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NITROGEN SOURCES AND THEIR EFFECTS ON NITROUS OXIDE EMISSION AND MAIZE YIELD IN WESTERN KENYA

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Abstract
This study assessed the effect of applying inorganic or organic sources of nitrogen, or their combination, on N_2O emission, maize yield and Nitrogen Use Efficiency (NUE) at Nyakach, a lowland and Soin, a highland in western Kenya. A randomized complete block design, was used with six treatments; a control with no N input, urea applied alone at 30 or 100 kg N ha^{-1}, sole manure at 30 kg N ha^{-1},a combined application of manure and urea, each providing 50 kg N ha^{-1}, and NPK (17:17:17) applied at 100 kg N ha^{-1}. N_2O emissions were quantified by gas chromatography. The cumulative seasonal emissions were low and ranged from of 0.11 (control) to 0.31 kg N_2O-N ha^{-1} (urea100 kg N ha^{-1}). N_2O emission was higher from urea and NPK treatments than from the urea + manure treatments at the same application rate of 100 kg N ha^{-1}. At Nyakach there were no treatment effects on maize grain yield but in Soin, the grain yield ranged from 1.4 (control) to 4.0 ton ha^{-1} (manure + urea). Overall, sole manure (30 kg N ha^{-1}) had the highest (55%) NUE while urea (100 kg N ha^{-1}) had the least (14%). However, at the highest N rate of 100 kg N ha^{-1}, combined application of manure and urea had higher NUE than comparable treatments of urea and NPK fertilizer.The results suggest that it may be possible to improve the NUE, reduce the overall contribution of N fertilizer application to N_2O emissions and increase maize yield by combining the organic and inorganic N sources.

Key Words: *Greenhouse gases, Manure, Nutrient use efficiency, Maize yield*

Introduction

Nitrogen is an essential nutrient for crop production but its availability remains globally the most limiting plant growth factor (Vanlauwe *et al.,* 2011). In Kenya, soil N deficiencies limit maize yields in many farmers' fields with yield gaps of up to 5.0 ton ha^{-1} between N deficient and adequately fertilized farms being reported (Tittonel *et al*., 2008). There is therefore an urgent need to increase use of N inputs in order to realize higher maize yields and attain food security. Strategies of replenishing soil N are well documented (Okalebo *et al.,* 2006; Sanginga and Woomer, 2009). These include application of inorganic or organic N fertilizers, applied either alone or in combination. Inorganic fertilizer N is readily available for crop uptake and often gives high yields when timely applied and at the correct rates (Fageria, 2009). High rates of inorganic N fertilizer are however likely to reduce nitrogen use efficiency

(NUE) (Hickman *et al.,* 2014; Benincasa *et al*., 2011) and increase emissions of N_2O, greenhouse gas (GHG) (Pires *et al,* 2015).

Locally available organic resources such as cattle manure have been reported to produce lower emissions of GHGs such as N_2O compared to inorganic-N fertilizers (Mapanda *et al.,* 2011) and hence are likely to have a higher NUE. However, their use is limited by their often poor quality and low quantities available on most farms to meet nutrient demands for most crops (Rufino *et al*., 2011). Technologies that combine organic and inorganic N sources have therefore been suggested as better options in increasing NUE by providing a more balanced supply of nutrients (Palm *et al.,* 1997; Palm *et al*., 2001; Schoebitz and Vidal, 2016) but there is still paucity of information on the effects of nitrogen sources on GHG emission, maize yield and NUE in Kenya. The objective of this study was therefore to assess the effects of inorganic N fertilizer and cattle manure when applied alone or in combination on N_2O emissions, maize yield and NUE in western Kenya.

Materials and Methods

Study Area

The study was conducted from April to August in 2014 at two sites, Nyakach and Soin, in western Kenya (Figure 1). Nyakach is a lowland, at an altitude of 1226 m above sea level, 0.30° S latitude and 34.9° E longitude. It has a mean annual rainfall of 1,100 mm. The soil at this site is a Vertisol with a pH of 6.6, 1.2 % C, 0.11 %N and bulk density of 1.3 g cm^{-3}.

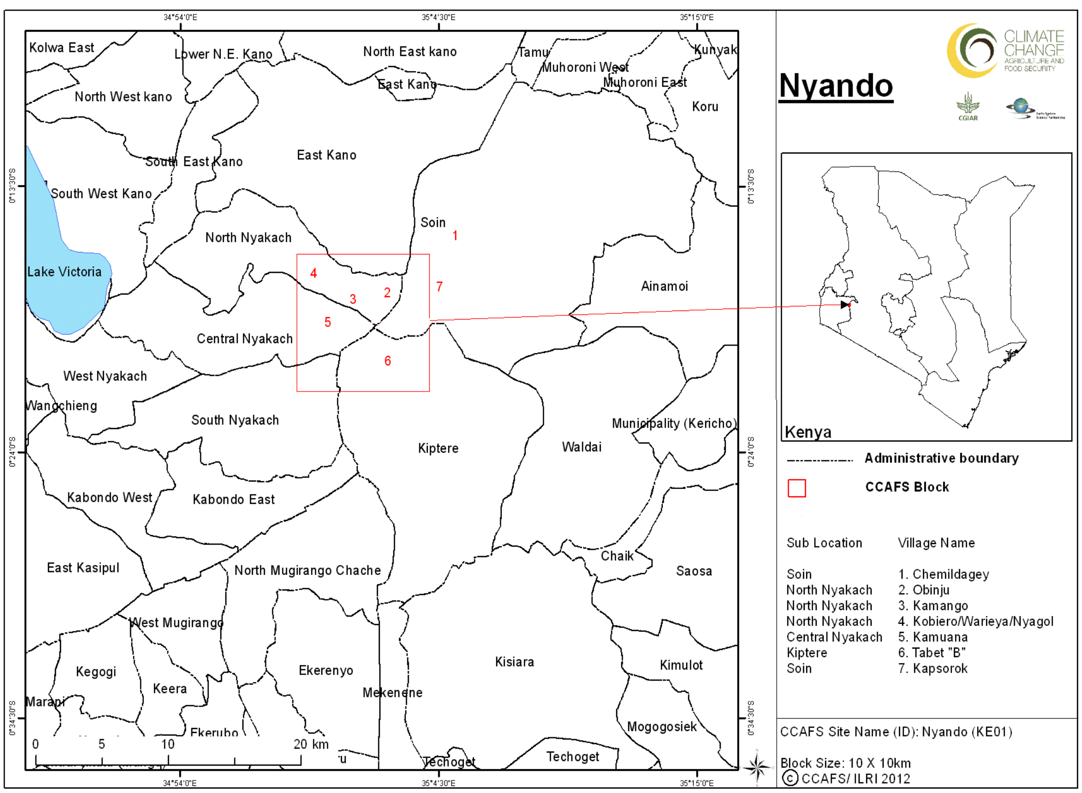

Fig. 1: The study area in western Kenya

Soin is a highland at 1676 m above sea level, 0.35° S latitude and 35.0° E longitude with a mean annual rainfall of 1,700 mm. The soil at this site is a Nitisol with pH of 5.6, 2.3 % C, 0.24 %N and bulk density of 1 g cm^{-3}

Experimental Layout and Management

A randomized complete block design with three replications was used. The treatments at both sites consisted of a control (no N input), manure or urea each applied alone at N rate of 30 kg N ha^{-1}, urea applied alone at 100 kg N ha^{-1}, urea at 50 kg N ha^{-1} combined with manure at 50 kg N ha^{-1} to give a total N rate of 100 kg ha^{-1} and NPK (17:17:17) applied at 100 kg N ha^{-1}. Plot sizes of 7.5 x 7.5 m were used. All the nutrient inputs were spot applied at planting time. Maize was planted at spacing of 75 cm by 30 cm and managed using the recommended agronomic practices. It was harvested at physiological maturity and the grain yield determined.

Gas Sampling and Analysis

Soil gases were sampled using the gas pooling technique (Arias-Navarro *et al.,* 2013) by trapping them using chambers located within the plots. The emitted gas in each chamber was collected into 10 ml glass vials using a 60 ml-graduated syringe. The chambers had a septum through which the gas was sampled, a fan and temperature sensors. The initial temperatures of the chambers were recorded and immediately closed by using clips and the gas sampled by using a 60 ml-graduated syringe and immediately transferred into 20 ml glass vials fitted with crimp seals. By using an exhaust needle and the sample syringe needle, a vial was flushed up to 20 ml mark with sample gas, the exhaust needle removed and the vial filled with the remaining gas to create an overpressure. The process was repeated after 15, 30 and 45 minutes. The vials were transported to the laboratory where the samples were analyzed for N_2O by chromatography within four days. N_2O fluxes were calculated by the rate of change in concentration over time in the chamber headspace. Cumulative seasonal emissions were estimated using trapezoidal integration between sampling dates.

Determination of Nitrogen Use Efficiency

The N content in the grain, stover and core were determined using a CN analyzer elemental combustion system. The results of plant samples analysis were used to determine NUE as measured by the apparent nitrogen recovery (ANR) using the following equation:

$$\% \text{ ANR} = (N_T - N_C) / N_R \times 100$$

Where N_T and N_C are the nutrient uptakes by the treatment and control, respectively, and N_R is the rate of N applied.

Data Analysis

Data on N_2O emission and maize yield were subjected to analysis of variance ($p < 0.05$) and the least significant difference of means (LSD) used to separate means.

Results

Rainfall, Soil Moisture and Temperature

Soin (highland) received a higher amount of seasonal rainfall (790 mm) than Nyakach (lowland) (552 mm) during the four months of the experiment (Figure 2). The soil moisture ranged from 13.4% to 43% at Soin and 9.6% to 64.8% at Nyakach (Figure 2). The greatest soil moisture content was obtained during weeks 5 and 6 at both sites, when rainfall amount was highest. The lowest soil moisture content was recorded in weeks 7 and 8 when rainfall was at the minimum at both sites. The variations in soil moisture during the season were closely correlated to seasonal rainfall patterns (r^2=0.776 and 0.867 for Soin and Nyakach respectively). The soil temperature at a depth of 15 cm ranged from 17.6 to 25.8°C with a mean of 22.0°C at the Soin and 23.0 to 28.9°C with a mean of 25.3°C at Nyakach. The atmospheric temperatures in Soin were considerably higher (average daily minimum 16.0°C and maximum 30.9°C) than in the highland (average daily minimum 13.0°C and maximum 27.2°C).

Nitrous oxide Emission

Mean N_2O fluxes ranged from 4.5 to 11.5 µg N_2O-N m^{-2} $hour^{-1}$ at Soin and 3.8 to 10.8 µg N_2O-N m^{-2} $hour^{-1}$ at Nyakach (Table 1) with the control treatment having the lowest and urea (100 kg N ha^{-1}) the highest fluxes at both sites. Only urea (100 kg N ha^{-1}) and NPK (100 kg N ha^{-1}) gave significantly higher mean fluxes than the control at both sites.

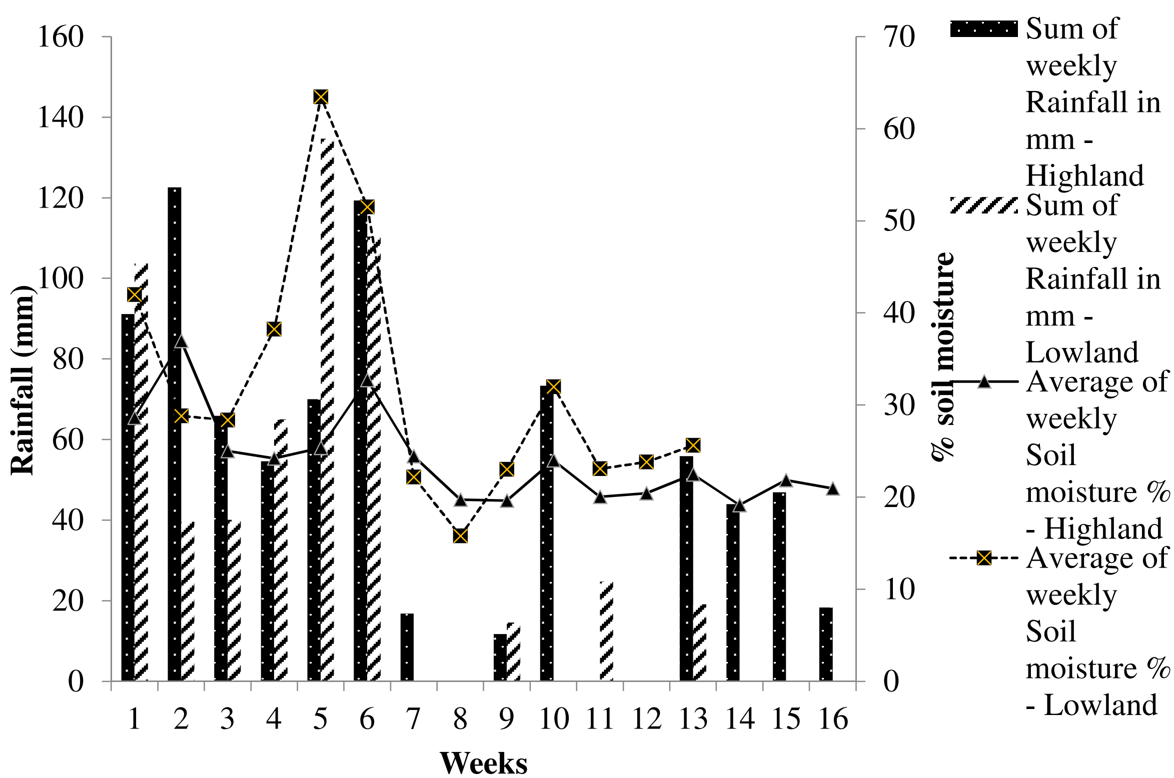

Fig. 2: Amount of rainfall and changes in soil moisture content at the experimental sites.

Table 1: Average N_2O fluxes (µg N_2O-N m^{-2} hr^{-1}) at Soin and Nyakach

Treatments	Soin	Nyakach
Control	4.5	3.8
Manure (30 kg N ha^{-1})	6.5	5.4
Urea (30 kg N ha^{-1})	6.6	5.8
Urea (100 kg N ha^{-1})	11.5	10.8
Urea+ Manure (100 kg N ha^{-1})	6.8	6.2
NPK (100 kg N ha^{-1})	11.0	10.0
LSD	4.2	3.7

The cumulative emissions of N_2O estimated over a period of 112 and 91 days for Soin and Nyakach respectively are shown in Figures 3 and 4. The treatment that received urea (100 kg N ha^{-1}) produced the highest seasonal emissions of 0.31 kg N_2O-N ha^{-1} and 0.30 kg N_2O-N ha^{-1}at Soin and Nyakach respectively. At the same rate of 100 kg N ha^{-1}, the cumulative emissions followed the order urea > NPK > urea + manure at both sites.

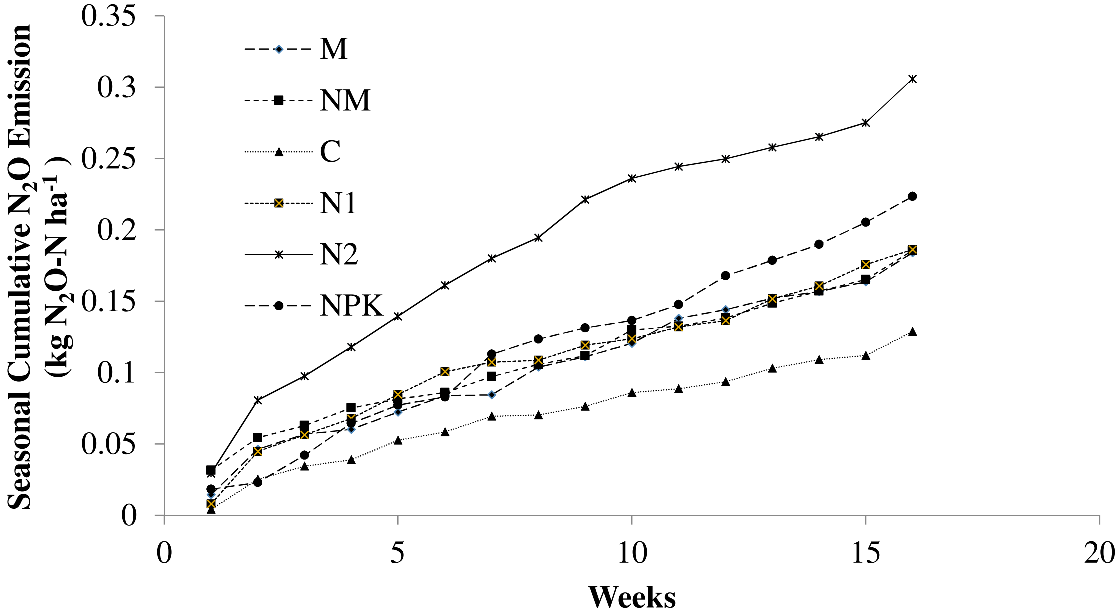

Fig. 3: Seasonal cumulative N_2O emissions Soin
C= Control; M=Manure (30 kg N ha^{-1}; N1=Urea (30 kg N ha^{-1}); N2=Urea (100 kg N ha^{-1} ;) NM=Urea+ Manure (100 kg N ha^{-1}) and NPK (100 kg N ha^{-1}

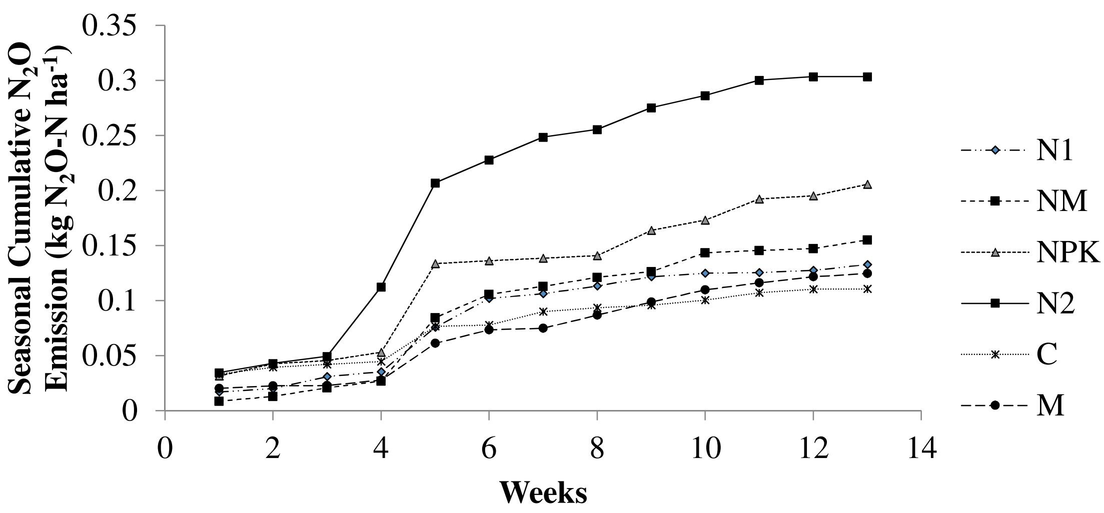

Fig. 4: Seasonal cumulative N_2O emissions at Nyakach
C= Control; M=Manure (30 kg N ha^{-1}; N1=Urea (30 kg N ha^{-1}); N2=Urea (100 kg N ha^{-1} ;) NM=Urea+ Manure (100 kg N ha^{-1}) and NPK (100 kg N ha^{-1})

Maize Yield

The Nyakach site had lower yields compared to Soin (Table 2). There were no significant treatment effects on maize yields at Nyakach. At Soin, the grain yields ranged from 1.4 ton ha^{-1} (control) to 4.0 ton ha^{-1} (urea + manure). Manure (30 kg N ha^{-1}) gave significantly higher maize yield compared to urea (30 kg N ha^{-1}). However, there was no significant difference in yield between urea applied alone, at 30 or 100 kg N ha^{-1}, and the control. Manure applied alone (30 kg N ha^{-1}), urea + manure (100 kg N ha^{-1}) and NPK (100 kg N ha^{-1}) gave significantly higher yields than urea applied at 30 or 100 kg N ha^{-1} but the yields among these three treatments did not differ significantly.

Table 2: Effect of nitrogen sources on maize yield (ton ha^{-1}) at Soin and Nyakach

Treatments	Soin	Nyakach
Control	1.4	0.6
Manure 30 kg N ha^{-1}	3.2	1.8
Urea 30 kg N ha^{-1}	1.8	0.9
Urea 100 kg N ha^{-1}	2.1	1.4
Urea + Manure (100 kg N ha^{-1})	4.0	2.0
NPK (100 kg N ha^{-1})	3.8	1.7
LSD	1.0	2.0

Nitrogen Uptake and Nitrogen Use Efficiency

There were no significant treatment effects on N uptake at Nyakach but the N uptake trends at Soin were similar to the grain yields (Figure 5). The sole addition of cattle manure at 30 kg N ha^{-1} resulted into 4 times the amount of total N-uptake than the control at Soin. However, the additional of urea at the same rate did not significantly increase the N-uptake compared with the control. The combined application of cattle manure and urea produced the highest N-uptake but this was significantly not better than the uptake by the NPK treatment. The N-uptake of maize when manure applied alone at 30 kg N ha^{-1} was greater than that of urea applied at 100 kg N ha^{-1}.

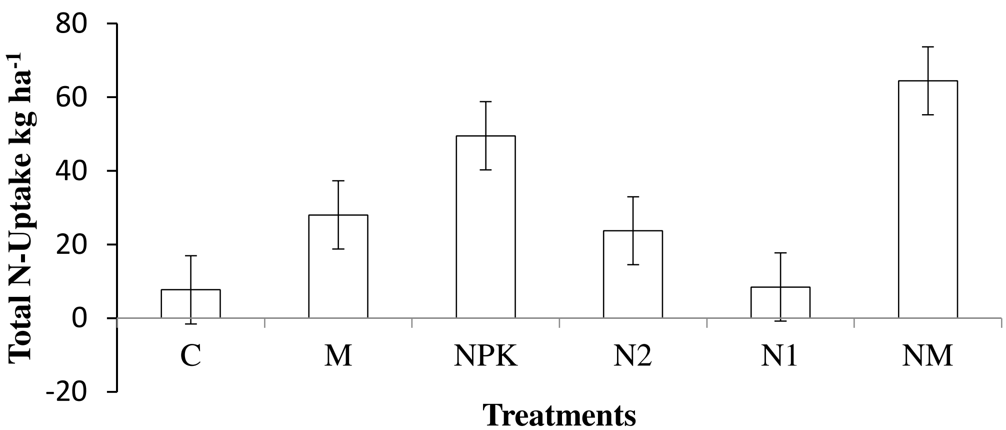

Fig. 5: Treatment effect on N-uptake at the highland site

C= Control (no fertilizer); M=Manure 30 kg N ha^{-1}; N1=Urea 30 kg N ha^{-1}; N2=Urea 100 kg N ha^{-1}; NM=Urea+ Manure (50 kg N ha^{-1} each) and NPK= NPK (17:17:17) 100 kg N ha^{-1}

Since there were no treatment effects on N uptakes at Nyakach, the NUE at this site was not determined. At Soin, manure (30 kg N ha^{-1}) gave the highest ANR (55%) while urea (100 kg N ha^{-1}) had the lowest (14%).

Table 3: The apparent nitrogen recovery at Nyakach

Treatments	ANR (%)
Control	---
Manure 30 kg N ha^{-1}	55
Urea 30 kg N ha^{-1}	16
Urea 100 kg N ha^{-1}	14
Urea+Manure (100 kg N ha^{-1})	43
NPK 100 kg N ha^{-1}	36

Discussion

Effects of N Sources and Rate on Nitrous Oxide Emission

The higher N_2O fluxes that were obtained at Soin compared to Nyakach are likely due its higher soil nitrogen status. Though data are scarce, Todd *et al.* (2016) reported that N_2O fluxes from degraded soils with low N may be less than their fertile counterparts. The emissions found in this study were within the ranges of -0.1 to 1.8 kg N_2O-N ha^{-1} reported by Pelster *et al.* (2017) on smallholder farms in western Kenya and Mapanda *et al.* (2011) in Zimbabwe and confirm that nitrous oxide emissions on smallholder farms are low. The failure of manure and urea at 30 Kg N ha^{-1} to significantly increase N_2O emissions compared to the control at both sites is likely because of the low N rates used. Similar findings were reported by Pelster *et al.* (2017). The Significantly higher N_2O emissions at higher application rates of 100 kg N ha^{-1} of urea or NPK are to be expected. According to Qui *et al.* (2010), N_2O emissions are proportional to the amount of N added to soil.The relatively lower N_2O emissions from combined application of urea and manure is attributed to the higher NUE of this treatment.

Maize Yields

The higher maize yields obtained at Soin than Nyakach are attributed to the higher rainfall (790 mm) with a better distribution during the cropping season. The Nyakach site received lower rainfall (552 mm) and also experienced instances of high intensity rainfall over shot durations which interchanged with shot spells of drought. This led to cases of flooding and water stress which negatively affected the growth of maize. Consequently the treatment effects were not significant at this site. The higher yields from sole manure and integration of manure with urea compared to sole urea is likely due to the P content in the manure. This is confirmed by the better yield obtained in NPK than urea at the same rate of 100 kg N ha^{-1}. Soils in western Kenya are known to have simultaneous deficiencies of N and P (Opala *et al.,* 2010). In addition K is also deficient in some of the soils (Jama *et al.,* 1997) and could also have contributed to the better performance of NPK and manures. Higher maize yields with organic and a combination of organics with mineral fertilizer has also been reported in other studies (e.g. Fairhurst, 2012; Admas *et al.,* 2015; Ch'ng *et al*., 2019). It has been postulated that a combination of organic and mineral nutrient sources results into synergy and improved synchronization of nutrient release and uptake by plants leading to higher yields (Vanlauwe *et al.,* 2011; Lal and Stewart, 2014).

Nitrogen Use Efficiency

Manure applied alone at 30 kg P ha^{-1}had the highest NUE as reflected in the high ANR by maize. This is because organic matter improves soil physical, chemical and biological properties (Palm *et al.,* 2001; Mahmood *et al.,* 2017) hence creating a conducive environment for the plants to absorb N. In addition, a better balance of nutrients in manure has been reported (Mugwira *et al.,* 2010)) to largely account for its greater effectiveness than fertilizer and make such manure a viable alternative to chemical fertilizer.Nitrogen supplied by inorganic fertilizers is more susceptible to losses through leaching, erosion, denitrification and volatilization, all of which impact negatively on NUE (Roberts, 2008).

Conclusion and Recommendations

Although application of urea and NPK at 100 kg N ha^{-1} produced a significant increase in the emission of N_2O gas compared to combined application of urea and manure at the same rate, and urea and manure at 30 kg N ha^{-1}, they were still low compared to the global emissions and may therefore presently not be a major concern compared to nitrogen deficiencies. Integration of manure and urea resulted into higher yields than the application of either source alone, which was attributed to increased fertilizer use efficiency. Generally, our findings suggest that it may be possible to improve the NUE, reduce the overall contribution of N fertilizer application to N_2O emissions and increase maize yield by combining the organic and inorganic N sources.

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