Nitrous oxide emission from livestock production

*¹ Nasiru, A., ² Suleiman, M. S. ² Idris, A. A., ³ Jinjiri, A., ⁴ Aminu, M. U., ⁵ Gilima, Z. S. and ⁶ Jibrin, M. J.

¹Department of Animal Science, Faculty of Agriculture, Bayero University Kano, Nigeria

²Department of Agricultural Economics and Extension, Faculty of Agriculture, Bayero University Kano, Nigeria

³Rabiu Musa Kwankwaso College of Advance and Remedial Studies Tudun Wada, Kano

⁴Department of Fisheries and Aquaculture, Faculty of Agriculture, Bayero University Kano, Nigeria

⁵Department of Crop Protection, Faculty of Agriculture, Bayero University Kano, Nigeria

⁶Department of Soil Science, Faculty of Agriculture, Bayero University Kano, Nigeria

*Corresponding author: nasirua4601@buk.edu.ng

Abstract

Livestock production provides food and raw materials in addition to being means of livelihoods to millions of people. However, their production is associated with pollution among which is greenhouse gas (GHG) emissions. Livestock contributes 80% of the total GHG emission from agricultural sector. These emissions are originated from enteric fermentations and manure management. Emissions from manure management are mostly Nitrous oxide. Five (5) sources of N_2O emission from livestock were identified and are dung and urine from grazing animals deposited in pastures, indirect sources, animal wastes in stables and storages, application of animal wastes to land and burning of dung with emission proportion of 41, 27, 19, 10 and 3% respectively. IPCC developed methods for estimation N_2O emission designated as Tier 1, 2 and 3 respectively. Using Tier 1 method a total of 453.027 gigagrams of N_2O were emitted from livestock, considering class of livestock ruminant dominated the emission with cattle alone emitted 47.83% of the total emission. Based on regions, Asia produces the highest emission from N_2O with 51% in the year 2016. Tier 3 method can be used to get a relative accurate measurement of the emission as well as GLEAM model. Mitigation options should be explored in order to minimise GHG emission and environmental pollution from livestock as well as nutrients losses which translate to increase cost of production.

Keywords: livestock; nitrous oxide; emission; GHG; ruminant

Émissions d'oxyde nitreux provenant de la production animale

Résumé

La production animale fournit de la nourriture et des matières premières en plus d'être un moyen de subsistance pour des millions de personnes. Cependant, leur production est associée à une pollution dont les émissions de gaz à effet de serre (GES). L'élevage contribue à 80% des émissions totales de GES du secteur agricole. Ces émissions proviennent des fermentations entériques et de la gestion du fumier. Les émissions provenant de la gestion du fumier sont principalement de l'oxyde nitreux. Cinq (5) sources d'émission de N_2O provenant du bétail ont été identifiées et sont les excréments et l'urine d'animaux de pâturage déposés dans les pâturages, les sources indirectes, les déchets animaux dans les étables et les entrepôts, l'épandage de déchets animaux sur le sol et le brûlage des excréments avec une

proportion d'émission de 41, 27, 19, 10 et 3% respectivement. Le GIEC a développé des méthodes d'estimation des émissions de N₂O désignées respectivement de niveau 1, 2 et 3. En utilisant la méthode de niveau 1, un total de 453 027 gigagrammes de N₂O ont été émis par le bétail, compte tenu du fait que la classe des ruminants de bétail dominait l'émission, le bétail émettant à lui seul 47,83% de l'émission totale. Sur la base des régions, l'Asie produit les émissions de N₂O les plus élevées avec 51% en 2016. La méthode de niveau 3 peut être utilisée pour obtenir une mesure relativement précise des émissions ainsi que le modèle GLEAM. Des options d'atténuation devraient être explorées afin de minimiser les émissions de GES et la pollution environnementale du bétail ainsi que les pertes de nutriments qui se traduisent par une augmentation des coûts de production.

Mots-clés: bétail; protoxyde d'azote; émission; GES; ruminant

Introduction

The significant importance of livestock to the society cannot be over emphasized; among others they provide food, income, nutrients to the soil, employment, insurance, traction, clothing, raw materials to the industries etc (Herrero *et al.*, 2009). With increasing global human population and urbanisation, demands of animal products are predicted to increase by more than 50% by the year 2050. Therefore, food production (animal production inclusive) has to be intensified to ensure sustainably surplus and affordable supply. Increased animal production has the potential effects to the environment, usually perceived as negative (Chaudhry, 2008; Dijkstra *et al.* 2013a; Dijkstra *et al.* 2013b). Growing specialisation of agricultural sectors has left modern livestock producers with a surplus of on-farm nutrients in the form of manure (Leytem *et al.* 2013). Ruminant are important source of meat and milk. Ruminant production is associated with manure production. Excreta of undigested and unutilised nutrients from ruminants are released into the environment in form of faeces and urine (Tamminga, 1992). Nutrients losses may exceed the carrying capacity of an area and posed an environmental challenge. Poorly managed manure contributes to air pollution through odour and ammonia gasses as well as greenhouse gas emission through methane and nitrous oxide, soil pollution through

heavy metals accumulation as well as eutrophication of surface and underground water. All these result to loss of human health, biodiversity, climate change, acidification and ecosystem degradation (Menzi *et al.*, 2010). Manure production from ruminant is unavoidable. High manure production is mainly from an intensive ruminant production, high stocking density, and or from over-feeding nutrients. Without efficient management it causes environmental pollution and health hazards. The nature and compositions of ruminant manure are functions of physiological status of the animal, type and composition of animal diet and farm management practice (Mathot *et al.*, 2012). Ruminant has the highest contribution to environmental pollution among livestock (Zervis and Tsiplakou, 2012). Increase of greenhouse gases (GHGs) emission in the atmosphere is of great environmental concern, as they play a vital role in global warming (Yang *et al.* 2003).

Agriculture is major source of GHG emissions contributing to air pollution and climate change (Gac *et al.* 2007). Directly and indirectly, livestock production contributes 18% of global greenhouse emission (Steinfeld, 2006). Livestock contributes to climate change through emissions of carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O) into the atmosphere. Rojas-Downing *et al.* (2017) reported that livestock contribute

44%, 53% and 5% of global anthropogenic CH₄, N₂O and CO₂ respectively. Nitrous oxide is present in atmosphere in very small amounts. However, it is an important greenhouse gas as it has global warming potential of 310 CO₂-equivalent over 100-year time horizon compared with CH₄ with global warming potential of 34 CO₂-equivalent (FAO, 2006). The CH₄ and N₂O emissions are of environmental concern, because of their global warming potentials are 25 and 298 times than that of CO₂ respectively (IPCC, 2007). The GHG emissions from animal agriculture are dominated by emissions from ruminants. Ruminant caters for 80 percent of the livestock sector emission, emission from beef and milk production represents 35 and 30% of livestock sector emission. Buffalos and small ruminants have lower contribution of 8.7 and 6.7 percent respectively of the sector emission (Opio *et al.* 2013). Directly, GHG emissions from livestock originate from enteric fermentations and manure management. While indirect emissions result from manure application to soil, other indirect emissions include deforestation, desertification, and release of carbons from cultivated soils due to expansion of livestock husbandry (Gac *et al.* 2007; Sejian *et al.* 2015).

The N₂O emissions from agriculture are from three distinguished sources. The sources are: (i) emissions from agricultural soils, (ii) emissions from animal production, and (iii) N₂O emissions induced by agricultural activities (Mosier *et al.*, 1998). Livestock activities contribute substantially to the emission of nitrous oxide, the most potent of the three major greenhouse gases. They contribute almost two-thirds of all anthropogenic N₂O emissions, and 75–80 percent of agricultural emissions. Current trends show that this level will substantially increase over the coming decades (FAO, 2006).

Wastes from animal production systems contribute as much as 30–50% to the global N₂O emissions from agriculture. Oenema *et al.* (2005) identified five sources of N₂O emission from livestock which includes dung and urine from grazing animals deposited in pastures, indirect sources, animal wastes in stables and storages, application of animal wastes to land and burning of dung with emission proportion of 41, 27, 19, 10 and 3%, respectively.

Livestock global distribution and manure production

The ruminant sector comprises cattle, sheep and goat, and buffalo. The global ruminant population in 2016 was estimated to be 3.850 billion (FAOSTAT, 2018), with cattle making up 38.30 percent, sheep and goat 56.52 percent and buffalo with 5.18 percent. Opio *et al.* (2013) reported that in the ruminant sector, the cattle are the most important: contributing about 79% (64million tonnes) and 83% (600 million tonnes) of total meat and milk production from ruminants. Other ruminant products constitute a relatively small share of globally produced ruminant meat and milk, about 17 and 4% respectively. Ruminants are mainly reared in either grazing or mixed systems and the relative global importance of mixed systems compared with grazing systems is reflected by the fact that about 73 percent of all ruminants are reared in mixed farming systems. Agro-ecological conditions determine the characteristics of ruminant production. An estimate of relative importance of meat and milk production within the Agro-ecological zones varies between cattle, buffalo, and small ruminants. Temperate zones contribute 50 and 38% of the milk and beef compared with 21and 33% from humid zones and 29% for both meat and milk from arid zones. However, arid zones contribute the bulk of milk and meat production from small ruminants and buffalo; contributing 69 and 52% of small ruminant milk and

meat and 84 and 70% of buffalo milk and meat. The humid and temperate zones contribute 12 and 18% of small ruminant milk and 18 and 29% of the meat (Opio *et al.* 2013).

The monogastric sector comprises pigs and chickens. The global pig population in 2016 was estimated to be 981 million animals and the global poultry population in the same year was estimated to be almost 23 billion animals (FAOSTAT, 2018). There was up to 20percent increase in pig population compared with 1980 and nearly three times of poultry population compared with 1980, with chickens making up 90 percent, ducks' six percent, geese 2percent and turkeys' two percent (MacLeod *et al.* 2013). Pig production is practiced in all continents, except for some regions with cultural and religious taboos regarding the consumption of pork. Pigs are geographically concentrated in East and Southeast Asia, Europe and the Americas, these regions account for 95 percent of production. Regardless of production system practice pig production is also driven by factors such as proximity of output markets, infrastructures and cost of land (Robinson *et al.* 2011). Pig production worldwide ranges from subsistence-driven small-scale

production to specialized industrial farming. MacLeod *et al.* (2013) reported three different types of pig systems: backyard, intermediate and industrial, with respective contributions to total pig production of 19, 20 and 61%, respectively. Poultry production also ranges from extensive production system which supports livelihoods and supplying local markets to industrialized production systems of large- and medium-size feeding into integrated value chains. Three production systems were identified viz: backyard, broiler and layers production systems. Backyard systems can be found worldwide and contribute to 4 and 14% of total poultry meat and eggs production. Broiler production has increased tenfold over the past 50 years; they account for 81% of total poultry meat production. The production is concentrated in Latin America and the Caribbean, North America and East and Southeast Asia. Specialized layers production systems contribute to 86 percent of total egg production and to 6 percent of total poultry meat production. East and Southeast Asia dominate egg production, accounting for 42 percent (by mass) of eggs from layers (MacLeod *et al.* 2013). The relative distribution of the number of ruminants in different regions of the world is shown in Table 1.

Table 1: Distribution of selected livestock by region 2016

Regions	Class of livestock in (000) million						
	Buffaloes	Cattle	Chickens	Goats	Pigs	Sheep	Turkey
Africa	3.69	324.84	1, 903.55	387.67	36.63	351.58	0.03
Americas	1.38	522.00	5, 604.73	37.87	179.09	83.85	0.32
Asia	193.80	477.22	12,830.78	556.02	573.69	511.71	0.01
Europe	0.41	121.93	2, 239.72	16.97	186.99	131.06	0.09
Oceania	-	35.88	126.64	4.29	5.44	95.15	-

Source: FAOSTAT, 2018

N₂O in animal production

Three sources of N₂O emission within the animal production system were identified by Mosier *et al.* (1998). The source includes animals themselves, emission from manure management and emission from animal grazing. Direct emission from animals themselves losses is insignificant account for less than one percent, therefore, it does not count in the emission estimate. Nitrogen in faecal matter is predominantly from undigested feed, microbial and endogenous origin; however, urea is the main N in urine. In manure, nitrogen is lost as ammonia or nitrous oxide. Volatilisation is the major pathway for Nitrogen loss as ammonia. Emissions can be due to manure exposure to atmosphere in barns, during storage and application. NH₃ emitted from livestock facilities is mainly product of urinary urea breakdown. When mixed with faeces; urea is quickly converted into ammonia by the abundant urease activity present in the faecal matter. Depending on factors such as pH, air velocity, temperature and concentration of NH₄, a large proportion of NH₃ can be rapidly volatilised and lost to the environment (Hristov *et al.*, 2006). Another form of nitrogen loss from manure is through nitrous oxide emission, and this could be as much as 30-50% of global nitrous oxide emission. The feeds types and manure management largely determine the emission of N₂O. Manure possesses most elements require for stimulating soil nitrification and denitrification processes that result in N₂O formation. Nitrification and denitrification processes resulting in N₂O formation, depending on the amount and form of available N (NH₄⁺ or NO₃⁻), oxidation-reduction potential, degradable Carbon sources, and microbial population. Therefore, production of N₂O from soil or manure storages is immensely variable, difficult to measure and even more difficult to predict (Hristov *et al.* 2013). Most of the

N₂O comes from microbiological transformations (through Nitrification and denitrification) of N present in the urine and dung during storage and management and following application or deposition to land (Granli and Bøckman 1994). Nitrifying microorganisms produce N₂O by nitrification and by nitrifier denitrification. In nitrification, N₂O is produce during the oxidation of hydroxylamine (NH₂OH). During the process of nitrifier denitrification, nitrifiers reduce nitrite (NO₂⁻) via N₂O to dinitrogen (N₂). However, the process is supposed to be similar to denitrification, where nitrate (NO₃⁻) and NO₂⁻ are reduced via nitric oxide (NO) and N₂O to N₂ (Oenema *et al.* 2005). In denitrification process, N₂O normally escape to atmosphere if the rate of its production and consumption differ during the cycle. The quantity of N₂O produced during denitrification depends on the absence of molecular O₂, NO₃⁻ and metabolizable organic carbon. In addition to these microbiological sources, N₂O can be produce chemically in reactions involving NO₂ which has been produced biologically under acidic conditions. The chemical production (chemodenitrification) of N₂O is found to be the predominant source of N₂O under specific conditions. Because of the various sources of N₂O and environmental factors which tampers with its production processes, N₂O emissions from animal production systems have a highly stochastic nature (Oenema *et al.* 2005). The effect of grazing animals on N₂O emission are caused by two factors, these are the high N concentration in urine and excreta which are unevenly distributed over the grassland, and soil compaction by treading. Excreta from grazing animals is a major source of N₂O, contributing more than 10 percent to the global annual N₂O budget (Oenema *et al.*

1997). Urine patches and dung pats from grazing livestock (Chadwick *et al.* 2011), and compaction of soil by livestock trampling create hotspots for production and emission of N_2O (Mosier *et al.* 1998; Oenema *et al.* 1997). Treading by grazing animals compact the soil. Soil compaction decreases water infiltration and gas diffusivity, leading to a decreased Oxygen concentration and more anaerobic sites in which N_2O is produced (Hansen and Bakken, 1993). Factors such as stocking rate, soil type, moisture content and size and type of animal affect the magnitude of compaction (Oenema *et al.* 1997). Douglas and Crawford (1993) reported that N_2O emissions and denitrification rates were two-fold larger in compacted soil than in uncompacted grassland soil.

Estimating N_2O emissions

IPCC (2006) provide detailed guidelines for N_2O estimation. Nitrous oxide emission can be directly or indirectly during storage and treatment of manure before it is applied to land or otherwise used for feed, fuel, or construction purposes. Direct manure N_2O emissions occur through combined nitrification and denitrification. The emission of N_2O from manure during storage and treatment depends on the nitrogen and carbon content of manure, and on the duration of the storage and type of treatment. Indirect emissions are due to volatile nitrogen losses that occur primarily in the forms of ammonia and NO_x . Duration and temperature determine the proportion of excreted organic nitrogen that is mineralized to ammonia nitrogen during manure collection and storage. The detail and methods chosen for estimating N_2O emissions from manure management systems depends upon national circumstances in choosing a method accordingly. Five stages are used to estimate direct N_2O emissions from Manure Management: a) livestock population data from population Characterisation; b) use of

default values or develop the annual average nitrogen excretion rate per head ($N_{ex}(T)$) for each defined livestock species/category T; c) default values or determine the fraction of total annual nitrogen excretion for each livestock species/category T that is managed in each manure management system S ($MS(T,S)$); d) default values or develop N_2O emission factors for each manure management system S ($EF_{3(s)}$); and e) For each manure management system type S, multiply its emission factor ($EF_{3(s)}$) by the total amount of nitrogen managed (from all livestock species/categories) in that system, to estimate N_2O emissions from that manure management system. Then sum over all manure management systems.

Three different methods were identified based on the availability of information required for N_2O estimation. The methods are known as tier, and are:

Tier 1: The Tier 1 method entails multiplying the total amount of N excretion from all livestock species/categories in each type of manure management system by an emission factor for that type of manure management system. Emissions are then summed over all manure management systems. The Tier 1 method is applied using IPCC default N_2O emission factors, default nitrogen excretion data, and default manure management system data.

Tier 2: A Tier 2 method follows the same calculation equation as Tier 1 in addition with country-specific data for some or all of these variables. The use of country-specific nitrogen excretion rates for livestock categories would constitute a Tier 2 methodology.

Tier 3: A Tier 3 method utilizes alternative estimation procedures based on a country-specific methodology. Tier 3 uses mass balance approach which tracks nitrogen throughout the system starting with feed input through final use/disposal. Tier 3 methods should be well documented to

clearly describe estimation procedures.

Indirect emission also follows the same methods of estimating direct emission of N_2O with tier 1, 2 and 3 respectively.

Tier 1: The Tier 1 calculate the volatilisation in forms of ammonia (NH_3) and NO_x from manure management systems based on multiplication of the amount of nitrogen excreted (from all livestock categories) and managed in each manure management system by a fraction of volatilised nitrogen. N losses are then summed over all manure management systems. The Tier 1 method is applied using default nitrogen excretion data, default manure management system data and default fractions of N losses from manure management systems due to volatilisation.

Tier 2: Like direct N_2O emission from manure management, a Tier 2 method follow the same calculation equation as Tier 1 but include the use of country-specific data for some or all of these variables. National NH_3 emission inventories developed by some countries could be used for Tier 2 estimation of nitrogen volatilisation from manure management systems. A Tier 2 method require more detailed characterisation of the flow of nitrogen throughout the animal housing and manure management systems used in the country.

Tier 3: To reduce uncertainty of the estimates, a Tier 3 method could be developed with country-specific emission factors for volatilisation and nitrogen leaching and runoff based on actual measurements.

In 2009 FAO developed a model for assessing livestock emission known as global livestock emission assessment model (GLEAM). GLEAM is a process-

based model based on a Life Cycle Assessment (LCA) framework. It covers eleven (11) main livestock commodities at global scale, these are: meat and milk from cattle, sheep, goats and buffalo; meat from pigs; and meat and eggs from chickens. The model runs in a Geographic Information System (GIS) environment and provides spatially disaggregated estimates on greenhouse gas (GHG) emissions and commodity production by production system, thereby enabling the calculation of the emission intensity for any combination of commodity and farming systems at different spatial scales. The highest spatial resolution considered by the model is defined by squared cells of approximately 10 km x 10 km at the equator. Each cell represents a portion of the earth and has an attribute value associated with it, such as crop yields or animal numbers, being the smallest unit of information in the GIS environment (Robinson *et al.* 2014). GLEAM was developed to address the need for comprehensive tool to assess the interactions between livestock and environment.

Regional N_2O emission

IPCC (2006) Tier 1 emission factor for nitrous oxide emission was used for all the estimates in this study. In 2016, a total of 453.027 gigagrammes of N_2O (Table, 2) were emitted from livestock (FAOSTAT, 2018). Regional emissions and production profiles vary widely (Figure 1). Differences are explained by the respective shares of ruminants or monogastric in total livestock production, and by differences in emission intensities for each product, between regions. Asia has the largest proportion (51%) of N_2O emission.

Table 2: N₂O emission from selected livestock by region in 2016 (Gigagrammes)

Species	Regions				
	Africa	Americas	Asia	Europe	Oceania
Buffaloes	0.1256	0.0048	32.3029	0.5333	0.00
Cattle	5.7608	39.6964	110.5161	68.7739	6.3004
Chickens	1.1623	12.8438	23.1295	7.7947	0.3795
Goats	0.4569	0.0520	3.0785	0.1232	0.00
Sheep	1.1957	0.0547	6.6376	3.0605	0.00
Swine	16.0633	33.2609	54.4691	18.8526	0.6348
Turkey	0.0794	4.1595	0.0847	1.4255	0.0146

Source: FAOSTAT. 2018

Figure 1: Regional N₂O emission in 2016

Conclusion and recommendation

Nitrous Oxide emissions from livestock originate mostly from manure. Ruminants dominate the emission contributing over 50%. Cattle alone produce up to 47.83% of the total emission. In terms of regional N₂O emission Asia dominate with 51%. Tier 3 estimation method gives relatively accurate estimate of the emission. It is recommended that mitigation methods should be explored in order to reduce the emission as well as nutrients losses.

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Received: 28th October, 2020

Accepted: 5th January, 2021