Soil Nitrous Oxide (N_2O) Emission from Integrated Soil Fertility Management in Maize (*Zea mays* L.) Cropping Systems

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Abstract

Integrated Soil Fertility Management (ISFM) has been recommended to address challenges of low soil fertility by incorporating locally available organic resources (ORs) together with inorganic nitrogen (N) fertilizers. Despite ISFM success in field trials, there is limited information on ORs contribution to atmospheric greenhouse gas concentrations through N_2O emission. A short-term field study was conducted at two sites with different soil types; silt loam (Aludeka) and silty-clay soil (Sidada) to assess the influence of selected ORs on soil N_2O emissions. The ORs treatments included; *Calliandra carothyrsus (CL),* farmyard manure (FYM) and maize stover (MS) with (+N) and without (-N) inorganic N fertilizer. The study also evaluated the relationship between N_2O emissions and soil organic carbon, mineral N, total nitrogen, soil temperature, moisture content, soil nitrate (NO_3^-) and ammonium (NH_4^+). Relative to the control (0.19±0.1 Kg N_2O-N ha^{-1}), cumulative N_2O emissions were significantly (P= 0.01) higher by 6, 9 and 13 fold under MS +N (1.05±0.8 Kg N_2O-N ha^{-1}), FYM +N (1.74±0.8 Kg N_2O-N ha^{-1}) and CL +N (2.54±1.2 Kg N_2O-N ha^{-1}), respectively at the Aludeka site. At Sidada, cumulative N_2O emissions were similar across all the treatments (P = 0.149). Approximately 240% and 411% of increase in cumulative N_2O emissions across treatments at Sidada and Aludeka, respectively, was related to inorganic N fertilizer application. At Aludeka, cumulative N_2O emissions exhibited significant positive relationship with soil NO_3^-(r = 0.894, P = 0.03) and NH_4^+ (r = 0.817, P = 0.013), and negatively correlated with soil C: N ratio (r = -0.710, P = 0.049). While at Sidada soil properties did not exhibit significant relationship with cumulative N_2O emissions. The study suggests that influence of OR on N_2O emissions in maize based-cropping system vary depending on the type of soil and increases when OR are applied in combination with inorganic N fertilizers.

1.0. Introduction

Agriculture is a major source of nitrous oxide (N_2O) gas in the atmosphere, mainly from soils through application of inorganic nitrogen (N) fertilizers, livestock manures and crop residues, representing 40% of total global agricultural N_2O emissions (Narayan and Qu, 2016). The rate of N_2O emissions from managed agricultural soils is influenced by weather events such as rainfall, fertilizer applications and soil properties (Li et al., 2013). The use of integrated soil fertility management (ISFM) has particularly been the main focus in agronomic research on soil fertility improvement in maize based cropping systems in Sub Saharan Africa (Vanlauwe *et al*., 2010). But the role of ISFM in climate change mitigation on N_2O emissions has limited investigations.

Determination of OR with inorganic N fertilizer that minimizes N losses due to N_2O emissions would increase N use efficiency]' and reduce on the costs of fertilizers. Understanding the key drivers responsible for N_2O emissions from different soil and climatic conditions is essential for the development of a good soil structure. Our study was conducted in an existing long-term experiment to assess the influence of three ORs with and without inorganic N fertilizer on soil N_2O emissions. We also examined N_2O emissions relationship with soil properties of moisture content (MC), soil pH, total nitrogen (TN) and soil organic carbon (SOC).

2.0. Methods and Study Site

2.1. Description of the study site

The research was conducted on two farms of the International Institute of Tropical Agriculture (IITA) in Busia and Siaya counties, in Western Kenya. In Busia, the soil was silt loam while in Siaya it was silty clay.

2.2. Experimental design and field management

This experiment was laid out in a completely randomized block design with a split plot arrangement. The OR represented the main plot (6 x 12 m) whereas the addition of inorganic N fertilizer was the sub-plot (6 x 6 m). In one sub-plot, the OR was applied with inorganic N fertilizer (+N) and in the other without inorganic N (–

N). Three OR amendments and control were used in this study: *Zea mays* stover, *Calliandra calothyrsus* and farmyard manure giving a total of eight treatment combinations replicated three times. All ORs were incorporated through shallow tillage during planting at a rate of 1.2t C/ha/yr C equivalent content basis.

2.3. Gas sampling

Soil N_2O emissions was measured using static vented chamber and gas chromatography (GC) methods (Rochette and Hutchinson, 2005). We used the pooling method as described in (Arias-navarro *et al*., 2017) in gas sampling at an interval of 0, 15, 30 and 45 minutes from 8.00 am to 1 pm, for a total of 20 sampling events at each site. The gas samples were analyzed for N_2O concentration at Mazingira Centre located at ILRI, Nairobi. The GC analytical method is described in detail by (Rosenstock et al., 2016)**.** Daily fluxes were calculated from observed linear changes in headspace N_2O concentration over the chamber closure time for each sampling date after accounting for air temperature and pressure according to Parkin et al., (2012). The cumulative N_2O fluxes were obtained by calculating the area under the flux-time curve and summing the results while assuming linear changes in measurements between time intervals (Wanyama et al., 2018).

2.4. Statistical analyses

Data on mean N_2O fluxes and cumulative (CUM) N_2O fluxes were analyzed using analysis of variance in a general treatment structure (in Randomized Blocks) independently for each site using Genstat Statistical Software Version 15. Statistical differences were tested at $\alpha \leq 0.05$. Means were separated using the Fishers protected least significant differences while Pearson's correlation analyses was conducted using SPSS (version 23) to determine interactions between different soil properties and N_2O fluxes.

3.0. Results

3.1. Soil N_2O fluxes from different Organic Resources

OR with N fertilizer application significantly increased N_2O emissions and produced higher peak pulses compared to OR treatments alone at both sites (P>0.001). There was a small N_2O flux before planting and then increased for a period of about 15 days at the beginning of the sampling season, before gradually decreasing to background emissions towards the end of the sampling season under all the treatments.

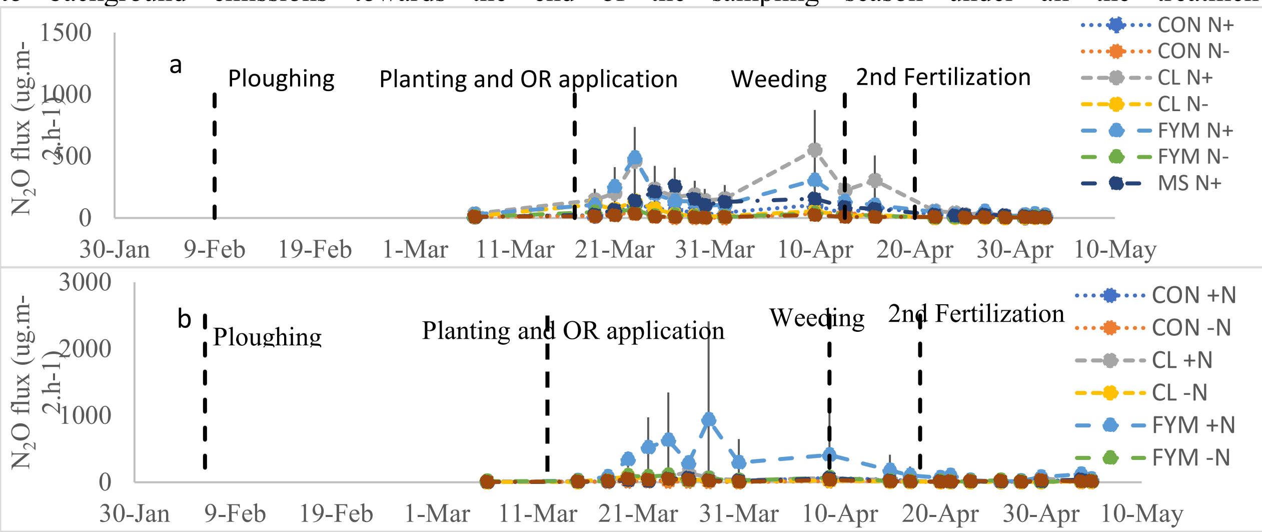

Figure 1. Temporal soil N_2O fluxes a) Aludeka and b) Sidada from 6th March to 5th May under different treatments with and without mineral N fertilizer. Error bars represent SD. Dotted vertical lines indicate different farm management activities.

3.2. Effect of Organic Resources on mean and cumulative N_2O emissions

Mean N_2O fluxes from treatment with inorganic N fertilizer were on average 5 times higher than those without inorganic N fertilizer. Significantly (*P*<0.001) higher N_2O emissions was observed under CL +N (153.2 ± 170.8 μg m^{-2} h^{-1}) and FYM+N (212.3± 425.1 μg m^{-2} h^{-1}) in Aludeka and Sidada respectively, while lower emissions were observed under MS -N (9.4 ± 9.6 μg m^{-2} h^{-1}) and CON –N (6.8 ± 6.3 μg m^{-2} h^{-1}) in Aludeka and Sidada, respectively. A similar trend was observed for cumulative N_2O emissions during the growing season with the treatments exhibiting significant (*P*=0.03) differences in Aludeka but not at Sidada (*P*=0.149) (Table 3). There was a significant effect observed on both mean hourly fluxes and cumulative N_2O emissions because of total N inputs at Aludeka (P<0.001).

3.3. Relationships between daily N_2O fluxes and soil parameters

Table 1. Pearson correlation coefficients of linear association between soil properties and daily N_2O emissions

		Aludeka	Sidada
Soil properties	n	Cumulative N_2O	Cumulative N_2O
Soil pH	8	-0.739*	0.023
Total C	8	0.760*	0.605
Total N	8	0.820*	0.579
Soil C: N	8	-0.710*	0.177
NH_4^+-N	8	0.738*	0.002
NO_3^--N	8	0.905**	0.711*

*, ** denote significance at $p \leq 0.05$ and $p \leq 0.05$ 0.001 respectively.

For all the sites, soil NO_3^--N was positively correlated with the cumulative N_2O fluxes (P=0.002) and (P=0.048) at Aludeka and Sidada, respectively. On the other hand, soil NH_4^+-N, TN and SOC showed a positive correlation at Aludeka site. The correlation analysis also indicated that there was a negative relationship between soil pH, and C:N ratio with cumulative N_2O emissions at Aludeka (Table 4).

4.0. Discussion

4.1. Effect of organic resources and added inorganic N fertilizers on Mean and Cumulative N_2O fluxes

This study estimate 239% and 411% of the cumulative N_2O emissions as a result of an inorganic N fertilization at Sidada and Aludeka, respectively. This we can be attributed to high concentration of readily available N in the soils from the inorganic N fertilizers. The present findings seems to agree with previous studies who reported increased annual N_2O production from treatment combination of OR and inorganic N fertilizers (Charles et al., 2017). However, high emissions from treatments with inorganic N fertilizer took place for about 15 days after fertilization. This was closely linked with the first onset of rains which took place for about two weeks in our studies areas. This was also observed by Maljanen et al, (2003) who noted that N_2O emissions from treatments involving inorganic N fertilizer application was short-lived.

At Aludeka site ORs of FYM and CL with increased N_2O emissions could be due to increased rate of microbial activities in the soil due to lower C: N ratio of 11 and 15, respectively of the organics. Khalil et al. (2002) observed an increased rate in nitrification with a reduction in C:N ratio of ORs. However, at Sidada site our findings are contrary to this observation where we observed no significant differences between the OR treatments with C:N ratio below 12. We attribute this to differences in soil properties and environmental factors in our studied sites. According to (Charles et al., 2017) ORs with lower C:N ratio of 25, only a part of the variations is explained by the C:N ratio, and attributed emissions to influence from management and environmental related factors.

4.2. Effect of soil properties on N_2O emission

The difference in correlation of soil NO_3 with cumulative N_2O emissions in our studied sites could be due to the differences in soil properties in terms of SOC and TN between the two sites. The significant positive correlation of NO_3- at Aludeka site despite its low concentration levels could be as a result of low SOC concentration in the area, which suggests that N_2O emissions is C limited (Azam et al., 2002; Pelster et al., 2012). Which also explains why we had a significant positive correlation between SOC and N_2O emissions at Aludeka. The no significant differences observed in cumulative N_2O emissions in our treatments at Sidada most likely resulted from high soil mineral N and SOC availability. According to (Bateman and Baggs, 2005) N_2O emissions are not closely related to high NO_3^--N concentrations in soils but could be as a result of SOC which provide substrates of inorganic N and labile organic C for denitrification and nitrification processes.

Conclusion

Inorganic N fertilizer additions to silt loam soils significantly increased N_2O emissions. Importantly, NO_3^--N level had a greater impact on N_2O emissions, being most significant where SOC was low, implying that the difference in SOC in the two sites could have been a major factor in regulating N available for N_2O emissions.

Hence, the reduction of N_2O emissions under high SOC content serves as a good mitigation strategy. The OR and inorganic N fertilizer interactions is important in addressing the problem of N_2O emissions from soils.

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References

Arias-navarro, C., Kiese, R., & Rosenstock, T. (2017). Gas pooling : A sampling technique to overcome spatial heterogeneity of soil carbon dioxide and nitrous oxide fluxes. *Soil Biology and Biochemistry*, *67*(December), 20–23.

Azam, F., Müller, C., Weiske, A., Benckiser, G., & Ottow, J. C. G. (2002). *Nitrification and denitrification as sources of atmospheric nitrous oxide – role of oxidizable carbon and applied nitrogen*. *3*, 54–61.

Bateman, E. J., & Baggs, E. M. (2005). Contributions of nitrification and denitrification to N 2 O emissions from soils at different water-filled pore space. *Biol Fertil Soils*, *41*, 379–388.

Charles, A., Rochette, P., Whalen, J. K., Angers, D. A., Chantigny, M. H., & Bertrand, N. (2017). Global nitrous oxide emission factors from agricultural soils after addition of organic amendments: A meta-analysis. *Agriculture, Ecosystems and Environment*, *236*(3), 88–98.

Khalil, M. I., Rosenani, A. B., Van Ceemput, O., Boeckx, P., Shamshuddin, J., & Fauziah, C. I. (2002). Nitrous oxide production from an ultisol of the humid tropics treated with different nitrogen sources and moisture regimes. *Biol Fertil Soils*, *June 2014*.

Li, L. J., Han, X. Z., You, M. Y., & Horwath, W. R. (2013). Nitrous oxide emissions from Mollisols as affected by long-term applications of organic amendments and chemical fertilizers. *Science of the Total Environment*, *452–453*, 302–308.

Maljanen, M., Liikanen, A., Silvola, J., and Martikainen, P. J. (2003). *Measuring N 2 O emissions from organic soils by closed chamber or soil / snow N $_2$ O gradient methods*. *September*, 625–631.

Narayan, T., & Qu, J. (2016). An international comparison of agricultural nitrous oxide emissions. *Journal of Cleaner Production*, *135*, 1256–1266.

Pelster, D. E., Chantigny, M. H., Rochette, P., Angers, D. A., Rieux, C., & Vanasse, A. (2012). Nitrous Oxide Emissions Respond Differently to Mineral and Organic Nitrogen Sources in Contrasting Soil Types. *Journal of Environmental Quality*, *41*(2), 427–435.

Parkin, T. B., Venterea, R. T., & Hargreaves, S. K. (2012). Calculating the Detection Limits of Chamber-based Soil Greenhouse Gas Flux Measurements.

Rochette, P., & Hutchinson, G. L. (2005). Measurement of Soil Respiration in situ: Chamber Techniques. *Micrometeorology in Agricultural Systems*, *47*, 247–286.

Rosenstock, T. S., Mpanda, M., Pelster, D. E., Butterbach-bahl, K., Rufino, M. C., Thiong'o, M., Mutuo, P., Abwanda, S., Rioux, J., Kimaro, A. A., & Neufeldt, H. (2016). Greenhouse gas fluxes from agricultural soils of Kenya and Tanzania. *Journal of Geophysical Research: Biogeosciences*, *July*.

Vanlauwe, B., Kihara, J., Chivenge, P., Pypers, P., Coe, R., & Six, J. (2014). Agronomic use efficiency of N fertilizer in maize-based systems in sub-Saharan Africa within the context of integrated soil fertility*, May*.

Wanyama, I., Pelster, D. E., Arias-navarro, C., Butterbach-bahl, K., Verchot, L. V, & Ru, M. C. (2018). Management intensity controls soil N $_2$ O fluxes in an Afromontane ecosystem. *Science of the total Environment*, *624*, 769–780.