NEW ERA AGRICULTURE MAGAZINE

Emissions and Mitigation of Nitrous Oxide from Agriculture

Dr. Vishal D. Wale

SUMMARY:

Agriculture is a major contributor of global greenhouse gas emissions, with nitrous oxide being a significant contributor due to its high global warming potential (298 times that of CO_2) and its role in ozone depletion. Soil, synthetic fertilizer, livestock manures, crop residues, burning of biomass and fossil fuel are major sources of emissions of nitrous oxide. It is emitted through the soil by the processes of nitrification and denitrification. It can be effectively reduced by appropriate, split and timely application of nitrogenous fertilizer, proper method of application, tillage and irrigation practices, use of amendments, such as biochar and lime, use of slow-release fertilizers and nitrification inhibitors, plant treatment with arbuscular mycorrhizal fungi, appropriate crop rotations and integrated nutrient management.

INTRODUCTION

Agriculture is a major contributor to greenhouse gases including carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4) released into the atmosphere and accounts for 10–12 per cent of the total GHGs produced globally by anthropogenic activities (Tellez-Rio *et al*. 2017). Gases that trap heat in the atmosphere are called greenhouse gases (GHGs). The main GHGs of concern for agriculture is carbon dioxide, methane, and nitrous oxide. These GHGs are a major source of global warming and climate change across the globe and pose a serious threat to global food security. Global warming, caused by the increase in concentration of greenhouse gases in the atmosphere. The Indian agriculture being crucial for ensuring food, nutritional and livelihood security of India is exposed to the stresses arising from climatic variability and climate change. Due to the emissions of methane and nitrous oxide from agricultural soils and livestock, agriculture sector will be a major contributor to the enhanced greenhouse effect.

Nitrous oxide is one of the mightiest GHGs, and agriculture is one of the main sources of N_2O emissions. Global warming potential is the relative warming effect of a

Dr. Vishal D. Wale

Assistant Professor, Sahakarmaharshi Bhausaheb Thorat College of Agriculture, Amrutnagar

unit mass of the gas compared with the same mass of carbon dioxide over a specific period. It is a powerful and long-lasting GHG, has a global warming potential (GWP) 298 times as high as that of CO_2 and can contribute to the depletion of the stratospheric ozone layer. Agriculture is responsible for about 60 per cent of the global N_2O production, owing to the heavy usage of mineral N and the sustained use of legumes as cover and main crops releasing N at the end of their life cycle.

NITROUS OXIDE

Nitrous oxide is also naturally present in the atmosphere as part of the Earth's nitrogen cycle and has a variety of natural sources. Three main processes, namely nitrification, denitrification and dissimilatory nitrate reductions, are considered the main contributors to N_2O emissions. The contribution of each process to N_2O emission depends upon soil texture, organic C, soil pH, microbial activities and environmental conditions, including precipitation and temperature. Denitrification is the reduction of nitrogen oxides (usually nitrite and nitrate) to nitrogen oxides (NOx) with a lower oxidation state of nitrogen or molecular nitrogen by microbial activity (denitrification) or by chemical reactions involving nitrite and reduction of nitrogen oxides by combustion.

Nitrous oxide is primarily produced in soil by the activities of micro-organisms during nitrification of ammonium into nitrate, and denitrification of nitrate (and nitrite) into nitrogen gas. The lack of oxygen or limited oxygen supply in soil to the active micro-organisms is the primary cause of N_2O production during denitrification. When oxygen supply is low due to slow oxygen diffusion through water-filled pores in saturated or waterlogged soils or due to high oxygen demand created by abundant carbon food source, microorganisms utilize nitrite and nitrate in place of oxygen. Thus, nitrate and nitrite are denitrified to nitric oxide (NO), nitrous oxide, and nitrogen (N_2) gases. In soils, N_2O is mainly produced by transformation of reactive N through the microbes. When N enters the soil, either from organic or mineral fertilizers in the form of NH^{4+} and NO^{3-}, there are different processes that can result in N_2O formation. Denitrification occurs when soils are saturated (anaerobic, oxygen less). Anaerobic microbes convert nitrate to nitrite (NO^{2-}), nitric oxide (NO), N_2O, and nitrogen gas.

SOURCES OF EMISSION

- Land use and land management activities such as forest and grassland fires, application of synthetic nitrogen fertilizers to urban soils and forest lands.
- Burning of fuels emitted nitrous oxide and its amount depends on the type of

fuel and combustion technology, maintenance, and operating practices.

- Production of nitric acid, which is used to make synthetic commercial fertilizer, and in the production of adipic acid, which is used to make fibers, like nylon, and other synthetic products.
- Treatment of domestic wastewater during nitrification and denitrification of the nitrogen present, usually in the form of urea, ammonia, and proteins.
- It is emitted naturally through natural circulation of nitrogen among the atmosphere, plants, animals, and microorganisms that live in soil and water.
- Nitrous oxide is produced in soils through the processes of nitrification and denitrification.
- Nitrification is the aerobic microbial oxidation of ammonium to nitrate, and denitrification is the anaerobic microbial reduction of nitrate to nitrogen gas. Nitrous oxide is a gaseous intermediate in the reaction sequence of denitrification and a byproduct of nitrification that leaks from microbial cells into the soil and ultimately into the atmosphere.

The proportion of N_2O to N_2 gas in the denitrification process depends on

- Nitrate and nitrite supply : Higher N_2O/N_2 ratio at higher NO^{2-} or NO^{3-} concentrations.
- Oxygen supply or water-filled pore space : Higher N_2O/N_2 ratio at < 60-80% water-filled pore space, but at saturation or above, it is almost exclusively N_2 gas emissions.
- Temperature : N_2O production rate increases but the N_2O/N_2 ratio decreases with increasing temperature.
- Soil moisture : When soils are saturated with water, denitrification can occur. Practices like compaction are increases N_2O emissions and subsurface drainage will reduce emissions.
- Soil temperature : Nitrous oxide emissions increase with air temperatures and soil temperature. At higher temperatures microbial activity decreases and emissions are reduced.
- Soil organic matter : N_2O emissions are higher in soils with elevated organic matter levels, reflecting greater capacity to mineralize N and more available C for microbial activity as soil organic matter increases.
- Soil pH : N_2O emissions are lower in acidic soils than in neutral or alkaline soils. This is because microbes involved in the denitrification

processes are most abundant and active in soil with a pH between 7 and 8.

- Carbon substrate supply : Moderate supply of carbon substrate increases N_2O production but high carbon substrate may lead to N_2 production due to anaerobic conditions.

Mitigation of N2O emissions

- Availability of inorganic N in soil through additions of organic fertilizers, manure, crop residues, sewage sludge or mineralization of N in soil organic matter.
- Enhancing N use efficiency and reducing loss of applied N in soil through plant breeding and genetic modifications to increase the N uptake, use of manure or integrated use of manure and fertilizer to reduce reliance on chemical fertilizer.
- Enhancing the efficiency of fertilizer N with the use of right kind of fertilizer applied with right method at appropriate rate, time, place and when appropriate through split application..
- The demand-driven N use using a leaf colour chart could reduce the nitrous oxide emission and GWP (Bhatia *et al*., 2012; Jain *et al*., 2013).
- Use of nitrification inhibitors such as coated calcium carbide and dicyandiamide can reduce emission.
- There are some plant-derived organics such as neem oil, neem cake and karanja seed extract which can also act as nitrification inhibitors.
- Apply fertilizer N at optimum rates by taking into account all N sources available to the crop/pasture from soil, and other N sources such as legume, manure or waste.
- Provide fertilizer N application guide through crop/pasture monitoring, yield maps and soil tests.
- Avoid surface application, incorporate or band place so that fertilizer N losses are minimized and plant utilization maximized.
- Monitor and adjust fertilizer application equipment to ensure the precision and the amount of fertilizer applied.
- Improve spatial fertilizer application through global positioning system/geographical information system, yield/growth monitors, remote sensing, plant logging, soil tests and precision farming.
- Fertilizer should be in a form of granulated that can be applied evenly, conveniently and cost-effectively.
- For manure management, the early application and immediate incorporation of manure into soil to

reduce the direct N_2O emissions and secondary emissions from deposition of ammonia volatilized from manure and urine.

- Application of fertilizers through fertigation *i.e.* application of fertilizers through sprinkler/drip irrigation system.
- Fertilizer may be formulated with urease and/or nitrification inhibitors or physical coatings to mimic fertilizer N release to crop/pasture growth needs.
- Use non-legume cover crops to utilize the residual mineral N following N-fertilized main crops or mineral N accumulation following legume-leys.
- Direct emissions of N_2O into the atmosphere from field burning of agricultural residues are reduced by the use of stubble retention, composting and green cane harvesting.
- Land clearing disturbs the soil and thus enhances N mineralization and N_2O emissions. Restriction on land clearing will reduce N_2O emissions.
- To reduce nitrous oxide emission, the most efficient management practices are site-specific nutrient management.

CONCLUSION

Nitrous oxide emissions from agriculture significantly contribute to global warming and climate change, posing challenges to environmental sustainability and food security. These emissions arise from natural processes like nitrification and denitrification, influenced by agricultural practices and environmental conditions. Addressing this issue requires a multifaceted approach, including the adoption of precision farming, efficient fertilizer management, nitrification inhibitors, and sustainable land-use practices. By integrating innovative techniques with traditional knowledge, it is possible to mitigate N2O emissions while maintaining agricultural productivity, ensuring a balance between environmental health and global food security.

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