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Manure nitrous oxide emissions from smallholder farms in East Africa

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Extended Abstract

Due to improved living conditions and health provision, countries in East Africa experience rapid population growth and consequently a rising demand for food and nutrition [1]. To ensure food and nutrition security, an increase in the productivity of livestock products such as milk, meat or eggs is urgently required in this region. In addition, rural household income in East Africa (and most of sub-Saharan Africa), which are dominated by smallholder (<2 ha) farming systems, depends on livestock production (40-55 % contribution to household income and 26 % to dietary protein intake) [2]. These smallholder farmers supply >75 % of livestock products in the region [3]. In areas that are dominated by mixed crop-livestock systems, 50 % of the agricultural workforce are employed in the livestock sector, while in extensive drylands this figure can even exceed 90 % [1]. Thus, intensification of livestock productivity is not only important to ensure food and nutritional security, it also provides an important opportunity to improve smallholder farmers livelihoods.

At the same time, livestock manure is of great value as organic fertilizer for smallholder vegetable and crop production. However, this manure is also a source of greenhouse gases (GHGs) including nitrous oxide (N_2O), which has a global warming potential 298 times larger than that of carbon dioxide (CO_2) calculated over a 100-year period on a per mass basis and which also leads to stratospheric ozone (O_3) depletion [4]. In developing countries, livestock-related GHG emissions may contribute > 70 % of total agricultural GHG emissions [5]. Furthermore, because productivity in these countries is often low, GHG emission intensities (i.e. GHG emissions scaled per unit of product) are much higher compared to those from animal production systems in developed countries [6]. Therefore, methods for sustainable intensification of existing livestock systems (e.g. via improved manure management) that target improving food security as well as adaptation to and mitigation of climate change are urgently needed for East Africa.

Storage, management and application of animal manures are major contributors to N_2O emissions from livestock farming and are estimated to be responsible for 25 % of total GHG emissions from the agriculture, forestry and land-use (AFOLU) sector [5]. However, the numbers reported in national GHG inventories of East African countries are almost exclusively based on

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IPCC Tier 1 emission estimates, which use default emission factors (EFs) to scale GHG emissions from different sources in the agricultural sector to the national level [7,8]. The major caveat of this approach is that the currently available EFs were largely generated in developed countries and consequently reflect the characteristics of highly-industrialized farming operations such as high-producing animal breeds, year-round availability of high-quality animal feeds, and a high degree of mechanization. In East African smallholder farms, however, most of the on-farm work is based on manual labour, animals are mostly local, indigenous breeds, and animal feed is often of poor quality and not always available in sufficient quantities throughout the year [9]. Taken together, these factors affect the processes underlying GHG formation from animals and subsequently manure, and as a result, EFs that were developed for industrialized farming systems may not adequately represent the situation of East African smallholder farms. Thus, baselines of livestock GHG emissions in East Africa are most likely biased, which in turn could invalidate potential GHG mitigation practices. Given the projected growth of the livestock sector in East Africa and the commitment of East African countries (via National Determined Contributions – NDCs) to accurately report their national GHG emissions and sequentially to reduce these following the Paris Climate Agreement and the Sustainable Development Goal (SDG) 13 "Combat Climate Change", accurate Tier 2 baseline GHG emission estimates from smallholder farmers are necessary.

To close this knowledge gap, three experiments quantifying N_2O emissions originating from common manure management practices using local breeds and feeds representative for East Africa were conducted at ILRI's Mazingira Centre in Nairobi, Kenya. In the first experiment (1), an animal feeding trial using local Boran (*Bos indicus*) steers between 1-2 years old was conducted, where animals were fed one of three diets covering different levels of animal metabolic energy requirements (MERs). The levels tested were: 120 % MER (representative of the rainy season, where feeds are available in sufficient quantity and animals are growing), 100 % MER (intermediate treatment, animals are neither gaining nor losing weight), and 60 % MER (representing feed shortage as often occurring during the dry season, when animals lose weight). Animals were housed in individual pens, from which fresh manure was collected in the mornings and piled into heaps over a period of 7-10 days, until a heap size of 100 kg fresh manure (fresh weight – FW) was reached. N_2O fluxes were measured daily during the first 100 days and then three times per week for another 40 days using static opaque GHG chambers of 1 m^3 size that covered the entire heap. Gas samples were taken at 0, 4, 8, 12 and 24 minutes after chamber closure and were analysed directly after sampling in the laboratory by gas chromatography [10]. Following laboratory analysis, N_2O emissions were calculated by the concentration change over time and corrected for pressure and temperature using the ideal gas law [11].

Manure N_2O emissions were low at the start of the experiment but increased five days after reaching the full size of the manure heap and remained elevated for more than 35 days, after which they returned to baseline levels. Cumulative N_2O emissions (mean ± SE) over the 140-d experiment were significantly lower in the 100 % and 60 % MER treatments compared to 120 % MER, reaching 105.4 ± 16.0 (120 % MER), 47.8 ± 11.3 (100 % MER), and 35.7 ± 5.6 mg N_2O-N kg^{-1} DM (60 % MER). This was likely caused by lower nitrogen (N) concentrations and higher C/N ratios in manure of the below-MER treatments. Emission factors (% manure-N that is emitted as N_2O-N within the duration of our measurements) were 0.58 ± 0.11 % (120 % MER), 0.35 ± 0.10 % (100 % MER), and 0.31 ± 0.06 % (60 % MER), the last two being lower than the IPCC default factor for solid manure storage of 0.5 % [7].

The second experiment encompassed a similar animal feeding trial using Boran steers with the difference that the animals were fed *ad libitum* on one of three tropical forage grasses that are commonly available in East Africa: Napier grass (*Pennisetum purpureum*), Rhodes grass (*Chloris gayana*), and Brachiaria grass (*Brachiaria brizantha* cv. Xaraés). Similar to the first experiment, fresh manure was incubated in heaps of 100 kg FW, and N_2O was measured over a period of 140 d. Cumulative N_2O fluxes over the course of the observation period were 46.9 ± 1.1 (Brachiaria), 47.5 ± 12.8 (Rhodes), and 75.3 ± 9.1 mg N_2O-N kg^{-1} DM (Napier). Emission factors were similar among treatments, averaging 0.49 ± 0.07 %, which is in line with the IPCC default EF for solid storage (0.5 %).

In the third experiment, reported elsewhere [10], manure was collected from local (Boran) and imported (Friesian, *Bos taurus*) steers, and 1 kg of manure FW was deposited on pasture, representing an average manure deposition event of a grazing animal. N_2O emissions were measured for 28 days after deposition, with manual irrigation 1-2 weeks after application, and this was repeated three consecutive times. N_2O emissions from deposited manure were low and only peaked after rewetting events. Cumulative manure N_2O emissions from Boran (2.3 ± 1.6 mg N_2O-N kg^{-1} FW) and Friesian (5.9 ± 3.1 mg N_2O-N kg^{-1} FW) were not significantly different, and N_2O EFs were much lower (0.1 % for Friesian and 0.2 % for Boran manure) than the IPCC default EF for manure deposited on pasture (2 %) [7]. This can – similarly to experiments 1 and 2 – be attributed to low manure quality (C/N of 45.3 ± 2.4 for Friesian and 45.5 ± 2.1 for Boran).

In summary, our measured *in-situ* values show that the default IPCC N_2O EFs for solid manure storage and manure deposition on pasture might be too high to represent East African farming systems. The predominant reason for lower N_2O emissions and N_2O EFs are likely the low manure C/N values occurring due to feeding of animals on poor-quality diets and reduced feed availability during dry seasons [12]. Thus, default EFs overestimate manure-derived N_2O emissions from East African countries that experience similar conditions as simulated in these trials, calling for an update of the IPCC EFs for solid stored livestock manure within this region [13]. These updated Tier 2 EFs as presented in this study should also consider different livestock farming systems (e.g. mixed crop-livestock systems, pastoral grazing systems), feed and forage types, feed availability, and agro-ecological zones in the future to increase the robustness of region-wide GHG emission estimates from livestock farming and to identify evidence-based mitigation strategies.

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