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Stimulus of nitrogen fertilizers and soil characteristics on maize yield and nitrous oxide emission from Ferric Luvisol in the Guinea Savanna agro-ecological zone of Ghana

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ABSTRACT

Farmers in Ghana rely on different forms of fertilizers to increase crop yields. The quantity of applied mineral N fertilizer is lost through nitrification and denitrification in the form of the powerful greenhouse gas nitrous oxide (N_2O) has not been determined in the field until now. This study was conducted on a *Ferric Luvisol* in the Tolon District in Northern Ghana to determine the influence of nitrogen fertilizers, soil moisture and soil temperature on N_2O emissions and grain yield. Three different nitrogenous fertilizers, i.e. ammonia sulfate (AS), urea (U) and NPK 60–40–40, were applied at either 60 or 120 kg N ha^{-1} yr^{-1} to maize, termed AS 60, AS 120, U 60, U 120 and NPK 60–40–40 thereafter. A control was left without N application. The results showed that N fertilizer type and quantities applied affected N_2O emissions significantly. Plots of NPK 60–40–40, AS 60 and U 60 emitted 1.22, 1.45 and 1.79 kg N_2O–N ha^{-1}, respectively, throughout the sampling period and were not considerably higher than N_2O emissions from the control plots, which amounted to 0.32 kg N_2O–N ha^{-1}. In contrast, the N_2O emissions of U 120 and AS 120 were significantly higher than the controls, with values of 4.29 and 3.49 kg N_2O–N ha^{-1}, respectively. When N_2O flux was related to grain yield, 1.24 and 1.04 g N_2O kg^{-1} grain was emitted from AS 120 and U 120, respectively. Plots treated with NPK 60–40–40, AS 60 and U 60 produced 0.39, 0.47 and 0.55 g N_2O kg^{-1} grain, respectively, whereas plots without fertilization emitted 0.53 g N_2O kg^{-1} grain. Average N-induced N_2O emission factors ranged between 0.10% and 0.22%, with an overall emission factor of 0.15%.

Introduction

Nitrous oxide (N_2O) has imperative effects both on the climate system and on stratospheric ozone as reported by Wuebbles et al. [35]. Accordingly, it is produced in the soil mainly by the microbial processes of nitrification (ammonia oxidation)

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and denitrification (nitrate reduction) [38]. Several factors account for the release of nitrous oxide in the soil. Principal among these factors are processes that control N_2O production in soil. Available carbon, inorganic N, and oxygen in the presence of soil moisture, porosity, and probable aggregate structure regulate nitrification and denitrification, [38]. Other Research has also pointed out crop management practices that can influence emissions of N_2O from agricultural soils. For instance [23] reported N fertilizer rate, type, timing and application method as management factors that influence N_2O emissions. Other management practices such as crop, tillage, residue management, and irrigation are also deemed to enhance N_2O emissions. With certainty that N_2O in agricultural soil is produced mostly by the microbial conversions of inorganic nitrogen, the prospective to produce and emit N_2O increases with the increasing availability of nitrogen. Bouwman et al. [3] reported a similar occurrence when they measured N_2O emission from N fertilized plots. Therefore, it can also be deduced that any anthropogenic activity that lower the application of inorganic nitrogen into cropland agriculture can reduce emissions of N_2O. However, the consequence of this abridged N input on yields needs to be cautiously scrutinized in order not to compromise high crop output. With positive correlation between N_2O emission and nitrogen availability, an determination of equilibrium level of N applied would reduce N_2O emission while maintaining higher crop productivity.

Most research finding have concluded on nitrogen as generally the most limiting nutrient in intensive crop production systems as is applied to mostly cereal crops world-wide. For instance Robertson and Vitousek (2009), reported that N fertilizer is commonly applied to maize, rice, wheat and other non-leguminous crops. The trade-off between N_2O emissions, nitrogen fertilizer application and crop cultivation practices are key elements in determining management strategies that target the agricultural N_2O liability without conceding productivity and profitable yields. The increasing world population positively correlate with the need to increase food production. This has resulted in the increased use of both organic and inorganic fertilizer application to complement inherent soil fertility. With little knowledge and mostly few farmers conducting soil testing before fertilizer application, the use of mostly inorganic N based fertilizer in many areas has been unwarranted, with large quantities of the added fertilizer providing no benefit to crop, but prompting higher N_2O emissions. However, with N application resulting in N use efficiency between 26 and 60% [39] appropriate fertilizer applications in terms of rate, type and timing and application procedure can meaningfully lower N_2O emissions from cultivated soils. Tillage practices, which precisely consider the optimal quantity of fertilizer application essential for maximum crop yield, are vital both ecologically and economically.

Ghana's agriculture is faced with many challenges, notably by continuous soil fertility depletion. The reliance of inorganic fertilizer by farmers has gained popularity due to the expanding Ghana's population over the last decade. This continues expansion of the population has affected farm size and resulted in several land tenue issues. The practice of shifting cultivation where land is left to fallow are no longer attainable and therefore, to increase productivity inorganic fertilizers especially N based are relied upon. This has affected soil fertility and crop productivity with continues observation of soil nutrient depletion. Besides, the level of reduction advocates for efficient and sustainable use of fertilizers to maintain soil fertility as reported by Mwangi [40].

Nitrogen losses through gasses can also represent a substantial loss of fertility from non-fertile soils that in many cases have a severe undesirable nutrient balance [29]. Tropical savannas contribute presumably 16% of the global production of N_2O from terrestrial systems as reported by IPCC [14]. These estimates reported are based on research from few areas. Furthermore, the developments pertaining to N loss under tropical conditions are known to be considerably different from those in temperate regions where an in depth knowledge on greenhouse gas emissions from soils has taken place. Again, most studies on N_2O emissions from soils in the tropics have been carried out in natural forests while a few were conducted in tropical plantations ([19] and Mori et al., 2013). Only sporadically studies were conducted in tropical cropland, such as the one by Brümmer et al. [5] who reported measurements of N_2O flux from tropical agriculture in Burkina Faso.

For establishing and maintaining sustainable food production in the tropics, it is important to determine both the magnitude and the mitigation potential of N_2O emissions induced by mineral N fertilizers as a useful indicator of environmental compliance and of long-term sustainability in improving soil fertility for increased yields. The aim of this study, therefore, was to determine the influence(s) of mineral N fertilizers and the basic soil characteristics on N_2O emissions from cropland in the Guinea Savanna Northern Ghana. The guiding hypothesis was that, independent of the form of N fertilizer applied, effective application of mineral N fertilizer in accordance with the crop N demand will not only reduce input cost per unit of product harvested, but would also decrease yield-based N_2O emissions.

Materials and methods

Location of the study site

The study was carried out at Akukayilli, 09° 23′ 38.2″ N and 01° 00′ 18.4″ W, located in the Tolon district of the Northern region of Ghana. At this site, mean annual rainfall varies between 750 mm and 1100 mm. Daily minimum and maximum temperatures vary between 14 °C and 40 °C, with an annual mean of 26 °C. The soil at the experimental site was classified as Ferric Luvisol (USDA Soil Taxonomy). The parent material was Voltaian clay, well to moderately drained. The topsoil was strong brown according to the Munsell color chart, with occasional iron and magnesium concretions, and had an average depth of 90 cm.

Experimental design

Treatments with three types of N fertilizer, ammonium sulfate (AS) and urea (U) at two N levels each (60 and 120 kg N ha^{-1} yr^{-1}, respectively), and NPK 60–40–40 at 60 kg N ha^{-1} yr^{-1}, plus a control without N fertilizer application were established in a randomized complete block design with three replications. Triple superphosphate and muriate of potash, at a rate of 17.5 and 33.2 kg ha^{-1} yr^{-1} of P and K respectively, were applied together with the ammonium sulfate and urea fertilizer by dibbling. Application of NPK 60–40–40 is the current recommended fertilizer treatment for maize in Ghana (Safo et al. 1986). Plot size was 5 m × 5 m. Each plot was separated by a buffer zone of 1 m, which was left bare throughout the experimental period. A maize (*Zea mays*) cultivar, *Omankwa*, was sown on 28 July 2013 and 30 July 2014, respectively. Seven days after planting, plant numbers were adjusted where plant germination was found to be uneven, either by thinning or filling in, to establish an average plant density of 6.25 plants m^{-2}. Fifty percent of the mineral N fertilizer and 100% of P and K fertilizers were incorporated into the soil by dibbling two weeks after planting on August 12, 2013, and on August 14, 2014, as basal fertilizer. The remaining 50% of mineral N fertilizer was top-dressed by dibbling on August 28, 2013 and August 30, 2014, i.e. six weeks after planting, which is the recommended practice in Ghana. Weeding was done manually after crops had been established and whenever needed throughout the season. An area (16 m^2) within each plot was designated for measuring N_2O fluxes, while the remainder of the plot was used for plant sampling. Mean maize grain and stover yield was determined at 12.5% moisture content of maize.

Chamber measurements of N_2O fluxes

The static chamber technique [6] was used to determine gas fluxes from each plot. For N_2O flux measurements, one opaque chamber (0.50 m × 0.25 m × 0.17 m length/width/height) per plot was fitted onto a collar (0.50 m × 0.25 m × 0.06 m length/width/height), covering an area of 0.125 m^2. Collars had been inserted into the soil permanently at a depth of 3 cm, one week after planting in each experimental year. Chambers were fitted to the collar at the time of gas sampling and were removed after flux measurements. Four gas samples were taken during each measurement 0, 20, 40 and 60 min after chamber closure, respectively. Each time, a volume of 20 ml was collected with a syringe through a three-way stop cock, which was fitted gas-tight to the chamber. The syringe was flushed three times before sampling in order to mix the chamber air. Samples were transferred into vials with septum, which had been pre-evacuated down to a vacuum of 0.3 mbar using a vacuum pump. The vials were transported by express air cargo to the laboratory at Forschungszentrum Jülich, Germany, for analysis. Samples were analyzed for N_2O immediately upon arrival, using a gas chromatograph (Clarus 580, PerkinElmer, Rodgau, Germany), equipped with an electron capture detector (ECD, detection limit: $\Delta N_2O < 1$ ppbv). Chamber closure and gas sampling were conducted between 09:00 and 16:00 h each day of gas sampling. Gas sampling started two days before fertilizer application on a daily basis until three weeks after fertilization. Sampling was then reduced to two-day intervals for two weeks, and then performed weekly until the end of the season. Flux rates were calculated according to the following equations:

$$F_{N_2O} = \frac{b \times V_{ch} \times MW_{N_2O} - N \times 10^6}{A_{ch} \times MV_{corr} \times 10_9}$$

where $F_{N_2O} = N_2O$ flux rate (µg N m^{-2} h^{-1}), b = mixing ratio increase (ppb h^{-1}), V_{Ch} = chamber volume (m^3), $MW_{N_2O\text{–}N}$ = molecular weight of N_2O–N (28 g mol^{-1}), A_{Ch} = base area of chamber (m^2), MV_{corr} = pressure and temperature-corrected molar volume of air (m^3 mol^{-1}), and

$$MV_{corr} = 0.0224 \times \left(\frac{273.15 + t}{273.15}\right) \times \left(\frac{po}{p1}\right)$$

where t = air temperature during measurements (°C), p_0 = standard atmospheric air pressure (Pa), p_1 = air pressure during measurements (Pa). Annual cumulative N_2O fluxes were calculated by linearly interpolating the N_2O fluxes measured between sampling periods, and multiplying the mean flux of each sampling period with the duration of the respective sampling period [41].

The N_2O emission factor (EF) was estimated as the percentage of N_2O–N emitted per fertilizer N applied. The observation-based EF was calculated for individual fertilization treatments in each year according to the following equation [10]:

$$EF\ (\%) = 100 \times \left(\frac{N_2O_{fert} - N_2O_{zero}N}{N_{fert}}\right)$$

where N_2O_{fert} represents the cumulative N_2O flux (kg N ha^{-1} yr^{-1}) in the fertilized plots, N_2O_{zeroN} is the cumulative flux in the zero-N treatment, N_{fert} denotes the amount of applied N (kg N ha^{-1}), [37].

Soil physical and chemical analysis

Particle size analysis was done by the hydrometer method as outlined by Anderson and Ingram [1]. Soil moisture content was determined gravimetrically by oven drying soil samples at 105 °C for 24 h until a constant weight was reached. Organic

Table 1
Physical properties of the Ferric Luvisol at the experimental site (0–20 cm).

Properties	Mean	Standard deviation
Stones (%)	3.42	±0.02
Bulk density (g cm^{-3})	1.31	±0.02
Lower limit (mm^3 mm^{-3}) (SLL)	0.04	±0.01
Upper limit (mm^3 mm^{-3}) (SDUL)	0.17	±0.01
Upper limit, saturated (mm^3 mm^{-3}) (SSAT)	0.46	±0.01
Particle size distribution (%)		
Sand	64.89	±3.65
Silt	34.34	±4.13
Clay	0.77	±4.54

Table 2
Mean chemical properties of a Ferric Luvisol at the experimental site.

Properties	2013	Standard deviation	2014	Standard deviation
pH (2:1 water)	5.18	±0.46	5.28	±0.09
Soil organic carbon (%)	0.57	±0.04	0.59	±0.02
Total nitrogen (%)	0.05	±0.02	0.04	±0.02
Available P, Bray 1 (mg kg^{-1} soil)	8.86	±1.36	6.86	±0.88
Al+*H* ($cmol_c$ kg^{-1} soil)	0.19	±0.03	0.17	±0.03
Ca ($cmol_c$ kg^{-1} soil)	1.97	±0.11	1.87	±0.09
Mg ($cmol_c$ kg^{-1} soil)	1.16	±0.12	1.13	±0.06
K ($cmol_c$ kg^{-1} soil)	0.54	±0.08	0.41	±0.06
Total exchangeable bases ($cmol_c$ kg^{-1} soil)	3.67	±0.10	3.41	±0.11
Effective cation exchange capacity (cmolc kg^{-1} soil)	3.87	±0.10	3.59	±0.12
Base saturation (%)	94.81	±0.59	95.59	±0.90

carbon was determined by the modified Walkley and Black Procedure outlined by Nelson and Sommers [21]. Total N was determined by the Kjeldahl procedure modified to include soil mineral nitrate by the use of salicylic acid to convert all nitrate into ammonium [31].

The exchangeable base cations Ca^{2+}, Mg^{2+}, K^+ and Na^+ were extracted with 1M neutral NH_4OAc solution (*Black*, 1965). After extraction, the Ca^{2+} and Mg^{2+} contents were determined using an atomic absorption spectrophotometer (AAnalyst 400, EN 55011-Class A Group 1, Perkin Elmer, Singapore) at wavelengths of 422.7 nm and 285 nm, respectively, and K^+ and Na^+ by a flame photometer (PFP7, Jenway, Bibby scientific Ltd, UK) at wavelengths of 766.5 nm and 589 nm, respectively.

The Bray 1 extraction solution procedure [4] was used for measurement of available P. Soil surface temperature was determined using an infrared thermometer (voltcraft IR 1000-30D, K-Type −50–1370 °C, Germany), while soil temperature at 10 cm depth was measured with a temperature probe (5TE, Decagon Devices, USA) inserted 10 cm below the soil surface. Soil moisture was measured daily using the gravimetric method.

The soil of the study site had a sandy loam texture, was moderately drained and had a bulk density of 1.3 g cm-3. Mean stone content was 3.4%. Mean lower limit of available soil water, drained upper limit and saturation were 0.04, 0.17 and 0.46 mm^3 mm^{-3}, respectively (Table 1). The soil was slightly acidic with a mean pH of 5.18 ± 0.46 and 5.28 ± 0.09 for 2013 and 2014, respectively (Table 2).

Data analysis

N_2O fluxes obtained from the field experiment were subjected to Analysis of Variance (ANOVA) using GenStat, 9th edition (VSN International Ltd, in collaboration with practicing statisticians at Rothamsted and other organizations in Britain, Australia and New Zealand). Comparisons of means were performed using Duncan's multiple range test and were separated using Least Significant Difference (LSD) test. The relationship between cumulative N_2O emissions and amount of fertilizer applied was subjected to analyses of variance. An exponential equation $y = ae^{bx}$ was used to determine the relationship among N_2O emitted during the period of evaluation and the quantity of fertilizer N applied. In this instance, y represented cumulative N_2O emission for the period of measurement and was measured in (µg N–N_2O m^{-2}), where x denotes N fertilizer applied (kg ha^{-1}), a represents the intercept with the y-axis, and b defines the shape of the curve.

To adjust the exponential equation, the *glm* in SAS 9.0 was used to bring the curve to a linear model $\ln(y) = b_0 + b_{1x}$. From this equation, the terms needed for the exponential equation was calculated bearing in mind that a corresponds to e^{b0} and b of the exponential equation is comparable to b_1 of the linear equation [26].

Results and discussion

Soil physical and chemical properties

The average soil organic carbon (SOC) content was low (Table 2) and showed no significant differences among plots ($P > 0.05$) in 2013 and 2014 (Table 2). Similarly, mean effective cation exchange capacity was also low with mean values of 3.87 ± 0.10 and 3.59 ± 0.12 cmol$_c$ kg^{-1} soil in 2013 and 2014, respectively. This finding was consistent with characteristics of soils in northern Ghana as described by Badu et al. (1965). Finally, total N, and partially available P, were below the critical crop nutrient requirement levels of 0.15% N and 8.5 mg P kg^{-1}, whereas available K was clearly above the critical level of 0.16 cmolc K kg^{-1} [42,43]. The low SOC content, low pH associated with low P availability, low cation exchange capacity and low clay content indicate that the soil at the experimental site was characterized by low inherent fertility typical of the West African Savannas. Maximizing crop production on these soils will require integrated nutrient management comprising application of inorganic and organic fertilizers.

Quantification of soil N_2O flux from fertilized and unfertilized plots

In 2013 and 2014, mean N_2O fluxes measured throughout the growing season ranged between 0.1 and 17 µg N_2O–N m^{-2} h^{-1} in 2013 and 2014 (Fig. 1(a) and (b)). Elevated N_2O fluxes occurred between two and ten days after fertilizer application, with a maximum of 17 µg N_2O–N m^{-2} h^{-1} in U 120 in 2013, followed by AS 120, U 60 and AS 60. Interestingly, N_2O fluxes measured after topdressing (two weeks after basal fertilizer application) were lower than after basal fertilizer application, which was conducted approximately two weeks after planting. Plots that received no N fertilizer consistently showed low N_2O fluxes throughout the growing seasons of both years. Mean N_2O flux of U 120 was significantly higher ($P < 0.001$) than the N_2O fluxes of U 60, AS 60, NPK 60–40–40 and control, but was not significantly different ($P > 0.05$) from AS 120. Also, N_2O fluxes of AS 60 and U 60 were not significantly different ($P > 0.05$) from each other, but from the control (Fig. 5).

In both years relatively high N_2O fluxes were found immediately following heavy rains, and comparatively high N_2O fluxes were also recorded in the last week of October 2013 as well as middle of October 2014, following the last heavy rains of the growing season (Fig. 1(c) and (d)). This observation is consistent with findings of Dick et al. [8], who reported N_2O fluxes of up to 2000 µg m^{-2} h^{-1} after heavy rainfall in Ugandan soils. In both years of our study, application of 120 kg N ha^{-1} yr^{-1} led to the highest increase in N_2O fluxes. The application of urea stimulated N_2O fluxes more than sulfate of ammonia, even though in some cases this was not significant for the application rate of 60 kg N ha^{-1} yr^{-1}. The results imply that the different levels and forms of N addition to the soil had strong effects on N_2O emissions in the period of August and December in each year in the study area. The significant N_2O emissions within 2–10 days after fertilizer application in our study are consistent with other studies. For instance, Bergstrom et al. [2] and Hyde et al. [13] reported similar N_2O emission patterns on N fertilized grasslands, and Liu et al. [16,17] and Schils et al. [25] reported highest N_2O fluxes occurring in the first or second week after application of N fertilizers to the soil. This demonstrates that N_2O production was strongly limited by the availability of inorganic N substrate during the growing season.

The relatively low N_2O fluxes measured after October in both years could be attributed to the low soil moisture on most sampling days in 2013 and 2014, respectively. Water-filled pore space (WFPS) below 30% might have slowed down microbial metabolism, the movement of microbes, and the diffusion of metabolic substrates (including ammonium and nitrate) to the position of consumption [33]. Furthermore, this report could be so as [7] findings indicated the optimal soil water content for nitrification to occur to be around 60% WFPS and greater than 80% for denitrification. More so, Zhang and Han [36] reported declining N_2O fluxes two months after fertilizer application due to fertilizer disappearance.

In our study, N_2O emission increased with increasing N application rates largely independent of N fertilizer type. Based on the observations of N_2O emissions at the two N fertilization levels (60 and 120 kg N ha^{-1} yr^{-1}) in our study, it can be inferred that the threshold N level beyond which N_2O emissions increase considerably, must be located between these two N levels. This is in accordance with the findings of Malhi et al. [18] who observed a significant increase in N_2O flux when fertilized N levels exceeded 80 kg N ha^{-1} yr^{-1} in a cropping season. Similarly, Kachanoski et al. [15] found that N_2O emissions began to increase significantly with fertilizer N levels above 100 kg N ha^{-1} in an irrigated maize field. The fact that N_2O fluxes exhibit a threshold response to N application level has likely its origin in a competition for N between assimilatory N immobilization by both microorganisms and plants, and N_2O-releasing processes of nitrifiers and denitrifiers in the soil. Therefore, it is only when N applied to soil exceeds microbial immobilization and plant N demand that N_2O emissions can increase [12,20,32].

There was a weak positive correlation between N_2O flux and soil temperature measured at 10 cm depth ($P=0.175$, $r^2 = 0.218$) (Fig. 2). The only marginal increase in N_2O flux with increasing soil temperature could be attributed on the one hand to enhanced microbial activity, also favoring nitrification and denitrification, but on the other hand also to moisture limitation of microbial activity. This result is in agreement with other findings. For instance, Firestone and Davidson [9] reported that production of nitric oxide (NO) and N_2O in soils by nitrification and denitrification is co-regulated by soil temperature, while the flow of nitrogen and soil water content are the main determinants of the magnitude of NO and N_2O fluxes. Pilegaard et al. [24] also reported a short-term relationship between soil temperature and N_2O fluxes which is consistent with the results of this study. Reports of NO and N_2O increase with elevated temperature are common. Most of

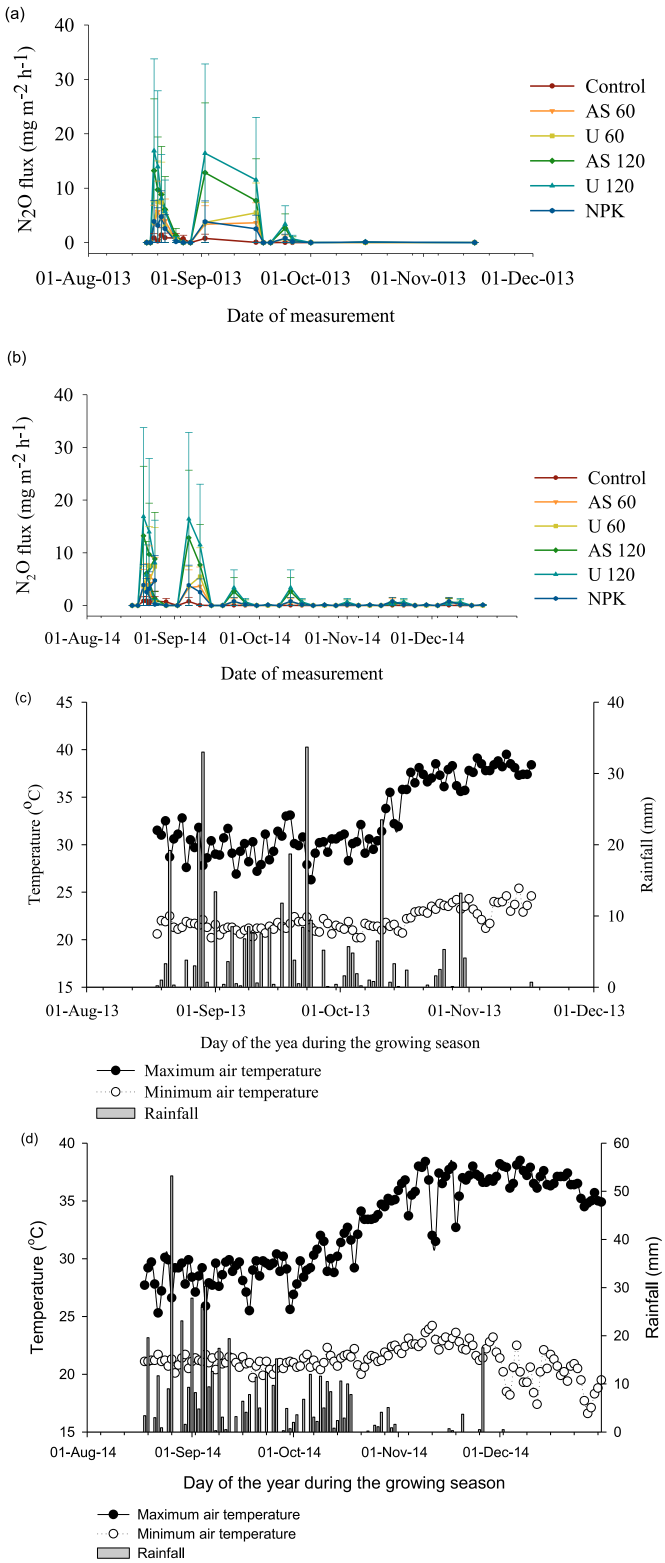

Fig. 1. Time course of N_2O flux (µg N_2O–N m^{-2} h^{-1}) in the growing season of 2013 (a) and 2014 (b) (error bars represent standard deviation). (c) and (d) Air temperature and precipitation for years 2013 and 2014.

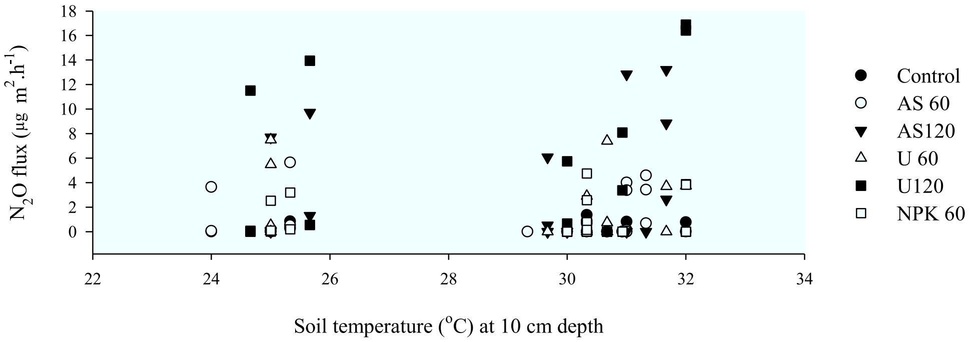

Fig. 2. N_2O flux as a function of soil temperature at 10 cm depth.

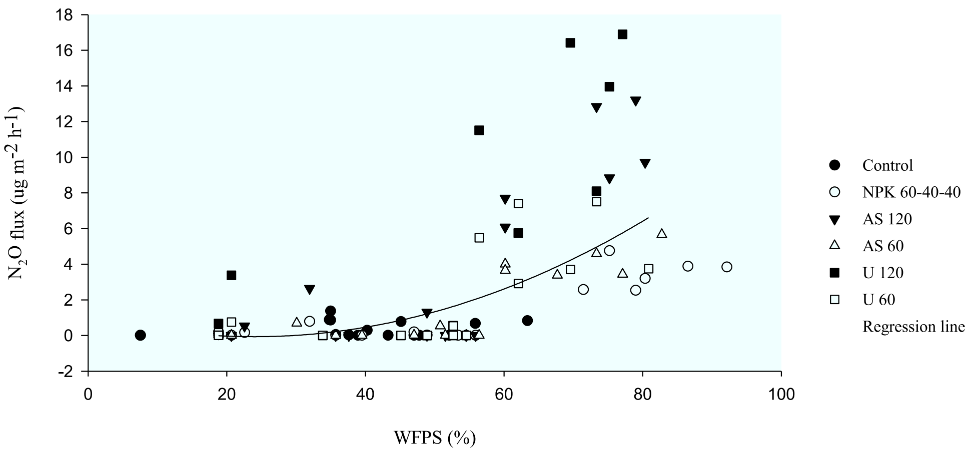

Fig. 3. N_2O flux as a function of water-filled pore space (WFPS), i.e. the ratio of volumetric soil water content to total soil porosity.

these reports attribute the phenomenon to increased enzymatic activities with substantial presence of substrate and moisture [27,28,30]. In this study, substantial N_2O flux was measured when WFPS was above 40% and mineral N was highly available between two and ten days after fertilizer application.

A positive and significant ($P = 0.007$, $r^2 = 0.51$) correlation was found between N_2O flux and WFPS (Fig. 3). These results are similar to the findings of Firestone and Davidson [9] that production of N_2O in soils by nitrification and denitrification is primarily depending on soil moisture as an essential factor beside N availability. The results further agree with the findings of other researchers [27,30], who reported that soil water acts as a transport medium for NO_3^-–N and NH_4^+–N, and in addition influences the rate of oxygen supply and thereby controls whether aerobic processes such as nitrification or anaerobic processes such as denitrification dominate within the soil. Wolf and Russow [34] and Papen and Butterbach-Bahl [22] reported that N_2O emissions are known to increase at higher water contents through larger losses from denitrification. In this study, soil moisture was relatively high when significant N_2O fluxes were measured between August and mid of October.

The average N-induced N_2O emission factors ranged between 0.096% and 0.22% (Fig. 4), with an overall average EF value of 0.149%. The EFs obtained from the different mineral N fertilizer applications were in the order U 120 > AS 120 > U 60 > AS 60 > NPK 60–40–40 (Fig. 4). The overall EF was calculated by averaging all EFs irrespective of the fertilizer type and rate.

The EF values obtained from this experiment are by far smaller than the default mean EF of 1% proposed by the IPCC (*IPCC* 2006), which is the most recent IPCC methodology for estimating direct N_2O emission from synthetic fertilizer applied to agricultural soils, which assumes N_2O emission to be a fixed percentage of 1% of the N applied. However, region-specific EFs have not been obtained for the Guinea Savanna of Ghana so far. This method will probably overestimate the GHG emission inventory in Guinea Savanna of Ghana. Certainly, considering the relatively small experimental plots and the observation period of only two years in this study, and also the crop planted on poor soils, the EFs obtained may be considered only a rough approximation of N_2O losses from the Guinea Savanna of Ghana.

Cumulative N_2O fluxes from the two-year study were averaged and are presented in Fig. 5. The highest cumulative N_2O flux at the end of the growing season was obtained for U 120, followed by AS 120, while NPK 60–40–40 and AS 60 exhibited the lowest N_2O flux (Fig. 5). The influence of N fertilizer on the total cumulative N_2O fluxes observed was in the order of U 120 > AS 120 > U 60 > AS 60 > NPK 60–40–40 > control. Using 298 as the conversion factor to convert N_2O to CO_2

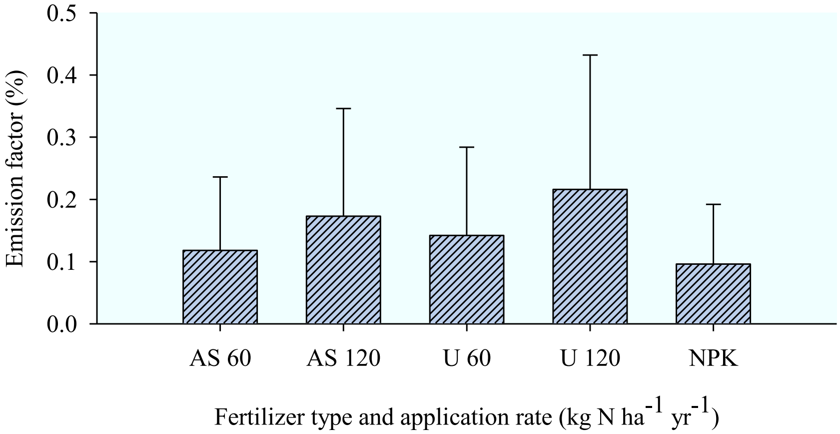

Fig. 4. Emission factors (percentage of N_2O–N emitted per kg fertilizer N ha^{-1} yr^{-1} applied) in relation to N fertilizer rate and type (error bars represent standard deviation, $n = 18$).

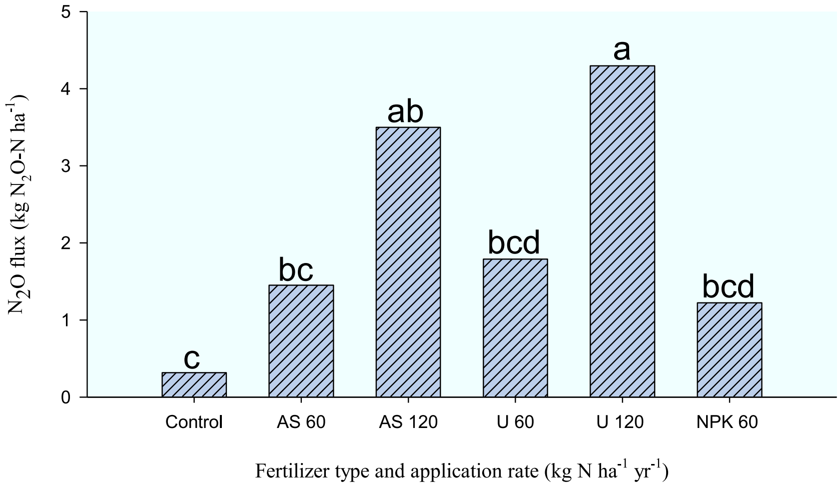

Fig. 5. Cumulative N_2O flux of fertilized and unfertilized maize treatments (different letters indicate significant differences ($P < 0.05$) between treatments).

equivalents (CO_2eq) according to the *IPCC* (2013) methodology, AS 120 and U120 emitted 2–2.5 times more CO_2eq in the form of N_2O than NPK 60–40–40, AS 60 and U 60. In contrast, without N fertilization, the emitted CO_2eq was 2–4 times less than from the fertilized plots.

Yield-scaled N_2O emissions of U 120 and AS 120 were 1.24 and 1.04 g N_2O kg^{-1} grain produced, while the non-fertilized control as well as U 60, AS 60 and NPK 60–40–40 emitted less than 0.6 g N_2O kg^{-1} grain (Fig. 6). The higher N_2O emitted from U 120 and AS 120 in this study can be attributed to lower nitrogen use efficiency. Although N_2O emitted kg^{-1} grain from plots without N fertilization was low, it cannot be regarded as an alternative because it resulted in dramatically lower grain yield (Table 3). Considering the demand for increased food production to supply Ghanaś increasing population, aggravated by poor soil fertility in the Guinea Savanna, production of crops, especially maize, without N fertilization should be discouraged. Instead, the use of optimum N fertilizer rates that increase crop productivity with minimum N_2O emissions and less NO_3^-–N losses should be considered. Results from this study showed that application of any of the treatments NPK 60–40–40, AS 60 and U 60, that produced an average grain yield of 2 t ha^{-1} with less cumulative N_2O emission and comparatively higher nitrogen use efficiency than plots fertilized with 120 kg N ha^{-1}, could be recommended as a good practice. Other studies have reported similar results. For instance, Ha et al. [11] reported that 399.4 kg CO_2eq of N_2O ha^{-1} was emitted from N-fertilized fields for each t ha^{-1} of summer maize grain produced.

Response of grain and stover yields to N fertilizer application

Grain and stover yields were significantly increased by N fertilization in both years ($P < 0.001$) (Table 3). Maximum grain yields of 2246 and 2446 kg ha^{-1} were obtained from U 120 in the two years of the study, but the grain yields from N fertilized plots were not significantly different from each other in both years (Table 3). Accordingly, N-fertilized plots produced significantly ($P < 0.05$) more stover than without N fertilization in both years. Although statistical analysis showed

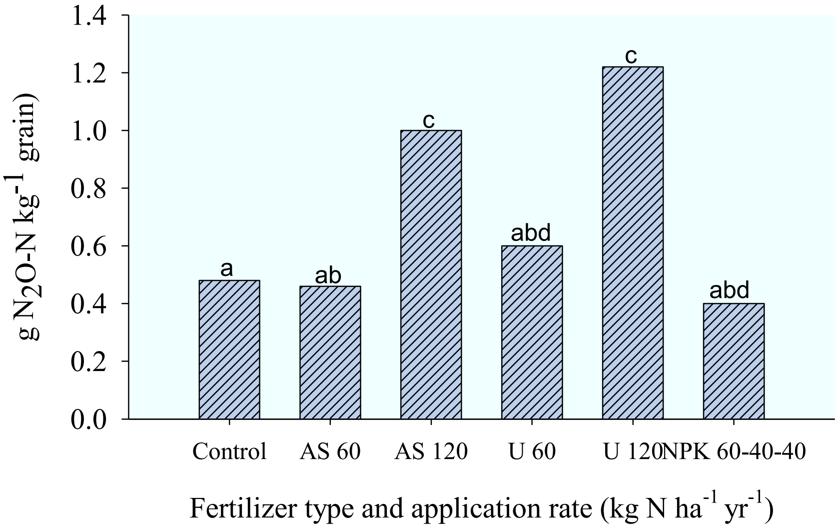

Fig. 6. Yield-scaled N_2O emissions of the different treatments (bars with the same letters are not significantly different ($P > 0.05$) from each other). $n = 18$.

Table 3
Mean maize grain and Stover yield (kg ha^{-1}).

Treatment	2013		2014		Stover-grain ratio	
kg ha^{-1} yr^{-1}	Grain	Stover	Grain	Stover	2013	2014
Control	387	2292	420	2591	5.92	6.17
AS 60	2000	4229	2110	4129	2.11	1.96
AS 120	2171	5917	2381	5927	2.73	2.49
U 60	2146	4938	2216	4958	2.30	2.24
U 120	2246	4542	2446	5142	2.02	2.10
NPK 60–40–40	2008	4829	2118	5989	2.40	2.83
LSD	748.7	685.9	628.7	615.9		
CV%	1.2	11.2	1.6	11.2		
p	<0.001	0.022	<0. 001	0.021		

AS, U and NPK means Ammonium Sulfate, Urea and Nitrogen, Phosphorus and Potassium.

no significant difference ($P < 0.05$) between grain yields produced in both years among N treated plots, grain yields in 2014 were found to be higher than in 2013. Lower and uneven distribution of rainfall might have accounted for the differences in the yields obtained. Total rainfall recorded in the 2013 growing season was 513 mm (June–November), and most of it occurred between late August and September, with scattered rainfall occurring in October when crops were tasseling. In contrast, 690 mm of rainfall was recorded in 2014 within the same period of time. The relatively short drought period that occurred after fertilizer application in 2013 might have reduced dissolution of the N fertilizer and the transport to the plant roots, making it less available for plant use. This then resulted in a delay in crop physiological activity at silking and/or tasseling and caused reduced grain yield.

The non-linear increase in grain yield with increasing mineral N application from 60 to 120 kg N ha^{-1} yr^{-1} could be explained by higher N loss from plots that received 120 kg ha^{-1} yr^{-1}N, irrespective of the N form. Analysis of agronomic N use efficiency indicated higher N use efficiencies when 60 kg^{-1} ha^{-1}N was applied, again irrespective of the N form. Agronomic N use efficiency was calculated using a modified procedure of Hashemidezfooli et al. [44]. Average agronomic N use efficiencies of 29.6, 27.7, 27.5, 16.2 and 15.6 g kg^{-1} were found for U 60, NPK 60–40–40, AS 60, U 120, and AS 120, respectively. This means that beyond 60 kg N ha^{-1}, grain yield increase produced by N fertilization was economically and environmentally less favorable. This result agrees with the findings of *Shahzad* et al. (2010), who also reported a decline in agronomic N use efficiency with increasing N application from 60 to 180 kg N ha^{-1}. More so, the use of mineral fertilizers in Sub Saharan Africa (SSA) has been promoted through blanket recommendations that are based on agro-ecological zones. Adaptation of the blanket recommendations to account for variability in soil fertility between land units is necessary to maximize the benefits of projected increases in fertilizer use (Table 4).

In both years, maize grain yields differed between types and rates of N application, but not significantly. The application of urea produced slightly higher grain yields than sulfate of ammonia, which in turn led to slightly higher grain yields than the NPK fertilizer. Increasing the rate of N applied promoted greater vegetative growth of the maize crop at the expense of grain formation and resulted in a grain yield increase of 8.6% and 4.7% in 2013, and 12.8% and 10.4% in 2014, when sulfate of ammonia and urea were applied, respectively. Without N application, stover-to-grain ratio was 5.9 and 6.2 in 2013 and

Table 4
Annual cumulative N_2O (kg N_2O–N ha^{-1}) fluxes of the different treatments of the study (different letters indicate significant differences ($P < 0.05$) between treatments).

Treatment	2013		2014	
Control	0.30	c	0.32	c
AS 60	1.44	bc	1.35	bc
AS 120	3.49	ab	3.64	ab
U 60	1.78	bcd	1.86	bcd
U 120	4.28	ab	4.28	ab
NPK 60–40–40	1.21	bcd	1.26	bcd

AS, U and NPK means Ammonium Sulfate, Urea and Nitrogen, Phosphorus and Potassium (different letters in each column are significantly different from each other).

2014, respectively. With N application, the ratios were drastically smaller and ranged from 2.0 to 2.7 in 2013 and 2.0 to 2.8 in 2014, depending on the type and rate of N application. Redistribution of assimilates to N-rich generative parts (corn cobs) as a consequence of N fertilization could probably explain the observed trend.

Conclusion

The increasing demand for food production to supply the growing Ghanaian population with the consequential decrease in soil nutrients, especially N, calls for an increased N fertilization to increase crop yield. Therefore, maize production without N fertilization should be discouraged. The results of this study have revealed superiority of application of 60 kg N ha^{-1} yr^{-1} to 120 kg N ha^{-1} yr^{-1}, regardless of the N type, in producing corn at a comparable yield level, but with improved N use efficiency, on *Ferric Luvisol*. The significantly lower N_2O fluxes, i.e., 2–2.5 times lower emitted N_2O emissions, and less than 50% N_2O kg^{-1} grain emitted following application of 60 kg N ha^{-1} yr^{-1} as com to application of 120 kg N ha^{-1} yr^{-1}, suggest that the use of the current fertilizer formulation 60–(40–40) kg N–P_2O_5–K_2O ha^{-1} in the Guinea Savanna of Ghana is likely to significantly decrease global warming when compared with higher N fertilization rates. Whether this recommendation is also valid for other regions of tropical West Africa, or even beyond, needs to be determined in independent research projects.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

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