Nitrogen Emissions from Agriculture and Livestock Sector, Among the Causes of Climate Change

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Abstract

This paper aimed to review the nitrogen emissions from the agriculture and livestock sector and their impact on the environment in the light of the actual global climate change picture. Emissions of ammonia, nitrogen oxide and nitrous oxide contribute to air pollution and global warming, while nitrates contribute to soil and water pollution. The agriculture and livestock sector is responsible for ammonia emissions representing approximately 80-90% of total anthropogenic emissions. Approximately 52% of total nitrous oxide emissions are coming from agriculture, and there is a strong correlation with the application rates of synthetic fertilizers. The nitrogen lost in the soil and water through leaching represents an important nitrate emission with negative effects on the environment due to acidification and eutrophication. As a result of human activity in recent decades, significant amounts of reactive nitrogen were released into the environment, disrupting the natural nitrogen cycle. The main causes of nitrogen emissions in the agriculture and livestock sector are represented by the excessive and inefficient use of synthetic fertilizers, manure management, including the low efficiency of nitrogen conversion into milk, meat and eggs by animals.

Keywords: agriculture, emission, livestock, nitrogen, nitrogen cycle, nitrogen efficiency

1. Introduction

The nitrogen cycle is one of the most important cycles on earth alongside the carbon cycle [1]. Approximately 425 Tg (Teragram=10^{12} grams) of reactive nitrogen (Nr) is fixed in the atmosphere annually, from atmospheric nitrogen (N_2) through natural processes in the oceans, on land and from human activities [2]. The nitrogen induced by human activity increased rapidly since the pre-industrial period (1850) when it represented 15% from total Nr fixed and reached 60% in 2005 [3, 4]. It resulted from global population growth that requested more food and energy, leading to higher nitrogen fertilizers and burning fossil fuels, increasing the amount of Nr lost in the environment. Consequently, many thresholds for human health and ecosystems have been altered, including air quality (smog, particulate matter, tropospheric ozone), drinking water (nitrates), eutrophication of fresh and ocean water, biodiversity loss or stratospheric ozone depletion [5].

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2. Agriculture and livestock nitrogen sources

Nitrogen (N) is one of the essential nutrients for all living life creatures on Earth, starting from bacteria, animals, plants and humans. It is the main type of gas present within the air that we breathe, representing ≈78% of the Earth atmosphere [6]. However, the N_2 cannot be utilized directly by plants. It needs to be transformed into reactive forms like ammonia (NH_3) or ammonium (NH_4^+) [1]. Nr is generally produced in natural conditions mainly by lightning, wildfires, and through the biological fixation of atmospheric N_2 [7]. This changed in 19 century by Fritz Haber, who developed a commercial method to produce synthetic NH_3. However, synthetic NH_3 as fertilizer in agriculture has been heavily used by the end of World War II. The use of synthetic NH_3 led to an unprecedented development of agriculture and the livestock sector. Global production of synthetic NH_3 increased significantly from approximately 13 million tons in 1961 to 119.4 million tons in 2019 [8]. Consequently, the crop yields increased significantly but at the same time has increased the proportion of N wasted per hectare, especially in heavily developed countries. About 50 countries that represent 75% of the world's population use ≈ 95% of the total synthetic NH_3 produced [9]. In the Netherlands since 1990, when data on the N balance were reported, according to Eurostat data, an average of 240 kg N/hectare was lost annually until 2017. Among the main causes are the excessive use and inefficiency of synthetic fertilizers. About 50% of the N applied to the soil as a fertilizer is not used by plants [4, 10]. The N that the plants have not fixed is transformed into the non-reactive form N_2 through the denitrification, but this process is accompanied by the formation of greenhouse gases and gases that deplete the stratospheric ozone layer [11].

Agriculture and livestock sectors are mainly responsible for ammonia emissions representing ≈80-90% of total anthropogenic emissions [12]. It is estimated that the contribution from the use of synthetic fertilizers is similar to that produced from the livestock sector due to the widespread use of urea [9]. In 2014, the global NH_3 emissions from the use of synthetic fertilizers and manure were estimated at 12.32 and 3.79 Tg N per year, respectively. China with 4.20 Tg N per year followed by India with 2.37 Tg N per year and America with 1.05 Tg N per year together contributed to over 60% of total global NH_3 emissions from agriculture from the use of synthetic fertilizers [13].

The atmospheric concentration of N_2O increased by approximately 23% compared to the pre-industrial period, from 270 ppbv (part per billion by volume) in 1750 to 332 ppbv in 2019. It is estimated that agriculture is also the main source of nitrous oxide (N_2O), accounting for about 52% of total global human-induced emissions [14]. The effect of N_2O emissions is closely correlated with application rates of fertilizers. In areas where small amounts of fertilizers are used, an increase in fertilizer rates would generate relatively small increases in N_2O emissions. Instead, declining application rates in areas where they are high, exceeding crop requirements, will significantly impact reducing N_2O emissions. The well-managed pastures used to feed ruminants represent about a quarter of the total land used for grazing, but it contributed more than three-quarters of the total N_2O emissions from grazing lands between 1961 and 2014. The pastures are accountable for more than one-third of the total anthropogenic N_2O [10].

Nitrogen lost through leaching in the form of nitrates (NO_3) is another source of Nr where agriculture has a significant impact. Several factors have been recognized to influence the accumulation and movement of NO_3 in the soil, including the dose and time of fertilizer application, the irrigation schedule and tillage practices. Given the current climate change in which periods of prolonged drought are followed by extremely heavy rainfall, an increase in the level of NO_3 lost by leaching is possibly expected. Approximately 19% of N applied to the soil in the form of synthetic fertilizers is lost by the leaching process [15]. In regions with abundant rainfalls, such as England, the percentage can reach ≈25%, according to research conducted by Allingham in 2002 [16].

Approximately 80% of the N obtained from agriculture is used in the livestock sector for feeding [17]. In 2010, the livestock sector used 76 Tg N in the form of synthetic fertilizers (55 Tg N) and biological N fixation (21,1 Tg N) to produce the feed for animals [9]. The animals convert the feed into meat, milk, eggs or wool, essential for human utilization. However, the efficiency of nitrogen conversion by animals is quite low, ranging from ≈5-45%, being higher in poultry and pigs than in ruminants [18].

Globally, the livestock sector represents about a third of the total N emissions induced by human activity. Uwizeye's estimates in 2010 that the livestock sector contributes ≈65Tg N annually to global human-induced N emissions. These emissions were in the form of NO_3 (29Tg N per year), NH_3 (26Tg N per year), NOx (8Tg N per year) and N_2O (2Tg N per year) and resulted from the use of synthetic N fertilizers and manure on the arable land and pastures, from the manure management as well as from the transport of N-rich products such as fodder, food and manure. The share of each of the total N induced by human activity varies from 23% in the case of nitrogen oxide emissions to ≈60% in the case of NH_3 (Table 1). The most important sources are represented by the emissions associated with feed production and manure management, with 44Tg N annually and 20Tg N annually, respectively [9].

Table 1. Livestock N emissions

Name	Annually emissions	% Anthropogenic
Nitrate (NO_3)	29Tg	39%
Ammonia (NH_3)	26Tg	60%
Nitrogen oxide (NOx)	8Tg	23%
Nitrous oxide (N_2O)	2Tg	32%

Source: Aimable Uwizeye - Nitrogen emissions in the livestock sector 2020

The livestock sector is the main contributor to NH3 emissions due to manure management practices. In the European Union (EU-28), approximately 75% of total NH_3 emissions are caused by manure management [19]. From the perspective of N losses through leaching, the direct contribution through manure is much lower (4.2Tg per year) than synthetic fertilizers for feed production (23.9 Tg per year). Regarding the NOx emissions, relatively high amounts include burning biomass, on-farm energy use, international transport of feed, and livestock commodities. It is estimated that the use of synthetic fertilizers and the biological fixation of N to produce animal feed have already reached the planetary boundary for N [9].

The production of eggs and meat from poultry together with the production of pork represents a third of the total global nitrogen emissions induced by humans, the remaining two-thirds being attributed to ruminants [9]. NUE (Nitrogen-use efficiency) is an indicator used to measure the nitrogen use efficiency of animals. It is calculated by estimating the percentage of nitrogen converted into animal products, such as milk, meat or eggs, from the total ingested nitrogen [20]. In monogastric species, NUE ranges between 30 - 45%, whilst in ruminants, this indicator varies between 15-40% with an average of about 25% [23-25]. In the case of ruminant animals, multiple factors could influence NUE. For example, the most important factors are represented by animal nutrition, management and animal-related factors such as body weight and genetics [21, 22]. Ruminants play a special role in human nutrition because they convert plants with low nutritional value or unusable by humans, such as cellulose and hemicellulose, into nutrient-rich food that humans can use [23]. However, ruminants are not the most effective when converting them to milk, meat or wool. It is estimated that globally their emissions reach approximately 46Tg N per year and represents 71% of the total N emissions of the livestock sector. Cattle and buffaloes reared for meat or milk production is the main categories responsible for these emissions. Some regions are more affected than others depending on the number of animals, the breeding system (grazing, stable or mixed). Regions such as Asia or South America are hot spots of N emissions. For example, in South Asia, 87% of the N emissions of the livestock sector are due to the large population of buffaloes and cattle with low productivity, while in the American continent, the cattle raised for meat and milk represent 72% [9].

3. Impact of Nitrogen emissions on the environment

Within recent decades as a result of human activity significant amounts of reactive nitrogen were released into the environment, disrupting the natural nitrogen cycle. Ammonia, nitrogen oxide and nitrous oxide contribute to air pollution and global warming, while nitrates contribute to soil and water pollution [5, 24].

Air pollution is currently the foremost important environmental risk to human health and is perceived as the second biggest environmental concern for Europeans after climate change [25]. The N emissions can negatively affect air quality due to the formation of NO_3 particulate matter (PM). Furthermore, NO_3 can react with NH_3 to form ammonium nitrate. At the same time, NH_3 can react with acid gases such as sulfuric acid or hydrochloric acid to form ammonium sulfate or ammonium chloride aerosols. The NOx emissions contribute to the formation of secondary organic aerosols via the oxidation of volatile organic compounds [5]. Specifically, NO_3, ammonium compounds and secondary organic aerosols are the major component of PM2.5 (particulate matter <2.5 μm in diameter) and are associated with adverse effects on human health [5, 19].

N_2O is a gas that results from the production of synthetic fertilizers and the denitrification process of NO_3 [11]. Denitrification is a natural process through which microorganisms transform the Nr, through oxidation reactions, in their non-reactive form, respectively N_2 [26]. Likewise, the carbon dioxide and methane, N_2O is a greenhouse gas that accumulates in the atmosphere contributing to global climate change. Although it represents only 6% of the total greenhouse gases, N_2O is the most potent with a global warming potential of approximately 290 times higher than carbon dioxide and has a higher atmospheric lifetime (116±9 years) [4, 8]. The atmospheric concentration of N_2O increased by about 23% compared to the pre-industrial period, with human activity representing about 43% of total N2O emissions. Agriculture is considered the main source of human induced N_2O emissions due to excessive and inefficient use of synthetic fertilizers. In this case, the contribution of the livestock sector through manure is lower. According to EIA (Energy Information Administration) report, in 2009 in the United States, 87% of total N_2O emissions attributed to agriculture was represented by synthetic fertilizers, while manure accounted for only 13% [27]. Also, N from manure has a low potential for pollution due to its presented form, compared to synthetic fertilizers [28].

Aquatic ecosystems, especially those populating freshwaters, are subject to acidification following the atmospheric deposition of nitrogen and reactive sulfur. Due to measures taken in recent decades, sulfur emissions dropped significantly, so Nr has become the main element in the acidification of ecosystems in many parts of Europe, North America and many developing countries [29]. HNO_3 and NO_3 are the main ones responsible for the acidification of polluted areas [30]. The effect of continuous acidification leads to changes in the organisms at the base of the trophic chain favoring acid-resistant macrophyte and phytoplankton species. Growing fish, as well as invertebrates, can also be particularly sensitive to acidification. Overall, both direct and indirect effects of acidification due to Nr have been reported throughout the trophic chain [29]. At the soil level, the N deposition leads to a significant decrease in the cation reserve, such as Na^+, Mg^{2+} and Ca^{2+}, and a gradual increase of Al^{3+} concentrations that exert a toxic effect on plants [31]. Lowering the soil pH simultaneously as its chemical alteration can negatively impact the abundance of the organisms in the entire underground trophic chain and weaken the links between underground and above-ground subsystems [32].

Increasing N emissions in soil and water leads to eutrophication and reduces biodiversity. Eutrophication represents the overloading of water sources, both fresh and salty, with nutrients, mainly nitrogen and phosphorus, which lead to excessive algae growth. The excessive growth of algae has negative effects on benthic aquatic fauna and flora by reducing the transparency of water and especially by reducing the concentration of dissolved oxygen in the water and the formation of toxic substances that occur after the decomposition of algae at the end of the life cycle [33]. In the coastal areas, excessive accumulations of Nr have led to the formation of dead zones such as the Gulf of Mexico or Baltic Sea [34]. Both NOx and NH_3 emissions contribute to N deposition at the soil level and lead to big nitrogen-consuming plants. They grow at an accelerated rate and spread, eliminating species that grow more slowly and have naturally adapted to growth in a low N environment, ultimately leading to reduced biodiversity [24, 35]. The Nr also have a direct negative effect on plants. By depositing on the leaves, there are changes in their physiology, epicuticular and epistomatic waxes, smaller leaves and changes in the cuticle and stomata. Reducing biodiversity as an effect of eutrophication and acidification can lead to decreased resilience of ecosystems [5].

4. Conclusions

Ammonia, nitrogen oxide and nitrous oxide are emissions that contribute to air pollution and global warming, meanwhile, nitrates contribute to soil and water pollution. Consequently, as a result of human activity in recent decades, significant amounts of reactive nitrogen were released into the environment, disrupting the natural nitrogen cycle. The agriculture and livestock sectors contribute to Nr of the total emissions induced by human activity. Among the main causes are excessive use and inefficiency of synthetic fertilizers, manure management, and low efficiency of N conversion into milk, meat, and eggs by animals. The N cycle is complex and requires an in-depth understanding of both the biogeochemical pathways in agricultural and zootechnical systems and the different management practices to draw up the best solutions to make the use of N more efficient and to reduce global emissions.

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