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Fertilizer Management Strategy to Reduce Global Warming Potential and Improve Soil Fertility in a Nitisol in Southwestern Ethiopia †

Gebeyanesh Worku Zerssa [1,2,*], Philipp Koal [3] and Bettina Eichler-Löbermann [1]

[1] Department of Agronomy and Crop Science, Faculty of Agricultural and Environmental Sciences, University of Rostock, J. von Liebig Weg 6, 18059 Rostock, Germany; bettina.eichler@uni-rostock.de
[2] Department of Natural Resources Management, College of Agriculture and Veterinary Medicine, Jimma University, Jimma P.O. Box 307, Ethiopia
[3] Forestry Research and Competence Center, Thüringen Forst, Jägerstr. 1, 99876 Gotha, Germany; philko@t-online.de
* Correspondence: workugb2010@gmail.com; Tel.: +251-932000134
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Abstract: Proper fertilizer management and applications could effectively reduce global warming potential (GWP) by reducing GHG emissions and improve soil fertility under cereal production. However, the effect of soil fertilizer management practices on GWP and soil fertility is less understood in the agricultural soils of Ethiopia. The present study evaluated the effects of fertilizer application strategy on GWP, and soil fertility in a Nitisol. Both field and laboratory incubation experiments were conducted with the same treatments in Ethiopia and at the University of Rostock, Germany, respectively. Seven treatments (Cont: no input; 100 min: 100% mineral fertilizer, 80 min: 80% mineral fertilizer + 1.4 t ha^{-1} compost; 60 min: 60% mineral fertilizer + 2.8 t ha^{-1} compost; 50 min: 50% mineral fertilizer + 3.5 t ha^{-1} compost; 30 min: 30% mineral fertilizer + 4.9 t ha^{-1} compost, and 100 comp: 100% compost) with four replications were applied on maize crop (*Zea mays* L. Bako hybrid 661) for two-consecutive growing seasons. The laboratory incubation experiment was also done with two moisture levels (40% and 75% of water-filled pore space) to simulate the seasonal rainfall pattern. GWP was calculated by summing up the quantified gas emissions of nitrous oxide (N_2O), carbon dioxide (CO_2), and methane (CH_4). The laboratory result for GWP shown that soil fertilized with mineral fertilizer alone was significantly ($p < 0.05$) increased by 27.1–34% of the average GWP value compared to combined fertilizer treatments in the soil at a moisture level of 75%. From the field experiment, most plant nutrients were significantly improved in combined fertilizer treatments compared to sole mineral fertilizer application. For example, carbon, calcium, magnesium and potassium were increased by 26.21–39.81%, 73.2–168.8%, 146.6–251.5% and 47–99% respectively in combined fertilizer in comparison to 100 min treatment. The study revealed that combining 30 or 50 kg N ha^{-1} of mineral fertilizer with biowaste compost (4.9 or 3.5 t ha^{-1}) would be a suitable combination to mitigate the GWP and improve soil quality in smallholder farming systems, due to a slow release of N during decomposition into the soil compared to mineral fertilizer alone. However, to evaluate GWP under the field conditions, future investigations would be recommended.

Keywords: organic fertilizer; soil quality; greenhouse gas; Nitisol

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1. Introduction

Agricultural soil is one of the source for greenhouse gas (GHG) emissions as the result of the excessive application of N fertilizer, animal manure, and decomposition of organic material [1]. The major GHGs, which contribute for global warming potential (GWP), are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). The average amounts of GHG emitted from agricultural soils are estimated to be 14% of the total global GHG emissions and thereby accelerate GWP [2,3].

Based on the global average value Ethiopia is contributing insignificant amount of GHGs (0.03%) emissions as a global warming potential, from all agricultural activities [4–6]. GHGs emitted from fertilized crop fields are not well investigated and understood in Ethiopia. Currently the amount of N fertilizer (46 kg N ha^{-1}) applying in the crop field has not-significant effect on the GHGs emission when we compare with other developed country application rates (300 kg N ha^{-1}). However in the future, Ethiopia aimed to increase the use of mineral fertilizer per hectare from 65 kg ha^{-1} in 2010 to 247 kg ha^{-1} in 2030 [6]. In addition, N_2O emissions from mineral fertilizer expected bout 58% in 2030 from total soil based emissions, and will increase from 4.3 Mt CO_2e in 2010 to 35 Mt CO_2e in 2030. Various studies suggested combining organic and mineral fertilizers application is a viable option to reduce N losses through N_2O emission and its impact on GWP [5,7]. Combined uses of organic and mineral amendments have been widely used as a means for soil fertility improvement. Economically it is affordable for poor farmers, and environmentally it is suitable. However, the effect of soil fertilizer management practices on GWP and soil quality is less understood in agricultural soils of Ethiopia. The present study evaluated the effects of combined application of biowaste compost and mineral fertilizers on GWP, and soil fertility in a Nitisol.

2. Material and Method

The two year field experiment was performed at the research station of Jimma University in Southwestern Ethiopia with latitude, 7°42′ N; longitude 36°49′ E. The research site is characterized as humid tropical climate with a minimum of 13 °C and a maximum of 28 °C. The annual maximum and minimum precipitation in the area is around 1200 and 2400 mm, respectively. The soil was Nitisol with silty clay loam texture, pH of 4.98, organic carbon content of 2.4%, and total N of 0.22%.

The laboratory incubation experiment was conducted at the University of Rostock, Germany with the Nitisol from the field experiment in Ethiopia applying the same fertilizer treatments as in the field experiment in four replications. Two hundred grams of air-dried soil was filled into a 1000 mL jar, the soil aggregates were evenly compacted to a bulk density of 1.2 g cm^{-3} (to mimic the natural soil pore spaces) and after 15 days pre-incubation, fertilizers were applied and the moisture contents were adjusted to 40% and 75% WFPS in order to mimic the dry and rainy seasons. The fertilizer addition was adapted to the soil volume in the jars, whereas 100 kg N ha^{-1} corresponded to 33.33 mg N kg^{-1} soil.

Gas samples from the headspace of the sealed jars were collected by 60 mL syringes, transferred to evacuated vials, and the gas concentrations of N_2O, CO_2 and CH_4 were measured with a gas chromatograph (GC-2014, Shimadzu). Gas emissions (g ha^{-1} day^{-1}) were calculated by following Comeau et al. [8] equation for soil heterotrophic respiration assessment using minimally disturbed soil microcosm cores. The GWP was determined for fertilizer rate and type using the following equation.

$$\mathrm{GWP} = \mathrm{N_2O} * 298 + \mathrm{CO_2} + \mathrm{CH_4} * 25$$

where GWP = global warming potential (kg CO_2 eq. ha^{-1}); N_2O = is the amount of N_2O (kg ha^{-1}); CO_2 = the amount of CO_2 (kg ha^{-1}); CH_4 = the amount of CH_4 (kg ha^{-1}); 298, and 25 = GWP coefficients to convert N_2O and CH_4, respectively, to CO_2 equivalents.

In the beginning, before the treatment application, and after harvest, composite soil samples were collected from the surface layer (0–20 cm) was analyzed following the standard laboratory procedures for each soil parameter.

One-way analysis of variance (ANOVA) was used to determine the effect of different fertilizer types on GWP and soil parameters. The mean values were determined by using the Tukey multiple-comparison test by using SPSS (22.0 version).

3. Result and Discussion

3.1. Fertilizer Management Effect on Global Warming Potential

The result for GWP revealed significantly different ($p < 0.05$) values among the treatments (Figure 1). The soil amended with 100 min was significantly ($p < 0.05$) increased by 27.1%, 30.4% and 34% of the average GWP values compared to 80 min, 50 min and 30 min treatments respectively in wet soil. This may be attributed to slow release of mineral nitrogen by microbial activity and low contribution to GHGs emissions compared to 100 min treatment. The soil amended with 100 comp was significantly reduced by 62.7% of GWP compared to the 100 min treatment in wet soil. In 40% WFPS condition, the 100 min treatment significantly ($p < 0.05$) increased GWP by 34.1% and 51.1% in comparison to the 100 comp treatment and the Cont, respectively. With increasing ratios of mineral fertilizer, the GWP values were increased in both soil moisture conditions. However, in a dry soil condition, there was no significant difference among 100 min treatment and combined fertilizer treatments (Figure 1). The study is in opposite with the Bharali et al. [9] finding, who reported higher GWP (887.4 kg CO_2 ha^{-1}) in combined application of NPK with Sesbania aculeate compared to NPK alone applied filed (540.6 kg CO_2 ha^{-1}). The justified reason by the author was application of NPK together with organic source enhanced the emission of CH_4 by providing additional C substrate compared to NPK alone in the rice field. This might be not true in our case since the soil moisture condition in our experiment was lower compared to the previous study to enhance methanogenesis. In our study the main GHGs created GWP values variation among the treatments were due to N_2O and CO_2 than CH_4 [10]. The influence of fertilizer types are clearly observed on the emissions of N_2O and CO_2 compared to Ch_4. This indicates that the contribution of CH_4 gas to GWP is not only influenced by fertilizer type but also soil moisture. The present study provides very useful insights for policymakers to design an appropriate strategy to reduce GWP from cereal production systems in Ethiopia. In the current cereal production system, the contribution of fertilizer to GHG emissions and GWP are very low due to the application of low fertilizer rates. However, in the future, the amount of mineral fertilizer application will increase from about 65 kg ha^{-1} in 2010 to about 250 kg ha^{-1} in 2030 [11] to boost up cereals for the ever-increasing population in Ethiopia. This condition will be expected to contribute significantly to GWP. To minimize the future impact of fertilizer application on GWP without reducing the agricultural production in the country, applying the combined fertilizer at a rate of 30 or 50 kg N ha^{-1} of mineral fertilizer with biowaste compost (4.9 or 3.5 t ha^{-1}) is a viable option, for smallholder farmers [10].

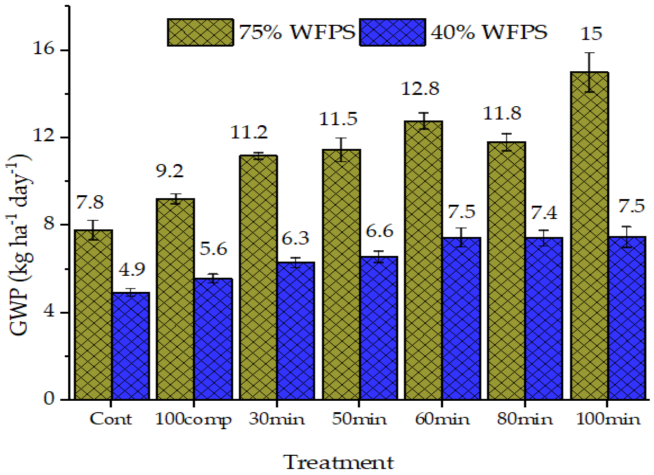

Figure 1. Global warming potential (GWP) in different fertilizer types and water filled pore-space (WFPS) (40% and 75%).

3.2. Effect of Combined Fertilizer on Soil Fertility

From the field experiment, most plant nutrients were significantly improved in combined fertilizer treatments compared to sole mineral fertilizer application. For example, carbon, calcium, magnesium and potassium were increased by 26.21–39.81%, 73.2–168.8%, 146.6–251.5% and 47–99% respectively in combined fertilizer in comparison to 100 min treatment (Table 1). Other combined fertilizer types also exhibited significantly higher values for Mg compared to 100 min fertilizer. The value for zinc (Zn) was significantly higher in 80 min compared to Cont, 100 comp, 50 min, and 100 min treatments. For the pH value, there was no significant difference between combined fertilizer and mineral alone. The field with 80 min exhibited significantly higher Ec value in comparison with other treatments. There were no significant differences between other treatments for Ec values. The result for cation exchange capacity (CEC) also showed a significant difference among treatments. The highest value was observed in the field with 80 min fertilizer compare to other treatments.

The significant increment of organic C in the combined fertilizer could be associated with the positive effects of biowate compost application on organic C storage. The result also supported by Ogundijo et al. [12] who reported the application of 10 t ha^{-1} poultry manure with (120 kg ha^{-1} NPK) significantly increased organic C amount over sole fertilizer application (120 kg ha^{-1} NPK). The highest value of total nitrogen was recorded in plots treated with combined fertilizer and the lowest value was recorded in the Cont plot (Table 1). The possible reason for the highest value of total nitrogen could be the slow release of mineral nitrogen reduces the losses of N by leaching in combined fertilizer than sole mineral. It indicates the positive influence of the integration of compost with mineral fertilizer on total nitrogen. The research finding is supported by the previous studies [13,14], that observed higher N value in the combined fertilizer field in comparison with mineral fertilizer received field. Nitrogen is the most susceptible plant nutrient and is greatly required by plants [15].

Table 1. Soil minerals (mg kg^{-1} soil) and chemical properties (0–20 cm) after harvest in different treatments (2018–2020) (mean ± SD).

Soil Parameters	Treatment						
	Cont	**100 min**	**80 min**	**60 min**	**50 min**	**30 min**	**100 comp**
Fe	46.5 ± 2.8 ^{ab}	52 ± 2 ^{ab}	65 ± 3.1 ^{ab}	58.9 ± 3.5 ^{ab}	48.2 ± 2.8 ^{ab}	13.5 ± 2.1 ^{b}	3.7 ± 0.6 ^{a}
Ca	266.1 ± 21 ^{b}	162.6 ± 30 ^{a}	350.3 ± 11.6 ^{d}	356.2 ± 21.2 ^{d}	281.7 ± 34.07 ^{b}	437.1 ± 38.9 ^{c}	121.7± 7.3 ^{a}
Mg	30.4 ± 2.3 ^{abd}	16.3 ± 2.9 ^{a}	47.7 ± 6.5 ^{cd}	42.9 ± 9.7 ^{d}	57.3 ± 10.5 ^{c}	40.2 ± 3.3 ^{bd}	20.5 ± 1.4 ^{a}

K	27.9 ± 3.6 ^{a}	61.7 ± 12.2 ^{e}	90.5 ± 6.3 ^{bc}	122.8 ± 11.2 ^{d}	108.6 ± 1.6 ^{d}	101.5 ± 7.9 ^{c}	75 ± 5.2 ^{be}
N	227.5 ± 7.1 ^{a}	332.5 ± 26.3 ^{bd}	315 ± 23.8 ^{ad}	371 ± 21.6 ^{b}	335.3 ± 12.8 ^{bd}	350 ± 18.3 ^{bd}	285 ± 17.3 ^{a}
P	0.3 ± 1 ^{a}	0.2 ± 0.05 ^{a}	−0.14 ± 0.1 ^{a}	0.4 ± 0.1 ^{a}	0.07 ± 0.01 ^{a}	−0.02 ±0.01 ^{a}	0.6 ± 0.1 ^{a}
S	45 ± 12 ^{a}	−2.2 ± 1.02 ^{a}	20 ± 8.02 ^{a}	10 ± 2.1 ^{a}	235 ± 55.1 ^{b}	30 ± 4.1 ^{a}	15 ± 2.8 ^{a}
C	2375±95.7 ^{a}	2575 ± 359.4 ^{a}	2975 ± 596.5 ^{ac}	3250 ± 70.2 ^{bc}	3600 ± 81.7 ^{b}	3475 ± 221.7 ^{bc}	3875 ± 170.8 ^{b}
Zn	8.4 ± 1.2 ^{ab}	7.9 ± 2.1 ^{ab}	18.2 ± 1.5 ^{c}	10.1 ± 91 ^{abc}	7.5 ± 1.3 ^{ab}	12 ± 0.4 ^{bc}	2.8 ± 0.4 ^{a}
Mn	158 ± 16.8 ^{a}	182.5 ± 17.3 ^{a}	407.6 ± 64.3 ^{b}	238.3 ±2.3 ^{c}	181.4 ± 12.7 ^{ac}	38.5 ± 14.6 ^{b}	179 ± 2 ^{a}
pH	0.04 ± 0.01 ^{a}	0.14 ± 0.01 ^{bc}	0.16 ± 0.04 ^{bc}	0.17 ± 0.03 ^{bc}	0.15 ± 0.06 ^{bc}	0.20 ± 0.01 ^{b}	0.09 ± 0.01 ^{ac}
Ec	0.2 ± 0.004 ^{a}	0.2 ± 0.01 ^{a}	0.17 ± 0.02 ^{a}	0.20 ± 0.01 ^{a}	0.17 ± 0.01 ^{a}	0.16 ± 0.01 ^{a}	0.18 ± 0.01 ^{a}
CEC	0.06 ± 0.006 ^{a}	0.1 ± 0.001 ^{d}	0.13 ± 0.006 ^{c}	0.10 ± 0.01 ^{b}	0.07 ± 0.004 ^{ab}	0.09 ± 0.01 ^{bd}	0.07 ± 0.003 ^{ad}

Means in the same letters are not significantly different at 5% level of significance; and means in the different letters are significant at ($p < 0.05$) by using Tukey-test.

4. Conclusions

The application of mineral fertilizer alone increases GWP in Nitisol in wet condition in comparison to combined fertilizer application. Most plant nutrients and some chemical soil properties were significantly improved in combined fertilizer application. We recommend that 30 or 50 kg N ha^{-1} of mineral fertilizer in combination with compost of 4.9 and 3.5 t ha^{-1} be applied in Nitisol to reduce GWP with increased soil resilience in smallholder farming systems in Ethiopia. In addition, future investigation would be recommended at on-farm and on-stations in the field to consider different factors, like plants. Because, in this study, we consider two moisture levels, one temperature, and one soil type; however, other factors should be investigated in the future at field conditions.

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References

1. Brevik, E. The Potential Impact of Climate Change on Soil Properties and Processes and Corresponding Influence on Food Security. *Agriculture* **2013**, *3*, 398–417. https://doi.org/10.3390/agriculture3030398.
2. Jiang, Q.; Qi, Z.; Madramootoo, C.A.; Crézé, C. Mitigating Greenhouse Gas Emissions in Subsurface-Drained Field Using RZWQM2. *Sci. Total Environ.* **2019**, *646*, 377–389. https://doi.org/10.1016/j.scitotenv.2018.07.285.
3. *IPCC Climate Change 2014 Synthesis Report Summary for Policymakers 2014*.
4. Kim, D.G.; Thomas, A.D.; Pelster, D.; Rosenstock, T.S.; Sanz-Cobena, A Greenhouse Gas Emissions from Natural Ecosystems and Agricultural Lands in Sub-Saharan Africa: Synthesis of Available Data and Suggestions for Further Research. *Biogeosciences* **2016**, *13*, 4789–4809.
5. Raji, S.G.; Dörsch, P. Effect of legume intercropping on N_2O emissions and CH4 uptake during maize production in the Great Rift Valley, Ethiopia. *Biogeosciences* **2020**, *17*, 345–359. https://doi.org/10.5194/bg7-345-2020.
6. Worku, M.A. Climate Change Mitigation in Agriculture and Forestry Sectors in Ethiopia: A Review. *Agric. For. J.* **2020**, *4*, 11–18.

7. Hu, Q.; Liu, T.; Jiang, S.; Cao, C.; Li, C.; Chen, B.; Liu, J. Combined Effects of Straw Returning and Chemical N Fertilization on Greenhouse Gas Emissions and Yield from Paddy Fields in Northwest Hubei Province, China. *J. Soil Sci. Plant Nutr.* **2020**, *20*, 392–406. https://doi.org/10.1007/s42729-019-00120-0.
8. Comeau, L.-P.; Lai, D.Y.F.; Cui, J.J.; Hartill, J. Soil Heterotrophic Respiration Assessment Using Minimally Disturbed Soil Microcosm Cores. *MethodsX* **2018**, *5*, 834–840. https://doi.org/10.1016/j.mex.2018.07.014.
9. Bharali, A.; Baruah, K.K.; Baruah, S.G.; Bhattacharyya, P. Impacts of Integrated Nutrient Management on Methane Emission, Global Warming Potential and Carbon Storage Capacity in Rice Grown in a Northeast India Soil. *Environ. Sci. Pollut. Res.* **2018**, *25*, 5889–5901. https://doi.org/10.1007/s11356-017-0879-0.
10. Zerssa, G.W.; Kim, D.-G.; Koal, P.; Eichler-Löbermann, B. Combination of Compost and Mineral Fertilizers as an Option for Enhancing Maize (*Zea mays* L.) Yields and Mitigating Greenhouse Gas Emissions from a Nitisol in Ethiopia. *Agronomy* **2021**, *11*, 2097.
11. FDRE Forest Development, Conservation, and Utilization Proclamation. *Proclamation No. 1065/2018*; Federal Democratic Republic of Ethiopia: Addis Ababa, Ethiopia, 2018. [Paper Reference 2].
12. Ogundijo, D.; Adetunji, M.; Azeez, J.; Arowolo, T.; Olla, N.; Adekunle, A. Influence of Organic and Inorganic Fertilizers on Soil Chemical Properties and Nutrient Changes in an Alfisol of South Western Nigeria. *Int. J. Plant Soil Sci.* **2015**, *7*, 329–337. https://doi.org/10.9734/IJPSS/2015/18355.
13. Tiwari, A.; Singh, N.B.; Kumar, A. Effect of Integrated Nutrient Management (INM) on Soil Properties,Yield and Economics of Rice (*Oryza sativa* L.). **2017**, *10*, 640–644, doi:doi.org/10.13140/RG.2.2.10695.19366.
14. Abraham, R.R.; Joseph, K.; Joseph, P Effect of Integrated Nutrient Management on Soil Quality and Growth of Hevea Brasiliensis during the Immature Phase. *Rubber Sci.* **2015**, *28*, 159–167.
15. Zenawi, G.; Mizan, A. Effect of Nitrogen Fertilization on the Growth and Seed Yield of Sesame (*Sesamum indicum* L.). *Int. J. Agron.* **2019**, *2019*, 5027254. https://doi.org/10.1155/2019/5027254.
16. Zolla, G.; Heimer, Y.M.; Barak, S. Mild Salinity Stimulates a Stress-Induced Morphogenic Response in Arabidopsis Thaliana Roots. *J. Exp. Bot.* **2010**, *61*, 211–224. https://doi.org/10.1093/jxb/erp290.