Cumulative and Yield-Scaled Greenhouse Gas Emissions Under Different Organic and Inorganic Soil Fertilization in Central Kenya

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Article

Cumulative and Yield-Scaled Greenhouse Gas Emissions Under Different Organic and Inorganic Soil Fertilization in Central Kenya

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Abstract: Demand for livestock products in East Africa is anticipated to triple by 2050. Therefore, sustainable intensification of livestock production systems for increased productivity is necessary in line with minimal negative environmental consequences. An agronomic field experiment was set up at the International Livestock Research Institute in Nairobi, Kenya, and the effects of organic and inorganic soil amendments on greenhouse gas emissions (particularly N_2O) from a Humic Nitisol planted with *Brachiaria brizantha cv. xaraes* were evaluated between October 2018 and August 2019. The treatments comprised mineral NPK fertilizer, Lablab intercrop, FYM, FYM-BC, Bioslurry, and control. Fertilizer treatments were applied at a rate of 45 kg N ha^{-1} following each harvest. GHG emissions were measured using the static vented chamber technique. Treatment and season significantly influenced daily N_2O emissions. The lowest (4.51±3.30 μg N m^{-2} h^{-1}) and highest (27.16±3.61 μg N m^{-2} h^{-1}) mean N_2O emissions were recorded under NPK and Control treatments during the short rains and dry seasons, respectively. Cumulative N_2O emissions and the corresponding yield-scaled emissions were similar across all the treatments but varied significantly ($p < 0.001$) between the wet and dry seasons. Cumulative N_2O emissions were 0.31±1.49, 0.33±1.47, 0.33±1.74, and 0.37±1.74, 0.38±2.3 and 0.42±1.81 Kg N ha^{-1} under FYM-BC, Lablab, NPK fertilizer, and FYM, Bioslurry and control treatments respectively. The corresponding yield-scaled emissions were also higher during the wet (0.23±1.16 g N kg^{-1} DM) than in the dry seasons (0.16±0.50 g N kg^{-1} DM). Higher (-21.86±4.47 mg CH_4-Ch^{-1}) CH_4 uptake was recorded under the control treatment whereas the lowest (-2.69±17.97 mg CH_4-Ch^{-1}) uptake was recorded under Bioslurry ($P < 0.01$). Treatment and season exhibited individual effects on daily CO_2 emissions ($P < 0.001$), with a significant interaction effect ($P < 0.001$). The highest (157.5±28.76 mg CO_2-C $m^{-2}h^{-1}$) and lowest (44.33±8.37 mg CO_2-C $m^{-2}h^{-1}$) CO_2 emissions were recorded under Control and FYM treatments during the October 2018-January 2019 and January-March 2019 HD. Since the experiment was newly established via ploughing a field which had been used as a permanent pasture during previous years, did not expect considerable yield differences between treatments. Yet, it is interesting to see first effects of fertilizer amendments, pointing to their potential as climate-smart forage intensification strategies. The study established that Manure + biochar is a better strategy for forage soil amendments in mitigating soil N_2O emissions.

Keywords: GHG emissions; Nitrous oxide; organic and inorganic fertilizers; forage quality

1. Introduction

1.1. Carbon Mineralization and CO_2 Emissions

During decomposition, organic matter (plant and microbial biomass, soil organic matter) is broken down and biochemically changed, processes during which CO_2 under aerobic conditions (heterotrophic respiration) and CH_4 under anaerobic conditions (methanogenesis) are produced. The soil microbial community is crucial for the turnover of nutrients, such as the incorporation of carbon into microbial biomass (the primary pathway of SOM formation), or the mineralization and immobilization of N. Soil microorganisms are driving the so-called C and N "humification", a term

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describing the production and decomposition of SOM. Humus affects soil parameters due to its slow decomposition rate, improving soil aggregate stability, and increasing cation exchange capacity (CEC) (Bot and Benites, 2005). Decomposition involves the physical breakdown and chemical amendment of organic fragments (e.g. cellulose, protein) from dead organic resources into shorter mineral and organic units (for example sugars, peptides and amino acids) (Janzen et al., 1998; Bot and Benites, 2005).

Organic material supplemented to the soil can increase microbial activity and accelerate turnover of C in the soil, a procedure in which inorganic and organic C compounds are continuously transformed by connections between various organic components, vegetation and atmosphere (Bengtsson et al., 2005; Bot and Benites, 2005). This process releases CO_2, energy, water, nutrients and C compounds. In addition to soil microorganisms, soil properties and conditions are also affected by plant roots, for example via excretion of root exudates. Furthermore, microorganisms and plant roots compete for Oxygen (O_2), with high O_2 use creating anoxic conditions (Hynes and Knowles, 1984). In cases of insufficient O_2, microorganisms have to use alternative respiration pathways, e.g. denitrifying bacteria that utilize NO_3^- instead of O_2 as electron acceptor during respiration (Robertson and Groffman, 2007), or methanogenic archaea that use CO_2 as electron acceptor and produce CH_4.

Variations in temperatures, rainfall and organic matter composition influence decomposition rates, which can be more rapid in tropics compared to temperate regions if moisture is not limiting. An increase in the level of yearly rainfall usually increases the rate of decomposition. Increased rate of decomposition and bacterial activity occur at 60 percent water-filled pore space (WFPS) (Linn and Doran, 1984). Though, periods of saturation and poorly aerated soil slows downs the rate of decomposition (Bot and Benites, 2005).

Higher soil temperatures too are associated with higher soil respiration rates by accelerating the rates of Carbon cycling through autotrophic respiration and providing a powerful positive feedback to climatic warming through the heterotrophic respiration of the soil organic Carbon (Hamdi et al., 2013). Other factors that have been reported to influence the rate of soil respiration are soil moisture, the levels of nutrients content and Oxygen levels in the soil (Moyano et al., 2013). Ploughing and soil disturbance too increase the rate of soil respiration through opening of the soil air spaces that accelerate the rate of microbial activity in the soil (Yiqi and Zhou, 2010).

The quantity and quality of organic matter added also affects the rate of decomposition in numerous ways. CO_2 emissions are stimulated whenever sources of C-based material hold easily decomposable C and N compounds. In tropical Africa, the use of organic substances possessing narrow C/N ratios such as manure and legume plant remnants, increases decomposition whereas the input of crop residues with high C/N ratios, like cereals and forage grasses, increases soil nutrient immobilization, the build-up of organic matter, and humus formation (Nicolardot et al., 2001; Bot and Benites, 2005). CO_2 is formed when autotrophic and heterotrophic organisms respire. CO_2 formation via heterotrophs occurs when O_2 is available. CO_2 is emitted from soils that are readily formed, more porous, leading to around 10 percent of CO_2 collects in the atmosphere annually (Raich and Tufekciogul, 2000). The soil carbon element is reduced through the process of heterotrophs that uses O_2 and emit CO_2 as a by-product (Cambardella, 2005).

1.2. Methane Consumption and Emissions

Methane is a GHG with a global warming potential 28 times larger compared to CO2 calculated over a 100-year time horizon (Myhre et al., 2013). Globally, the level of CH_4 in the atmosphere rose up from 750 ppb in the year 1800 up to 1,803 ppb by the year 2011 (Myhre et al., 2013). Segers (1998) reported that formation of CH_4 and its consumption are changes supported by organic matter mineralization in the soil. Soil conditions such as temperature, pH and inhibitory materials influences CH_4 production. High differences in absolute rise in microbial activity when temperature rises by 10 °c leads to values of CH_4 emissions of 1.3–28 (Segers, 1998). The pH of the soil is a factor that influences CH_4 formation. A lot of methanogenic microorganisms' work at optimum pH of seven and raising the pH of anaerobically induced soils raises CH_4 emissions. Methanogens are strictly anaerobic and can only survive under continuously O2-depleted conditions (for example wetlands, rice paddies).

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In anaerobic circumstances, the availability of organic materials is a limiting aspect for CH_4 release. Many studies have reported that addition of straight methanogenesis materials such as acetate and hydrogen or others like leachate and glucose promotes CH_4 emissions (Segers, 1998).

Methane consumption is a process whereby CH_4 is disintegrated by methanotrophic microorganisms (Segers, 1998). Le Mer and Pierre (2001) reason that these microorganisms use CH_4 as C and energy sources. They highlight that about 90 % of the CH_4 produced in low O2 environments may be broken down by methanotrophs in adequate supply of O2, for example in different layers of the same soil (methanogenesis in water-logged deep soil layers, methanotrophy in well-aerated topsoil) (Segers, 1998). Aerobic upland soils are vital sinks for CH_4, resulting to 15 % of the annual global CH_4 oxidation (Van den Pol-van Dasselaar et al., 1998). CH_4 usage is influenced by soil temperature, soil water levels, and soil N availability. When the temperature increases from 4 - 12 °C, the CH_4 absorption is doubled; however, additional temperature rises to 20 ° Celsius displays a smaller CH_4 usage. Van den Pol-van Dasselaar et al., (1998), outlined that the optimum temperature for CH_4 usage is within 20 to 25 °Celsius, moderately low compared to its production.

Methane consumption increases whenever H_2O levels rises from 22.5 % - 37.5 % w/w and decreases when water level is more than 45 % w/w. When H_2O level is less than 5 % and more than 50 % w/w, CH_4 absorption is stopped (Van den Pol-van Dasselaar et al., 1998), implying that wet or dry soil environments can stop CH_4 oxidation. It is also reported that the use of N fertilizer prevents the breakdown of CH_4 in soil because of competition between NH_3 and CH_4 for the CH_4 monooxygenase enzyme.

1.3. Soil N Turnover

Soil N_2O and NO are by-products of N-transformation processes (e.g. nitrification, denitrification, and many others) that are environmentally harmful (Figure 1) (Dhondt et al., 2004).

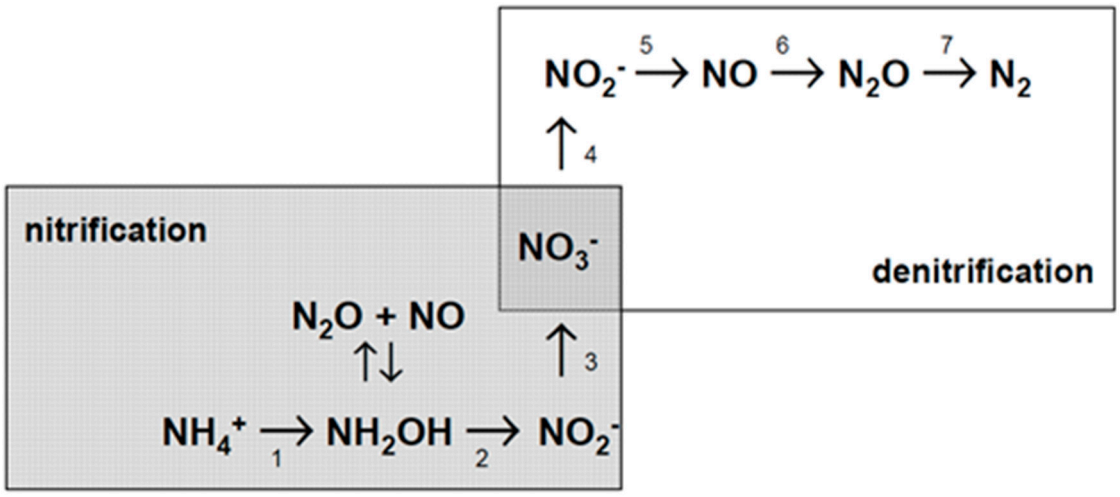

Figure 1. Processes of denitrification and nitrification (adapted from; (Kotsyurbenko et al., 2001; Dhondt et al., 2004).

The process of nitrification requires enough O_2 supply because it is an aerobic process. Subsequently, H_2O level in soil is one of the processes controlling the speed of nitrification process since soil H_2O stops air movement in the soil. The process of Nitrification ends when the levels of soil water hits the point of saturation due to lack of Oxygen. The high rates of the process are projected when the soil attains field capacity or 60% water filled pore spaces (WFPS) (Dhondt et al., 2004). The main complex bacteria to water stress are Nitrobacter species, therefore NH_4^+ and nitrite ions accumulate in drier soils. The process of Nitrification is slow when pH levels are low and increases

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when the pH goes up. However, in normal conditions, accumulation of nitrite happens as Nitrobacter species is thought to be immobile by NH_4^+, that build-up in alkaline conditions (Dhondt et al., 2004).

2. Materials and methods

2.1. Description of the Study Site

The study was conducted at the International Livestock Research Institute (ILRI)-Nairobi campus at elevation 900 m above sea level. It is a research Centre located in Nairobi County. It lies between latitude 1° 16' 11.73' South and longitude 36° 43' 26.0472" East (Figure 2). Mean annual temperature is 17 ºC and mean daily minimum and maximum temperatures are 12 ºC and 23 ºC. Mean annual rainfall is 875 mm and varies between 500-1500 mm. The total rainfall amount during the experimental period (eight months) was 802 mm. Soil temperature at the study site ranged between 16.6 º C in the wet season to 50.8 ºC in the dry season, with a mean of 34ºC.

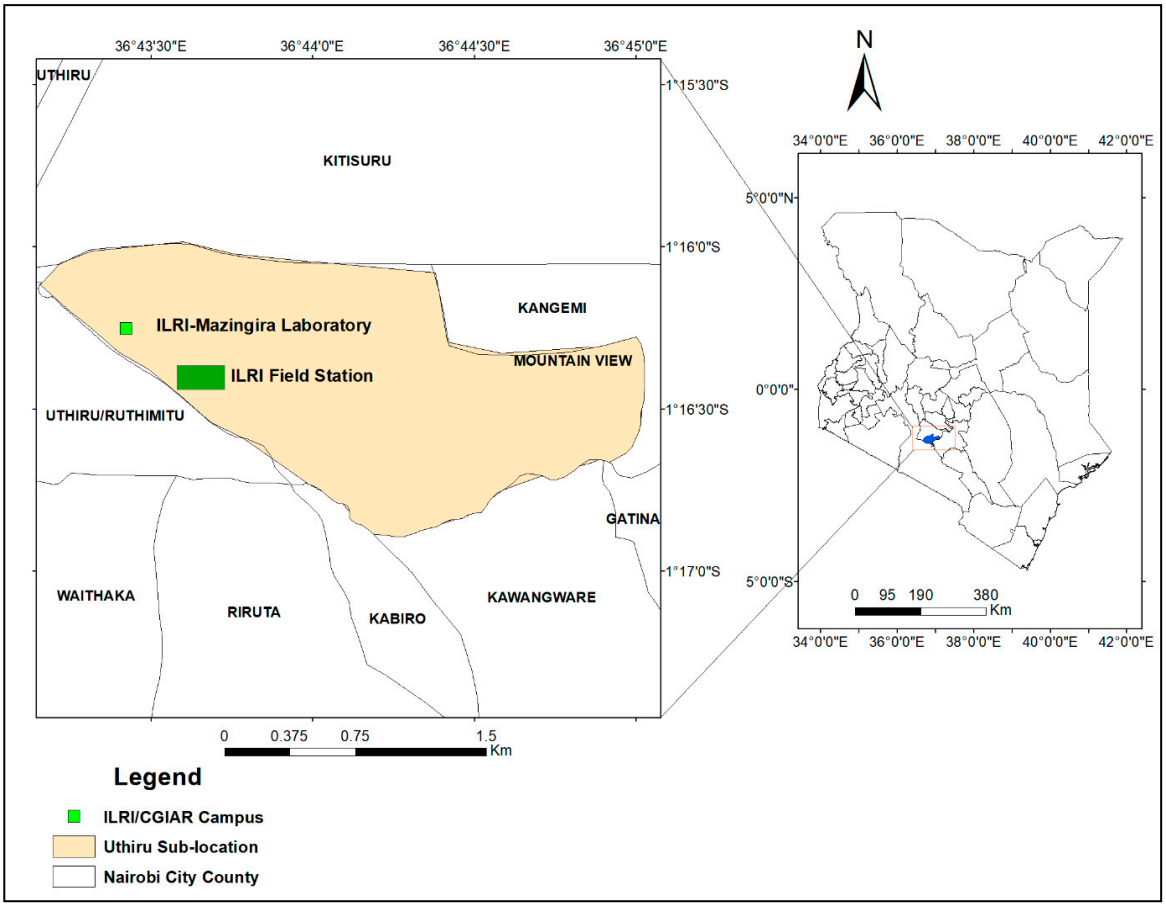

Figure 2. The study area (ILRI-Campus) Source: Author.

2.2. Treatments and Experimental Design

The study was conducted between October 2018 and August, 2019 comprising of four harvest seasons of 10 weeks each: short rains (SR, October 2018 to January 2019), hot dry season (HD, January 2019 to March 2019), long rains (LR, March 2019 to June 2019), and cold dry season (CD, June 2019 to August 2019). The setup consisted of 3 replicate blocks with 18 plots each (3 forage grass species and 6 fertilizer types), giving a total of 54 plots (4 m x 2 m).

2.3. Greenhouse Gas Sampling and Analysis

The soil-atmosphere fluxes of CH_4, CO_2 and N_2O were measured using the static chamber approach (Rosenstock et al., 2016). All sampling points followed the same scheme, between the plant

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rows at a specific distance from the borders, an opaque chamber was mounted for gas sampling (one chamber per plot). These chambers consisted of a plastic lid (0.27m×0.372m×0.125m) and a collar (0.27 m × 0.372 m × 0.1 m) (Figure 3). The collars were inserted up to 10 cm in the soil a week prior to the first GHG flux measurements and were left in place throughout the entire sampling period. The lids contained 50 cm long vent tubes with an inner diameter of 0.6 cm, thermometer ports to measure chamber headspace temperature during sampling, a fan to ensure headspace air mixing, and a sampling port with a rubber septum for collecting gas samples. When collecting the gases, the lid was put on the collar and tied with clamps with a seal between the lid and the collar for airtight closure. When collecting the gases, chamber closing was for 30 minutes, and four gas samples were drawn from each chamber at an interval of 10 minutes at 0, 10, 20, and 30 min for each plot. A 60 ml propylene syringe with Luerlocks was used to sample the gas and instantly put into pre-evacuated 10 ml gas chromatography glass vials fixed with crimp seals (Butterbach-bahl et al., 2011). The gas samples were analyzed within one week after every sampling campaign as described below in the Mazingira Centre.

Concentrations of CO_2, N_2O, and CH_4 were analyzed by use of a gas chromatograph (GC, model 8610C, SRI, Germany) equipped with two detectors: a flame ionization detector (FID) comprising of a Platinum catalyzed methanizer for catalytic conversion of CO_2 to CH_4 and for subsequent detection of CH_4 and CO_2, and an electron capture detector (ECD) to detect N_2O. A 5% CO_2-in-N_2 mixture was used as the ECD Make-up gas to improve on the detector sensitivity. The analytes were separated on chromatographic columns (Hayesep D, 3 m, and 1/8″) as the stationary phase at an isocratic oven temperature (70 °C). ECD and FID detector temperatures were set at 350 °C. High-purity N_2 was used as carrier gas at flow rates of 25 ml min^{-1} on both FID and ECD. Gas concentrations of the samples were calculated as the peak areas measured by the GC comparative to the peak areas measured from standard gases of known concentrations run at four calibration levels. Calibration gases ranged from 2.03 to 49.8 ppm for CH_4, 403 to 2420 ppm for CO_2 and 329 to 2530 ppb for N_2O. Concentrations in ppm or ppb were then changed to mass per volume by using the Ideal Gas Law (PV = nRT) using the chamber volume and area, internal chamber air temperature, and atmospheric pressure determined during sampling. GHG fluxes were calculated using linear regression of gas concentrations versus chamber closure time (that is change of concentration over time). The limit of detection (LOD) were as follows: CH4 (R-squared R2=0.7), CO_2 (R2=0.9) and N_2O (R2=0.7). Data quality checks and cleaning was performed whereby 5% of the data were discarded since they were below the LOD.

Figure 3. The plots before planting. b) The complete set of static GHG sampling assemblage. c) The inter-row positioning of the static chamber in the field in newly planted Brachiaria plots (approx. two weeks old).

2.4. Yield Scaled Emissions

The yield-scaled GHG emissions were estimated using the cumulative fluxes over the 8 months sampling period divided by the yield data for the 4 harvests.

Equation 1: Yield-scaled GHG emissions.

$$\textbf{Yield scale emissions (g N kg}^{-1}\textbf{)} = \frac{\textbf{N}_2\textbf{O emissons}\ (\textbf{kg ha}^{-1})}{\textbf{Yield}\ (\textbf{t ha}^{-1})}$$

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2.5. Brachiaria Brizantha Yields

Brachiaria brizantha cv. xaraes in individual plots was harvested after every 10 weeks down to a stubble height of 10 cm, and the entire aboveground biomass was collected and weighed. Maximum heights of Brachiaria (cm) was determined by use of a tape measure on separate plants per plot. All the biomass was weighed, and approximately a quarter of it was cut into 5 cm pieces using a machete. After cutting, 3 aliquots of about 300-500 g were selected from each plot and put into a pre-weighed and labelled bag. The samples were taken to the Mazingira Centre immediately after sampling and weighed (bag + fresh sample). The samples were then oven dried until constant weight (approximately. 96 hours) at 105 °C to determine dry matter content.

2.6. Statistical Analysis

A two-way ANOVA was conducted to determine if the GHG fluxes were significantly different among the fertilizer treatments. Significant differences for the analysis of variance were accepted at $P \leq 0.05$. Tukey 's HSD post hoc test was used to separate means of the determined daily fluxes, cumulative fluxes and yield-scaled N_2O emissions under the influence of various soil amendments. Backward elimination regression analysis was conducted using Stata to determine the soil properties that influence N_2O and CO_2 emissions.

3. Results

This section discusses the effects of various soil amendments on soil GHG fluxes, cumulative N_2O, CO_2 and yield-scaled N_2O emissions.

3.1. Effects of Soil Fertilization on Hourly CH_4 Uptake

All the treatments acted as net sink for methane (Table 1, Figure 4), with treatment and season significantly influencing the uptake. Higher (-21.86±17.97mg CH_4-C h^{-1}) CH_4 uptake was recorded in the Control treatment whereas the lowest (-2.69±4.47mg CH_4-C h^{-1}) uptake was recorded in Bioslurry ($P < 0.01$).

Table 1. Average CO2, N2O emissions and CH4 uptake across the treatments during the experiment period.

Treatment	CH_4 (mg CH_4-C m^{-2} h^{-1})	CO_2 (mg CO_2-C $m^{-2}h^{-1}$)	N_2O (mgN_2O-N $m^{-2}h^{-1}$)
Control	-21.86±17.97b	94.76 ±19.32a	12.95±3.61a
Lablab	-18.32 ±5.04b	86.71±15.89a	10.51±2.93ab
Bioslurry	-2.69 ±4.47a	74.38 ±11.08b	12.87±4.29a
NPK	-16.67±3.69b	66.06 ±12.88bc	10.00±3.30ab
FYM_BC	-17.84 ±6.05b	58.43±14.48c	6.70±2.44b
FYM	-18.30 ±2.91b	58.39 ±15.67c	8.20±2.34b
p-value	<0.01	<0.01	<0.01
L.S.D.	8.85	6.37	3.13

Values are means ± standard error (SE). Different lowercase letters within the same column indicate significant differences between the treatments.

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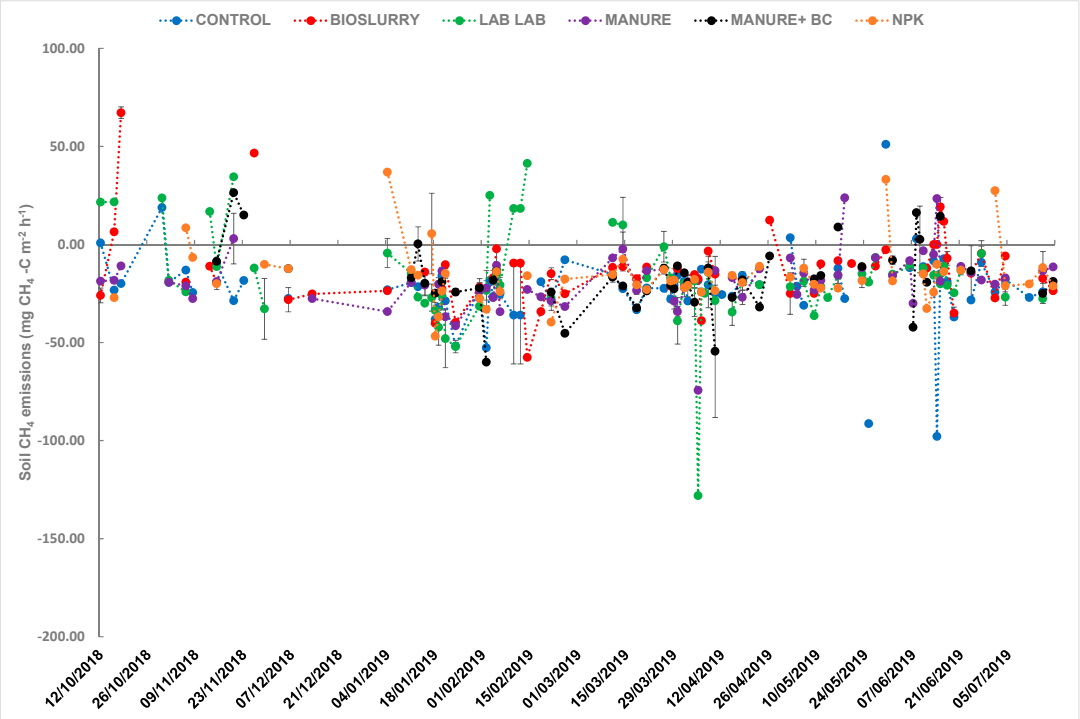

Figure 4. Daily temporal CH4 uptake during the entire study periodKey: Short rains season (October 2018 to January 2019) (SR), hot dry season (January 2019 to March 2019) (HD), long rains season (March 2019 to June 2019) (LR), cold dry season (June 2019 to August 2019) (CD).

Cumulative CH_4 uptake was 3.56% higher under FYM relative to the control, but the difference was not significant (Table 2). Daily and cumulative CH_4 uptake increased from season SR to HD and decreased in the subsequent seasons (Table 1).

Treatment and season significantly influenced daily CH_4 uptakes ($p < 0.01$ and $p = 0.009$ respectively) but did not show significant interaction ($p = 0.093$). Methane uptake was similar across all the treatments following the order of Control > Lablab > Manure > FYM-BC > NPK, except for Bioslurry which exhibited significantly lower (-2.69±4.47) CH_4 uptake ($p < 0.01$). Within the seasons, significantly lower (-11.43±13.87) and higher (-21.23±5.39) CH_4 uptakes were recorded during the cold dry seasons and hot dry respectively whereas short rains and Long rains had similar CH_4 uptake.

Table 2. Average CO2 and N2O emissions and CH4 uptake across the four growing seasons.

Season	CH_4 (mg CH_4-C m^{-2} h^{-1})	CO_2 (mg CO_2-C $m^{-2}h^{-1}$)	N_2O (mgN_2O-N $m^{-2}h^{-1}$)
SR	-11.69 ±4.67ab	97.89 ±20.45a	18.40 ±5.41a
HD	-21.23 ±5.39b	65.22 ±14.16c	7.26 ±2.03b
LR	-19.07 ±6.42ab	73.78 ±16.17b	9.40 ±2.93b
CD	-11.43 ±13.87a	63.21 ±13.32c	7.36 ±0.20b
p-value	0.01	<0.01	<0.01
L.S.D.	7.67	5.25	2.46

Values are means ± standard error (SE). Different lowercase letters within the same column indicate significant differences between seasons.

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Table 3. Average CO2 and N2O emissions and CH4 uptake of the different treatments across the four growing seasons.

Treatment	Season	CH_4 ($mg\ CH_4\text{-}C\ m^{-2}\ h^{-1}$)	CO_2 ($mg\ CO_2\text{-}C\ m^{-2}h^{-1}$)	N_2O ($mgN_2O\text{-}N\ m^{-2}h^{-1}$)
Control	SR	-357±2.60a	157.54 ±17.90a	27.16 ±8.79a
	HD	-506 ±12.60a	86.1 ±11.08bcde	9.20 ±2.96c
	LR	-282 ±13.55a	82.86 ±10.72 bcdef	9.60 ±3.12c
	CD	-302 ±58.22a	70.67 ± defghi	7.07 ±2.01c
Lablab	SR	-340 ±6.09a	96.70 ±23.55 bc	11.63 ±3.87bc
	HD	-252 ±6.20a	82.11 ±15.06bcdefg	9.76 ±2.33bc
	LR	-273 ±4.35a	90.16 ±15.75bcd	11.82 ±3.95bc
	CD	-302 ±2.82a	79.82 ±13.01bcdefgh	8.57 ±2.89c
Bioslurry	SR	-292 ±3.83a	100.10 ±28.76b	24.37 ±5.69a
	HD	-275 ±3.08a	67.07 ±25.75efghij	8.61 ±3.28c
	LR	-297 ±4.41a	73.62 ±14.75cdefghi	11.23 ±3.37bc
	CD	-105 ±6.36a	63.26 ±13.06fghij	8.90 ±2.86c
NPK	SR	-88 ±1.45a	95.23 ±19.81bc	20.97 ±7.86ab
	HD	-354 ±4.35a	57.91 ±9.45hij	4.51 ±0.96c
	LR	-179 ±3.26a	64.94 ±12.92efghij	8.37 ±1.93c
	CD	-81 ±5.63a	52.71 ±11.94ij	5.76 ±2.24c
FYM-BC	SR	-76 ±5.06a	67.81± 14.79defghij	10.45 ±3.88bc
	HD	-337 ±2.52a	51.26±15.27ij	5.29 ±1.88c
	LR	-150 ±10.99a	62.60 ±18.16fghij	5.60 ±2.00c
	CD	-234 ±9.60a	52.84 ±14.08ij	5.23 ±1.91c
FYM	SR	-540 ±8.99a	63.81 ±17.92efghij	11.24 ±2.36bc
	HD	-431 ±3.59a	44.33±8.37j	4.95 ±0.79c
	LR	-260 ±1.97a	66.68 ±24.72efghij	8.50 ±3.21c
	CD	-268 ±0.57a	58.87 ±18.49ghij	7.74 ±2.94c
p-value (Treatment * Season)		0.093	<0.01	<0.01
L.S.D.			13.112	6.36

Values are means ± standard error (SE). Different lowercase letters within the same column indicate significant differences between the treatments and seasons. Different lowercase letters within the same column indicate significant differences between the treatments.

Key: SR-Short rains season (October 2018 to January 2019)
HD- short season (January 2019 to March 2019)
LR- long rains season (March 2019 to June 2019)
CD- short (June 2019 to August 2019).

3.2. Effects of Soil Fertilization on Hourly and Cumulative CO_2 Fluxes

Treatment and season had significant ($p < 0.01$ respectively) effect on CO_2 emissions. CO_2 emissions in FYM-BC and FYM alone were on average lower by 61.6% compared to the CO_2 emissions in control which had the highest CO_2 emissions. Seasonal CO_2 emissions followed the order of CD>HD>LR>LR. Treatment and season also interacted significantly ($p<0.01$) to influence CO_2 emissions. Lower (44.33±8.37) emissions occurred under FYM alone during the HD season while the highest (157.54 ±17.90) CO_2 emissions were recorded under the control treatment during the 1st season. Figure 5 shows daily temporal CO2 fluxes during the entire study period. Figure 6 presents hourly (A) and cumulative (B) CO2 emissions of the different treatments during the four seasons.

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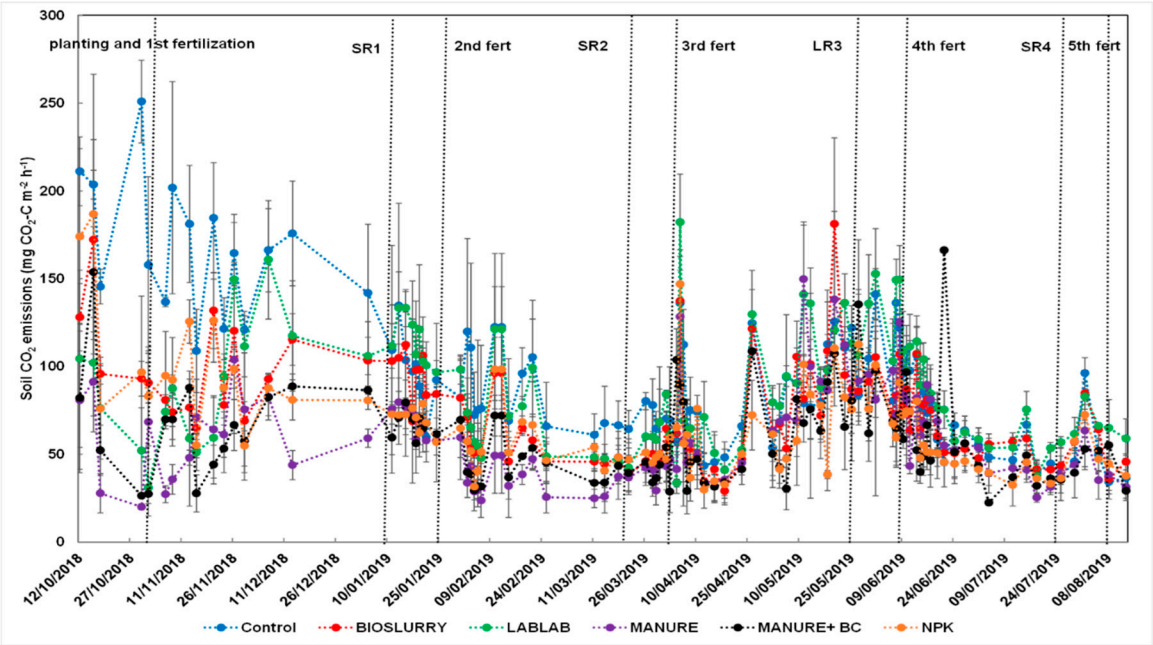

Figure 5. Daily temporal CO2 fluxes during the entire study period.

Key: Short rains season (October 2018 to January 2019) (SR), short rains season (January 2019 to March 2019) (HD), long rains season (March 2019 to June 2019) (LR), and short rains (June 2019 to August 2019) (CD).

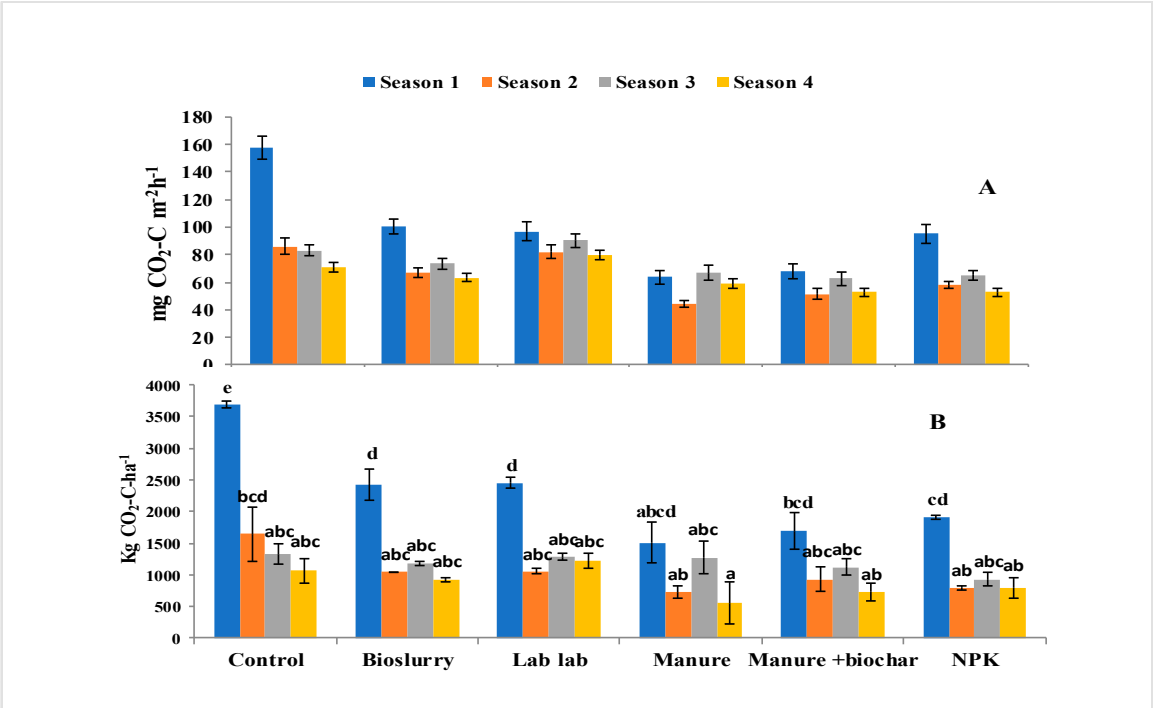

Figure 6. Hourly (A) and cumulative (B) CO2 emission of different treatments during the four seasons. Vertical error bars represent standard error of the mean. Different lowercase letters indicate significant differences between treatments and seasons.

Key: Season 1-SR: SR (October 2018-January 2019), Season 2-HD (January 2019- March 2019), Season 3-LR (March 2019-June 2019), CD (June 2019-August 2019).

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3.3. Effects of Soil Fertilization on Daily and Cumulative N_2O Fluxes

FYM-BC and FYM alone had significantly ($p < 0.01$) lower (6.70±2.44 and 8.20±2.34) N_2O emissions compared to the control which had the highest (12.95±3.61) N_2O emissions. Significant higher N_2O emissions were recorded during the first season while seasons 2, 3 and 4 had similar emission rates. Significant ($p < 0.01$) interaction between treatment and season was also observed with NPK recording the lowest (4.51 ±0.96) emissions during the second season relative to control which had the highest (27.16 ±8.79) N_2O emissions during the first season. However, cumulative N_2O emissions were similar across all treatments ($P = 0.235$) and seasons ($P = 0.736$) (Table 4). Figure 7 shows daily temporal soil N_2O fluxes during the entire period of study.

Table 4. Cumulative CH4 uptake and CO2 and N2O emissions under different treatments and seasons.

		CH_4(g CH_4-C ha^{-1})	**CO_2 (kg CO_2-C ha^{-1})**	**N_2O (Kg N_2O -N ha^{-1})**
Treatment	Control	-361.90±21.74ab	1929±208.89c	0.233±4.24a
	Lablab	-291.80±4.87ab	1504±73.82b	0.141±3.26a
	FYM	-374.80±3.78a	1015±250.61a	3.801±2.32a
	FYM-BC	-199.10±7.05ab	1117±185.33ab	1.252±2.42a
	NPK	-175.30±3.67b	1106±84.69a	2.265±3.25a
	Bioslurry	-242.20±4.42ab	1393±78.09ab	0.26±3.80a
	P-value	0.013	<0.001	0.235
	L.S.D.	130.5	263.0	5.193
Season	SR1	-282.4±4.67ab	2279±169.72c	0.32±5.41a
	SR2	-359.1±5.39a	1030±134.05ab	0.12±2.03a
	LR3	-240.0±6.42ab	1184±120.37b	0.16±2.93a
	SR4	-215.3±13.87b	883±163.45a	2.14±0.2a
	P-value	0.048	<0.001	0.736
	L.S.D.	106.6	214.7	2.109

(Values are mean ± SE).

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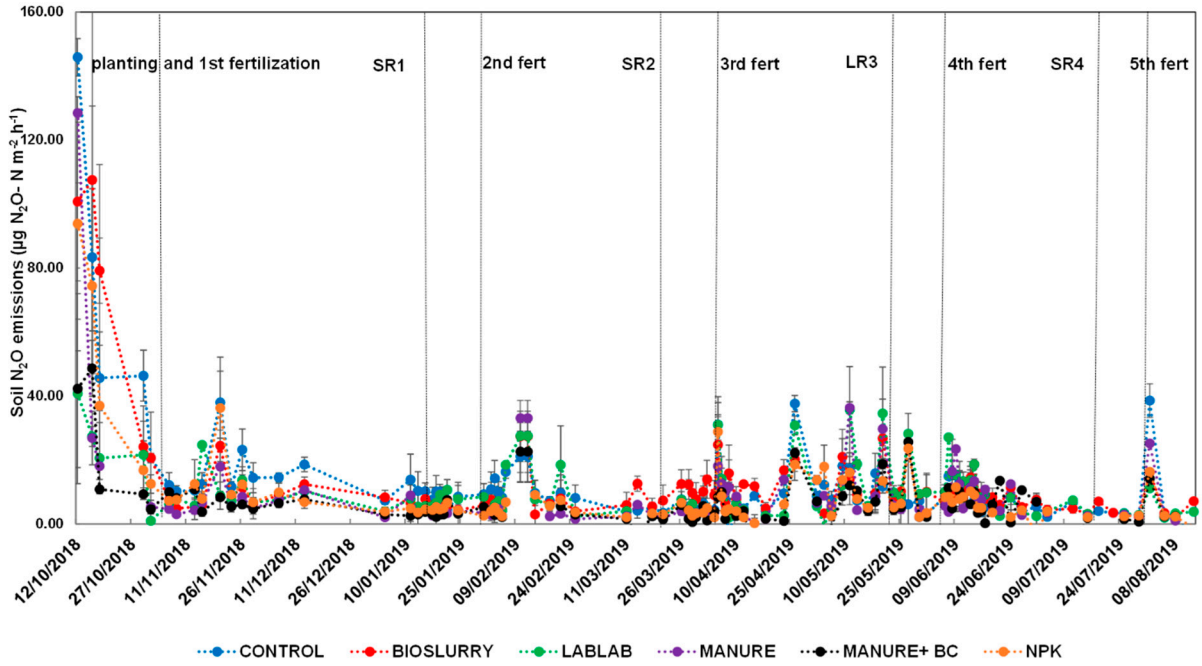

Figure 7. Daily temporal soil N2O fluxes during the entire period of studyKey: Short rains season (October 2018 to January 2019) (SR), short rains season (January 2019 to March 2019) (HD), long rains season (March 2019 to June 2019) (LR), and short rains (June 2019 to August 2019) (CD).

The total cumulative N_2O fluxes for the entire study period (8 months) was 1.4 Kg ha^{-1}±0.1. However, there was no significant differences recorded for the cumulative N_2O fluxes across the treatments for the entire study period (Figure 8).

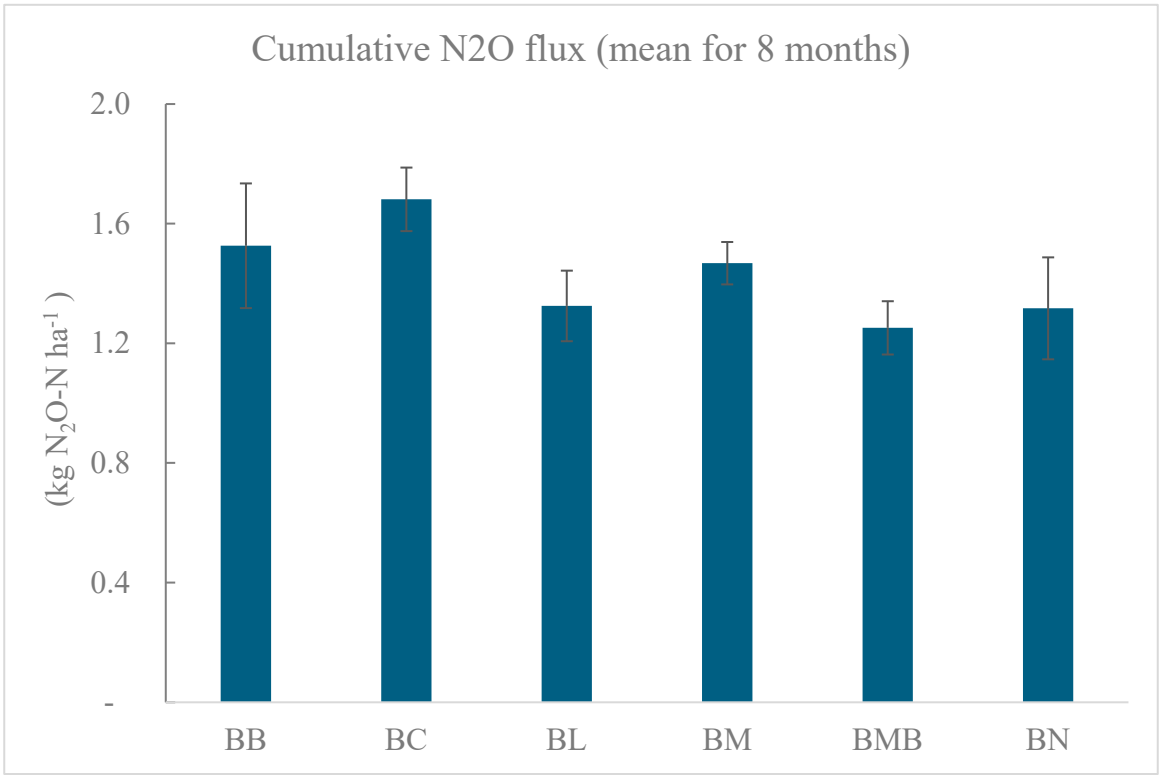

Figure 8. The total cumulative N2O fluxes for the entire study period.

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3.4. Effects of Soil Fertilization on Yield-Scaled N_2O Emissions

The treatments did not show significant effect on yield scaled N_2O emissions (P = 0.244) but interacted significantly with seasons to influence yield-scaled N_2O emissions (P = 0.026). Compared to Control, FYM-BC recorded a net N_2O uptake of 0.02±0.04 Kg N_2O-N kg^{-1} DM in the SR3 season whereas the highest (21.35±0.04 Kg N_2O-N kg^{-1} DM) N_2O emission was under Lablab in the SR1 season. The Yield-scaled N_2O emissions were generally higher in first season with the seasons 2, 3, and 4 exhibiting moderates to low yield-scaled N_2O emissions (Table 5).

Table 5. Yield-scaled N2O emissions under different treatments during the four seasons.

Treatment (Values are mean ± SE).	**Season**			
	SR	**HD**	**LR**	**CD**
		(g N_2O-N kg^{-1} DM yield)		
Control	4.47±0.05ab	0.08±0.01a	0.03±0.01a	0.03±0.05a
Bioslurry	7.05±0.04ab	0.12±0.02a	0.03±0.003a	0.07±0.003a
Lablab	21.35±0.04b	0.10±0.02a	0.07±0.01a	0.07±0.03a
FYM	0.74±0.01a	0.19±0.01a	0.02±0.01a	10.23±0.26a
FYM-BC	3.17±0.04ab	0.04±0.01a	0.02±0.01a	0.02±0.04a
NPK	2.77±0.15ab	0.06±0.01a	0.02±0.01a	6.89±0.05ab

Key: SR-Short rains season (October 2018 to January 2019)
HD- short rains season (January 2019 to March 2019)
LR- long rains season (March 2019 to June 2019)
CD- short rains (June 2019 to August 2019).

3.5. Effect of Fertilization and Harvesting on N_2O and CO_2 Emissions

Soil ammonium concentration, soil moisture (Table 6), CN ratio and CO_2 emissions were the main drivers of N_2O emissions during the fertilization period (P < 0.01, Adjusted R^2 = 0.83-Pearson correlations), while N_20 emission was the only parameter that influenced CO_2 emission (P < 0.01, Adjusted R^2 = 0.65). At harvesting, the soil parameters did not exhibit any relationship with N_2O (P = 0.62), while CO_2 was significantly influenced by soil moisture content (P = 0.01, Adjusted R^2 = 0.52).

Table 6. Factors affecting N2O and CO2 emissions during fertilization.

(n = 36)		**Coefficients**	**Standard Error**	**t Stat**	**P-value**
N_2O	(Constant)	-486.46	177.10	-2.75	0.01
	Soil temperature	1.08	0.68	1.59	0.12
	C/N ratio	39.77	17.29	2.30	**0.03**
	Soil moisture	0.96	0.37	2.60	**0.01**
	Ammonium	1.18	0.29	4.01	**0.00**
	Nitrate	-0.04	0.13	-0.35	0.73
	CO_2 flux	0.43	0.07	6.62	**0.00**
CO_2	(Constant)	729.28	329.40	2.21	0.03
	Soil temperature	-1.28	1.24	-1.03	0.31
	C/N ratio	-59.07	31.84	-1.85	0.07
	Soil moisture	-0.95	0.72	-1.32	0.20
	Ammonium	-1.03	0.63	-1.64	0.11

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Nitrate	-0.04	0.23	-0.15	0.88
N_2O flux	1.39	0.21	6.62	**0.00**

4. Discussions

4.1. Effects of Soil Moisture and Temperature on Soil GHG Emissions

The primary drivers of biochemical processes including GHG emissions, are soil moisture and temperature (Zhang et al., 2012); (Butterbach-Bahl et al., 2013). The GHG fluxes temporal patterns followed rainfall trends (moisture fluctuations), which is consistent with Hickman et al., (2014), whose fluxes were high during rainfall seasons. This is similar to the findings of other studies (Ding et al., 2012); (Zhang et al., 2012). A study by Wei-xin et al., (2007) reported that the optimum temperature for N_2O emissions ranges should be between 25 to 40 ^{0}C which was within our temperature range for GHG emissions.

4.2. Effects of Organic and Inorganic Fertilizers on Cumulative N_2O Fluxes

The cumulative N_2O fluxes observed in this research study were similar with those reported from some of the studies involving the use of organic and inorganic fertilizers (Baggs et al., 2003; Sarkodie-Addo et al., 2003; Millar, Ndufa, 2004). These cumulative N_2O fluxes are slightly lower than 0.45 kg N_2O-N ha^{-1} that was observed under fertilized agricultural soil in sub-Saharan Africa (Dick et al., 2008); (Wanyama et al., 2018). These figures suggest that yearly N_2O fluxes from Kenyan agricultural soils is at the lower end of the global estimate at 1.0 kg N_2O ha^{-1} year^{-1} (Bouwman, 1996).

However, manure recorded higher cumulative N_2O emissions (3.801 Kg N_2O -N ha^{-1}) compared to NPK (2.265 Kg N_2O -N ha^{-1}) although not significantly different. This finding is contradictory to other studies where inorganic fertilizers recorded higher cumulative N_2O emissions than the control and organic fertilizers (Ding et al., 2010; Frimpong and Baggs, 2010; Charles et al., 2017). Consequently, FYM + 10% BC recorded the least cumulative N_2O emissions (1.252 Kg N_2O -N ha^{-1}) which propose that FYM + 10% BC can be a viable strategy in mitigating N_2O emissions from agricultural soils. Nevertheless, N_2O emissions recorded in NPK plots increased after 15 days of fertilizer application. This was similarly recorded by Maljanen et al, (2003) who asserted that N_2O emissions from inorganic fertilizers is short-lived.

4.3. Yield-Scaled N_2O Emissions

Reducing yield-scaled N_2O emissions is vital in the realization of sustainable African agricultural systems rather than absolute N_2O emissions values for a given area (Scheer et al., 2012). Generally, yield-scaled N_2O emissions for this study showed a decline from harvest 1 to 4. FYM + 10% BC recorded the lowest values of N_2O yield-scaled emissions in harvest 2, 3 and 4, suggesting that the use of FYM-BC can be a good strategy in reducing N_2O yield scaled emissions. Other treatments recorded higher N_2O yield-scaled emissions from control and organic fertilizers compared to the inorganic fertilizer (NPK) which was in agreement to the findings reported by Nyamadzawo et al. (2014).

5. Conclusions

In conclusion, these results suggest that the use of FYM-BC can be a good strategy in reducing N_2O yield scaled emissions. From the study, the following recommendations can be made:

- Having recorded low N_2O emissions when *Brachiaria brizantha cv. xaraes* is grown at 45 kg N ha^{-1} harvest^{-1} (or 225 kg N ha^{-1} yr^{-1} for 5 annual harvests) of fertilizer implies that this fertilization rate can be a good GHG mitigation strategy in tropical forage production.

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- It is important to look at different rates of N fertilizer applications in evaluating the yields and emissions of GHG in forage crops. Further research can be conducted at varied fertilizer rates to evaluate the long-term effects of organic and mineral fertilizer on N_2O fluxes.
- Spatial variations in forage GHG emissions in tropical Africa need to be assessed further to understand how various ecological zones respond to varied organic and inorganic fertilizers in terms of yields and GHG emissions.

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