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Seasonal CO_2 and CH_4 Emissions from Termite Mounds in the Sub-Sahelian Area of Burkina Faso

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Abstract: CO_2 and CH_4 emissions from termites based on *in situ* measurements are less documented than Laboratory-based studies. Few data associated biotic and abiotic factors in ecological conditions to assess greenhouse gases emissions. The present study aims to quantify CO_2 and CH_4 emissions from *Macrotermes bellicosus* mounds during 12 months in a natural reserve of Ouagadougou, Burkina Faso. The CO_2 emission was significantly related to season, mound temperature, rainfall and relative humidity. During the wet season, high CO_2 emission rates were found (229-964 mg CO_2 $m^{-2}.h^{-1}$) compared to the dry season (58-261 mg CO_2 $m^{-2}h^{-1}$). Furthermore, high CO_2 emissions were noted for mound temperature < 30°C, rainfall > 47 mm and moisture > 65%. A rate of 15 µg CH_4 $m^{-2}h^{-1}$ was recorded during the first rain season in 2010 against a quasi-undetectable amount during the second rain season in 2011. This study emphasizes that most environmental parameters have a particular effect on CO_2 and CH_4 emissions from the termite mound species. It will also be necessary to investigate the diversity, distribution and spatiotemporal evolution of microbial community located in termite guts and mounds which are the relevant biotic factors involved in gas production and emission.

Key words: Carbon dioxide · Methane · *Macrotermes bellicosus* mounds · Season · Temperature · Moisture

INTRODUCTION

Methane (CH_4) and carbon dioxide (CO_2) are two powerful greenhouse gases (GHG) more released in the atmosphere. CH_4 has a global warming potential 25 times than that of CO_2 on a 100-years time horizon [1]. Globally, more than 580 Tg CH_4 are released annually in the atmosphere, with over 70-80% from biological sources [2]. 2/3 CH_4 emissions originate from anthropogenic sources as fossil fuel energy production and use, paddy rice cultivation, enteric fermentation in the guts of ruminant animals, biomass burning, land-use changes, animal waste and sewage and 1/3 comes from natural sources including wetlands, CH_4 hydrates, oceans, fresh water and termites [3].

The last-mentioned (termites) are widespread in tropical areas and occur between 45°N and 45°S, or approximately two-third of the earth's land surface [4]. Termites are an integral component in tropical ecosystems by cycling organic matter, fertilizing soil and maintaining soil structure. However, harboring a dense and different microbial community in their gut, termites produce CH_4 and CO_2 during organic matter digestion [5]. Numerous studies have shown the contribution of termites to magnitude of 3-56% of the global budget of CH_4 emissions [6-10]. However, these studies did not include biotic and abiotic factors to assess these contributions. The lack of measured emission rates from termite mound and representative field experiments including climatic factors could induce assessment errors and uncertainties. More recently, Sugimoto *et al.* [11] and Brümmer *et al.* [12] revealed 0.2-2.0% CO_2 and 0.15% CH_4 in termite contribution to global terrestrial emissions, respectively.

The sub-sahelian savanna of Burkina Faso, in West Africa, with high temperature and rainfall allows studying C trace emissions from termite mounds.

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The present study aims to investigate on seasonal CO_2 and CH_4 emissions from termite mounds using a fully replicated field experimental design. The main objectives were to quantify (1) CO_2 and CH_4 release from termite mounds, (2) determine the impact of temperature, precipitation and humidity on CO_2 and CH_4 release and (3) highlight season effect on the mentioned gas emissions.

MATERIALS AND METHODS

Experimental Site: The study site is localized in the natural reserve of Somgandé (12° 24' N, 1° 29' W and altitude 294 m) in Ouagadougou, in centre of Burkina Faso. It extends on a surface of 15 hectare (ha) where agricultural activities are carried out in rainy season. The study on the evaluation of CO_2 and CH_4 emissions was performed from August 2010 to August 2011 from *Macrotermes bellicosus* termite mounds.

CH_4 and CO_2 Emission Measurements from Termite Mounds: CH_4 and CO_2 emission measurements from *Macrotermes bellicosus* termite mounds (n=2) were recorded on monthly basis from August 2010 to August 2011 (except December, 2010). All measurements were performed between 6-7 h AM where gas emissions were higher than 6-7 h PM ones [Sawadogo *et al.* submitted]. Mounds were of approximately the same size, with an average diameter of 2 m and a height from 0.65 to 1.17 m. They are distant of 393 m. CH_4 and CO_2 emissions from the mounds were measured *in situ* by using static manual chambers of the same volume (8 cm diameter, 21 cm length) made from polyvinylchloride (PVC) fitted septum for headspace gas sampling. Static chambers (n=3) were installed to a depth < 20 cm into each mound, randomly, in order to reach main galleries from which gases are freely released and stored in the chamber headspace.

Headspace gas samples (10 ml) were withdrawn with 10 ml graduated pressure lock syringes. On each 10 ml gas sample, only 4 ml were immediately transferred into 4 ml vacutainer tube (Improvacuter). These tubes were transported to Laboratory for CH_4 and CO_2 analysis with a gas chromatograph (Girdel serie 30 catharometer) equipped with a manual injector, a 80/100 Porapak Q (for CH_4 analysis) and 100/120 Porapak Q (for CO_2 analysis) columns assembled in parallel and connected to a thermal conductivity detector (TCD) and a potentiometric recorder (SERVOTRACE type Sefram Paris, 1 mV). The analysis conditions were: injector temperature (90°C), oven (60°C), detector (100°C). H_2 was the carrier gas and reference gases (CH_4 and CO_2) were supplied by Burkina Industrial Gas and used as standards for determining linear regression as described by Sawadogo *et al.* [13]. In total, 106 gas samples were collected during this study period with a sampling frequency of once to twice per month from each termite mound.

Auxiliary Environmental Measurements: During gas sampling, mound temperature (T_{mound}) was measured immediately close to each static chamber using a field Bioblock Scientific Minitherm 16228 thermometer fitted stainless steel temperature probe length of 10 cm with an accuracy of ±1°C. Without touching mound wall, the probe was inserted 10 cm into mounds throughout a hole made at 20-30 cm depth and 0.7 cm diameter in order to reach small galleries and minimize gas escape. Triplicate of mound temperature were measured on each termite mound at each sampling time. In parallel, the air temperature (T_{air}) was also measured beside termite mound before and after gas sampling. The mean monthly meteorological temperature (T_m), rainfall (R_m) and relative humidity (RH_m) were provided by the Somgandé meteorological station (Direction Générale de la Météorologie de Somgandé) located near to our experiment site (~1.1 km).

Data Processing: Microsoft Excel (2007) and SPSS 17.0 were used for graphic representations and data statistical analysis, respectively. One-way analyses of variances (ANOVA) were performed to identify significant differences in means of CO_2 and CH_4 values (n=106) with regard to T_{mound}, T_{air}, R_m, RH_m and seasons. Statistical significance was defined at $P<0.05$, unless otherwise noted. Least Standardized Difference (LSD) Post Hoc tests were used to identify significantly different CO_2 or CH_4 means among seasonal scales (wet, cold dry and hot dry seasons). Linear regression and Pearson correlation analyses were used to evaluate, respectively, the significance and correlation of relationships between CO_2 or CH_4 emissions and one of the environmental parameters (T_{mound}, T_{air}, R_m, RH_m) with $P<0.05$.

RESULTS

CO_2 Emissions from Termite Mounds: CO_2 emissions measured at intervals of 15 days per month fluctuated more or less during samplings, generally (Fig. 1). For termite mound 1, the lowest and highest CO_2 emissions were 1923 ppmv recorded on April 15th and 31084 ppmv on July 15th. A similar range of CO_2 emissions (1918 ppmv on April 30th and 44568 ppmv on July 15th) was observed for the termite mound 2.

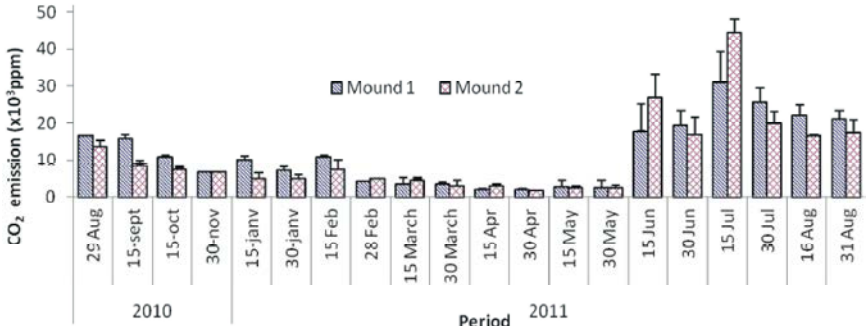

Fig. 1: Variation of CO_2 emissions (n=3, ± SE) from termite mounds during sampling periods in 2010 and 2011

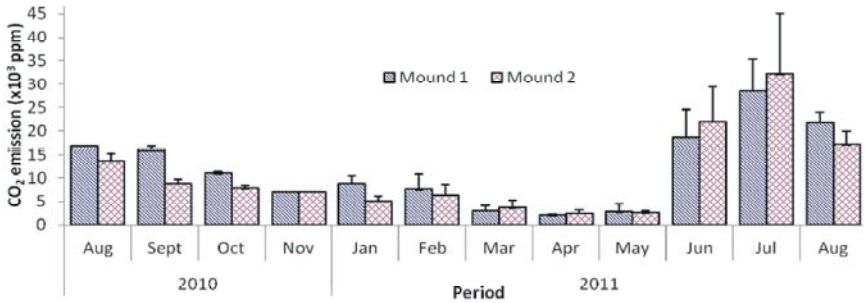

Fig. 2: Variation of monthly CO_2 emissions (n=6-12, ± SE) from termite mounds in 2010 and 2011

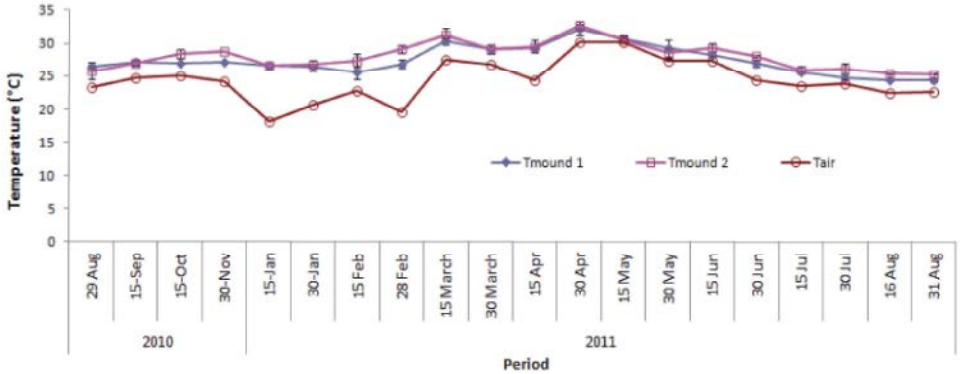

Fig. 3: Temperature variation inside termite mounds ($T_{mound\ 1}$ and $T_{mound\ 2}$) (n=3, ± SE) and air (T_{air}) (n=2) for each sampling period in 2010 and 2011

From both termite mounds, CO_2 releases were greater in July than April (Fig. 2). The lowest mean CO_2 emissions were 1959 ppmv for termite mound 1 and 2463 ppmv for mound 2 in April. The highest were recorded in July with 28407 and 32235 ppmv for mounds 1 and 2, respectively. Regardless of mound, there was a 13-14 fold difference in CO_2 emissions between the measurements of April and July of the same year.

Mound and Environmental Temperatures: In general, the termite mound temperatures ($T_{mound\ 1}$ and $T_{mound\ 2}$) were slightly high as compared to air temperature (T_{air}) during the sampling periods (Fig. 3). The low air temperatures ranged from 18.2 to 22.8°C between January 15th and February 28th 2011 and maximum air temperatures from 27.5 to 30.2°C between 15th March and 15 May 2011.

The temperatures of both termite mounds were not significantly different (P=0.64), but varied slightly from 24.2°C (August 16th) to 32.6°C (April 30th) compared to air temperature (18.2°C on January 15th to 30°C on April 30th and May 15th) during the experiment period. T_{air}, T_{mounds} and meteorological ambient temperature (T_m) moved in the same order and were very significantly different from each other (Table 1).

Table 1: Relationships between temperature of termite mound (T_{mounds}), air temperature (T_{air}) and meteorological temperature (T_m). R^2: Linear regression, r: Pearson correlation

Variable	R^2	r	*P* value
T_{mounds} x T_{air}	0.478	0.691	0.006
T_{mounds} x T_m	0.673	0.820	0.001
T_m x T_{air}	0.795	0.892	0.000

Table 2: Variations in termite mound CO_2 emissions between wet season (WS: June-October), cold-dry season (CDS: November-February) and hot-dry season (HDS: March-May). Values are difference of mean CO_2 emissions ± SE between both seasons

Interaction of factors	Difference of mean CO_2 emissions (ppmv)	*P* value
WS x CDS	13172±1754	0.000
WS x HDS	17174±1498	0.000
CDS x HDS	4001±1878	0.036

Table 3: Relationships between environmental parameters (T_{mounds}, T_{air}, T_m, R_m and RH_m) and CO_2 emissions from termite mound. R^2: Linear regression, R: Pearson correlation

Variable	*P* value	R^2	r
T_{mounds}	0.000	0.318	-0.564
T_{air}	0.169	0.049	-0.222^{ns}
T_m	0.100	0.174	-0.418^{ns}
R_m	0.000	0.806	0.898
RH_m	0.012	0.449	0.670

ns: not significant

Seasonal CO_2 Emission Variation: CO_2 emitted from Mound 1 and Mound 2 showed a non-significant difference (*P*=0.087, data not published) along seasons. The average monthly CO_2 emissions from both termite mounds were more important from August to October 2010 and June to August 2011 with ranges of 7710-16766 ppmv and 17018-32235 ppmv, respectively (Fig. 4a). Moreover, low values (1959-8746 ppmv) were recorded from November 2010 to May 2011. These variations followed seasonal changes. Indeed, in all mounds, the difference of mean CO_2 emissions between the wet season (June to October) and the dry season (November to May) was highly significant (Table 2). Likewise within the dry season, a significant difference between the cold-dry season (November-February) and the hot-dry season (March-May) was noted (Table 2). Mean CO_2 emissions ranged from 17794 ppmv (wet season) to 4818 ppmv (dry season). The seasonal variations were related to temperature, rainfall and humidity variations which could affect the CO_2 release from the termite mounds.

For both wet and dry season, CO_2 emissions were negatively correlated with T_{mounds}, T_{air} and T_m (r = -0.564, -0.222 and -0.418, respectively) (Fig. 4a, 4b, 4c; Table 3). However, the relationships between CO_2 release and T_{mound} was highly significant than that with T_{air} and T_m (Table 3). Although in the dry season (November-May) the temperature ranges were near to those in the wet season (June-October), the CO_2 productions in the dry season were lower than those in the wet season.

The rainfall (R_m) could influence the gravimetric water content of termite mound wall that was not measured during this study. R_m also differed with regard to different seasons. It varied from 0 (November to February), 0.8 to 33.9 mm (March to May) in the dry season, in contrast to the wet season with a variation of 47.2-378 mm (Fig. 4b). High CO_2 emissions (>7710 ppmv) were recorded for R_m values >47.2 mm with a maximum in July (28407 and 32235 ppmv for mound 1 and mound 2, respectively), under a R_m of 378 mm (Fig. 4a, 4b). The relationship between CO_2 emissions and rainfall were strongly correlated in wet season (r= 0.898) (Table 3). However, CO_2 emissions were relatively important in cold-dry season (November-February, 0 mm) than in hot-dry season (March-May, up to 33.9 mm) (Fig. 4a, 4b). The rainfall could not alone explain CO_2 emissions observed in dry season, but influence the level of humidity in atmosphere during gas release.

The variations of ambient relative humidity (RH_m) and CO_2 emission are shown on Figures 4a and 4c. The dependency of CO_2 emissions on seasons (dry and wet) was comparable to that on relative humidity. A 25-54% and 65-78% RH_m were recorded in the dry season and wet season, respectively. The relationship between CO_2 release and RH_m could be well described by linear regression (r= 0.670; Table 3).

Seasonal Mound CH_4 Emission: During all the experiment period, CH_4 emitted from both mounds was poorly recorded. The mound CH_4 amounts were just detectable at the threshold of 0.5 ppmv for the wet season time (August to October) and only at the beginning of dry season (November) in 2010. From January to August 2011, CH_4 measurements were low to the detection threshold (<0.5 ppmv). The CH_4 emission did not clearly follow the variation of temperature (T_{mound} or T_{air}), rainfall, ambient relative humidity and season, as the case of mound CO_2 emission.

DISCUSSION

Impact of Seasonal Variations on Mound CO_2 Emissions: In this study, the field based-experiment results revealed strongly environmental drivers as the main factors causing a significant seasonal variation in mound CO_2 emissions.

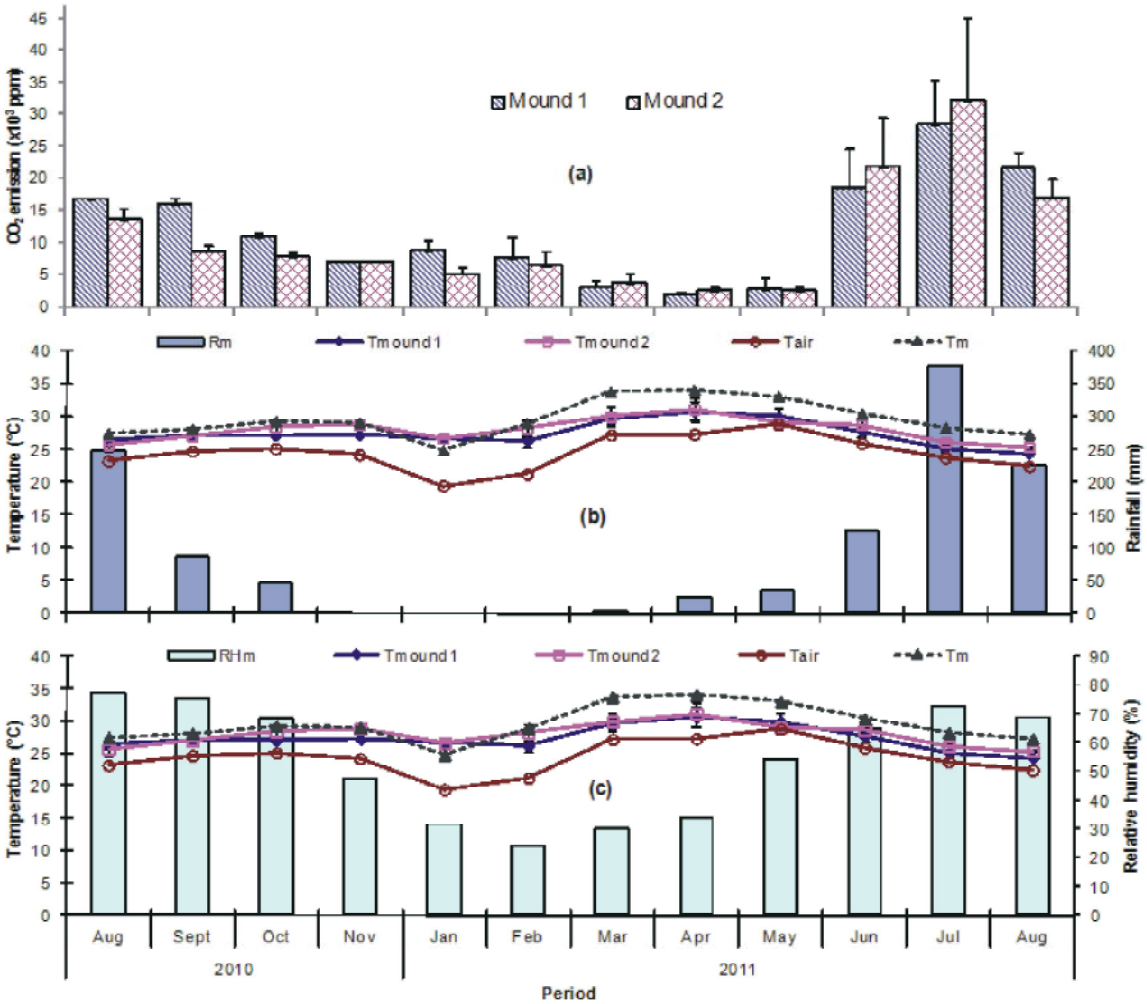

Fig. 4: Seasonal CO_2 emissions from termite mounds and related environmental parameters. Monthly means of mound CO_2 emission (n=6-12 ± SE), mound temperature ($T_{mound\ 1}$ and $T_{mound\ 2}$, n=6-12 ± SE), air temperature (T_{air}, n=2-4). Climate data [meteorological temperature (T_m), rainfall (R_m) and relative humidity (RH_m)] were obtained thanks to the Somgandé meteorological station (Direction Générale de la Météorologie de Somgandé)

Table 4: Mean CO_2 and CH_4 emission rates from *M. bellicosus* termite mounds during wet and dry seasons. Published data from other termite species are given for comparison

	CO_2 emissions ($mg\ CO_2\ m^{-2}.h^{-1}$)		CH_4 emissions ($\mu g\ CH_4\ m^{-2}.h^{-1}$)			
Termite mound species	Wet season	Dry season	Wet season	Dry season	Localization	Source
Macrotermes bellicosus	229-964	58-261	15	(-)	Somgandé natural reserve (Burkina Faso, BF)	This study
Cubitermes fungifaber	300-700	100-200	3000-5300	883-2800	Bontiolo natural reserve (BF)	[12]
Microcerotermes nervosus	nd	nd	4444	558	Tropical Ecosystem Research Center (Australia)	[14]
Tumulitermes Pastinator	nd	nd	8475	956	Charles Darwin National Park (Australia)	[14]
M. Bellicosus	269-329	59-120	nd	nd	Comoé national park, (Ivory Coast)	[15]

nd: not determined; (-): CH_4 not detected

Termite mound temperature (T_{mound}) had a higher significant effect than that of air (T_{air}, P=0.169) and meteorological (T_m, P= 0.100) temperatures on mound CO_2 emissions. T_{air} and T_m are assumed to have an indirect effect on CO_2 emissions by acting near enough on T_{mound}. Microclimate maintaining within mounds could result in termite activities with regard to external climate. Indeed, Korb and Linsenmair [15, 16] demonstrated a mound

building by *M. bellicosus* termites and lowest CO_2 emission from mounds exposed in rising ambient temperature. These results are in agreement with our data which also revealed a decrease in CO_2 emission when temperature increased, especially during the hottest period (March-May). We also observed that this period was correlated with mound architecture construction by the selected species of termite and others. The variation of temperature inside and outside the mounds seems to create changes of internal gas flux and mound structure [15; Sawadogo *et al.* submitted]. Moreover, Brümmer *et al.* [12] reported that the lowest CO_2 values from *Cubitermes fungifaber* mounds were important at termite mound temperatures >32°C. Although our termite species was different, the CO_2 emissions recorded from both *M. bellicosus* termite mounds at mound temperatures >30°C (in April) were also the lowest (1920-3000 ppmv). Contrasting these results, Ruelle [17] showed that CO_2 emission from *Coptotermes lacteus* termite mounds was more important when the mound temperature increased. This termite species (wood-feeding termites) belonging to Rhinotermitidae family does not perform the same activities of *M. bellicosus* (fungus-feeding termites) of Termitidae family. We can also assume that the recent rising trend of atmospheric greenhouse gas concentration with an increase in temperature might lead to changes in the metabolism and activities of termites allowing them to develop strategies of thermoregulation, adaptation and gas exchange according to termite mound [15, 18]. The variation in mound CO_2 emission response to temperature across seasons could be attributed to seasonal variations in moisture (rainfall, relative humidity).

Globally, mound CO_2 emissions increased with rainfall (47.2 mm < R_m < 378 mm) and moisture (RH_m> 65-78%) in rainy season. The latter case is in agreement with the findings of Brümmer et al. [12] who found important CO_2 emissions at high termite mound moisture values (>60%). Moreover, Konaté *et al*. [19] revealed high CO_2 emission rates (432-821 mg CO_2 m^{-2} h^{-1}) from *Ancistrotermes cavithorax* and *Odontotermes pauperans* termite mounds, in Ivory Coast savanna, with a mean monthly precipitation of 271 during rainy season from July to September. That also strongly supports our findings as these termite species and *M. bellicosus* belong to the Macrotermitinae subfamily. In general, CO_2 emissions were greater in wet season than in dry season as described by other studies [12, 15]. The importance of water availability during wet season leads to soil and termite mound moisture favoring food availability, degradation of vegetable organic matter by termites and metabolism of termite mound microorganisms. For instance, greater mound-building activities were observed in rainy season compared to dry season. That could change the inner structure of mound and consequently the CO_2 and CH_4 fluxes.

Seasonal Variations in CH_4 Emissions: The CH_4 emissions in our study did not follow the trend of CO_2 emission for all the considered environmental parameters. The detected CH_4 amounts during wet season in 2010 were in accordance with most previous studies data [12, 14, 20] (Table 4). CH_4 absence noted during dry season in this study was comparable to low CH_4 emission as found by other authors [12, 14, 20] (Table 4). The weak quantification of CH_4 emission in wet season in 2011 seems to be related to our designs continually installed under termite construction activity. Nevertheless, this gas absence could be also explained by the oxidation of CH_4 by methane-oxidizing bacteria (methanotrophs type I and/or II) suggested and highlighted from mound, desert and other soils where CH_4 is present [2, 21-23], particularly in oxic dry lands. Furthermore, a weak foraging activity of termites noted around mound, for the last period, could explain the low CH_4 emission rates recorded. Indeed, Sawadogo *et al.* [13] revealed a variation of CH_4 production in 1 L chamber by termites with respect to their food substrates. Some studies underlined at Laboratory scale [9, 24-25] and from field-based experiments [8] a parallel increase of CH_4 production with temperature ranging from 19.5°C to 30.5°C. In contrast, Sawadogo *et al.* [13] and Gomathi *et al.* [26] pointed out a decrease in CH_4 production from *Macrotermes* sp and *M. bellicosus* termite cultures when increasing temperature from 30 to 37°C. As explained above, the important variability of global climate and the real environment conditions can lead these insects to change their physiological mechanism.

In conclusion, our study showed CH_4 and CO_2 emissions from *Macrotermes bellicosus* termite mounds with regard to the ecosystem conditions of sahelian countries. Globally, CO_2 emissions varied significantly between seasons, with mound temperature, rainfall and moisture, whereas CH_4 was weakly emitted or undetectable during our experiment campaign. More CO_2 release was recorded in wet season, at low mound temperature, high rainfall and relative humidity. That is the first study which really provided monthly CO_2 and CH_4 emission data allowing observing variations along

seasons. The data obtained revealed that both gases emission was low at high mound temperature (>30°C), low rainfall (<47 mm) and low moisture (<54%). However, it will be necessary to extend the study over several seasons and years with respect to other termite species and ecological zones of Burkina Faso. Such studies may help to setting strategies for the mitigation of greenhouse emissions and climate change adaptation in sahelian areas.

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