-2})		Biomass ($g\,m^{-2}$)	
	Termite	Earthworm	Termite	Earthworm
Animal plow (S3–1)	1765a	43a	1.5a	0.9a
Hand hoe (S3–2)	272a	48a	0.41a	1.43a
p-Values	0.41	0.84	0.56	0.65
Lsd	–	–	–	–
Std errors	1462	23	1.59	1

that enhances termite development. In the sorghum–cotton and sorghum–cowpea rotations rooting depth varied between years which altered at least the location of the food stock and perhaps also the quality in the various soil horizons. This may have been a key factor in the fauna composition.

Our data showed no effect from the rotations on earthworm biological parameters. However, application of insecticides during the cowpea or cotton phase of the rotation may have been a factor in depressing earthworm population (Sawadogo et al., 2006).

Apart from this it has been observed that earthworms are very sensitive to tillage (Berry and Karlen, 1993; Heimbach, 1997). Since plots in the rotation studies are tractor tilled every year at the beginning of cropping period, we hypothesize that tillage effect is likely to have also been a more important factor. However the tractor plowing effect may be marginal since at Saria II, which was also plowed by tractor, increases in termite and earthworm abundance were noted.

Indeed, addition of organic matter is believed to be one of the major management variables affecting earthworm abundance (Leroy et al., 2008) and may be an important factor in integrating the benefits of crop rotation on soil quality and macro-fauna abundance. It appears that rotation plots which received 5 $Mg\,ha^{-1}\,yr^{-2}$ did not have sufficient soil organic matter to support macrofauna when compared to the two others trials where organic matter was annually applied at a rate four times greater (10 $Mg\,ha^{-1}\,yr^{-1}$) (Elbert and Bettany, 1995). In addition, the long-term crop rotation practices contained more undecomposed organic matter, which has a high C/N ratio (data shown in another paper), which is difficult for earthworms to consume (Schönholzer et al., 1998; Curry and Schmidt, 2007). This may explain why only one termite taxa was identified across the three rotation treatments and no earthworms were identified.

Habitat selecting factors (Brussaard et al., 2007), change in soil organic matter attribute to difference in the amount, placement and composition of organic residue returned to the soil, and to the change in the environment (i.e. temperature, moisture, accessibility of energy sources) (Elbert and Bettany, 1995; Sileshi and Mafongoya, 2006) and the disappearance of potential feeding capability (Lal, 2002) are likely to be the reasons for the insignificant effect of rotation practices on termite and earthworm taxonomic richness.

4.2. Termite and earthworm abundance and taxonomic richness under long-term management with organic amendments

The data showed an increase in the presence of termites under the sorghum straw treatment without addition of extra N. Most of the termites found were wood, litter, and grass feeders (Jones and Eggleton, 2000). Ouédraogo et al. (2004) who studied the disappearance of organic resources in semi-arid West Africa showed that termite density was strongly correlated with the availability of organic material with recalcitrant organic material being preferred over easily decomposable organic resources. This strongly suggests that use of crop residues is a strategy for increasing termite abundance in soil; however it does not appear to favor macro-fauna diversity.

The effect of organic amendment type and addition or with holding of nitrogen had interesting effects on both macrofauna biological components and lend insight to how to use this conservation soil management practice. Addition of nitrogen to organic amendments likely affected food quality and competition between soil macrofauna. Termites are more competitive than earthworms in the decomposition of recalcitrant organic amendment such as straw which explains their abundance in the straw – N treatment. Correspondingly, when N is added the number of termites was reduced suggesting higher competition from other organisms. Earthworms are more competitive than termites in the decomposition of easily decomposable organic material. This explains their abundance in manure treatments (Leroy et al., 2008). Previous studies showed that the quality, and not only the quantity, of organic matter determines the growth rate of the worms (Martin and Lavelle, 1992). More decomposed complex organic matter was contained in the organic amendment treatment with lower C/N ratio in aggregate fraction. The long-term management organic amendment practices employed to date have probably led to an adaptation by the more competitive taxa which, therefore, have reduced the taxonomic richness. However, a relative variability exists depending on the type of organic matter that was applied and the addition or with holding of extra N.

4.3. Termite and earthworm abundance and taxonomic richness under different tillage

The effects of tillage by animal plow and hand hoeing on soil characteristics (Table 1) and on most of the studied macrofauna components (Table 7) were similar. However, the intensity

Table 8
Termite taxonomic richness and functional (feeding) groups based on monolith and transect methods in Saria III, Burkina Faso (D = Dung/manure; F = fungus grower; G = dead/dry grass; L = leaf litter; S = soil; W = wood feeder).

Taxonomic group	Functional group[a]	Food type[b]	Possible pest[c]	S3–1	S3–2
Termitidae–Nasutitermitinae					
Trinervitermes sp.	II	LG	Yes	+	–
Termitidae–Macrotermitinae					
Macrotermes sp.	II	FWLG	Yes	–	+
Microtermes sp.	II	FWLG	Yes	+	+
Termitidae–Termitinae					
Amitermes stephensoni	II	WLSD	Yes	+	–
Taxonomic richness per treatment	3	2			
Taxonomic richness under Saria 3	4				

Treatments key: Animal plow (S3–1); Hand hoe (S3–2).
[a] Based on classification by Bignell and Eggleton (2000), Donovan et al. (2001) and Eggleton et al. (2002).
[b] Based on field notes/observation.
[c] Based on observations by Kooyman and Onck (1987) and Jannette (2002). (+/–) denotes present or absent respectively.

of the two tillage practices showed that both fauna were more developed compared to others practices (Saria I and II). Termite and earthworm development is related to the structure of their habitat selecting factors (Brussaard et al., 2007). Increased root biomass (data shown in another paper) from tillage increased food availability to termites and earthworms. Many termite species were recorded under animal plowing, and earthworm population increased in weight. This is in agreement with the findings of Black and Okwakol (1997). In fact, according to the feeding behavior of the identified termites it appears that plowing depth for both animal plow (15 cm) and hand hoeing (5 cm) was superficial and therefore would not affect the nesting zone of the identified termites (Black and Wood, 1989). In addition, earthworms are limited by the available carbon in soil irrespective of the total C content (Tiunov and Scheu, 2004; Leroy et al., 2008). The analysis of organic carbon in the soil aggregate fraction (data shown in another paper) showed more complex organic matter (lower C/N ratio) under tillage practices compared to rotation. Both tillage practices had therefore created more favorable living conditions for both fauna although in different ways. This was evidenced by the many species and higher taxonomic richness recorded for termites and higher abundance of earthworms. The incorporation of organic material (dead roots) into the bulk soil also enhances degradation and solubilization of organic substances exposing SOM to soil organisms. The lack of difference between animal plow and hand hoe effects could be due to the similar and homogeneous effects induced by both practices such as rooting depth, total carbon and crop yield (Mando et al., 2005). Both animal plowing and hand hoeing in Saria seem to lead to a consistency in the soil structure and conditions that resulted in the increases in fauna activity.

5. Conclusions

This study aimed at comparing the effects of selected conservation soil management techniques on two major soil-engineers: the termite and earthworm biological components (abundance, biomass and taxonomic richness), sampled at the sorghum maximum development phase. The motivation was that increasing the understanding the soil biodiversity effects of the conservation soil management practices would be beneficial to development of more sustainable use of the arable land. Termite and earthworm settlement is related to their habitat selecting factors. The management options were found to have different impacts on these factors, and therefore on the macrofauna abundance and diversity, depending on the particular macrofauna group.

Termites, which feed on a wide range of food sources, were in general present in greater taxonomic richness than earthworms. Termites were found in greater abundance in treatments with more recalcitrant organic materials, while earthworms were abundant in treatments which contained more decomposed, complex organic matter. Rotation practices showed lower populations for both macrofauna compared to monocropping, confirming other studies and suggesting that if rotation is desirable then other factors need to be managed to encourage macrofauna colonization. Tractor plowing coupled with lower organic matter application, insecticide (with the cotton and cowpea rotations) and the varying rooting depths of rotation crops lowered the population of both macrofauna. Manure and straw application at a rate of 10 Mg ha^{-1} with no additional N led to more earthworms and termite activity than the corresponding applications plus N, the lower rate of organic matter application, or the control. Animal plow and hand hoeing were similar in their influence, likely because the effects of both practices on soil characteristics are similar and insignificant to what matters for these fauna. To promote macrofauna abundance and taxonomic richness in soils, integrated conservation soil management practices with attention to the particular needs and preferences of termites and earthworms is needed.

Acknowledgements

This study was supported by Science for Global Development/WOTRO through Wageningen University. It is a result of collaborative research between IFDC and INERA in Burkina Faso; TSBF-CIAT, and KEFRI in Kenya; Wageningen in the Netherlands and UC-Davis in California. We wish to thank the numerous people involved in the field and laboratory activities, data analysis and process of writing and publishing this document.

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