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Impact and Emission of Greenhouse Gases from Paddy Fields and their Mitigation Techniques

Kakar Kifayatullah[1*], Durani Asmatullah[1], Hashimi Tariqullah[1], Baber Bakhtmuneer[1], Gulab Gulbuddin[2] and Safi Zabihullah[2]

[1]Department of Agronomy, Faculty of Agriculture, Nangarhar University, Nangarhar, Afghanistan
[2]Department of Horticulture, Faculty of Agriculture, Nangarhar University, Nangarhar, Afghanistan
*Corresponding author: kifayatullahkakar@gmail.com

ABSTRACT

Agricultural soil functions as both a supplier and absorber of significant greenhouse gases (GHGs) such as methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). The scientific community has expressed significant concern regarding rice paddies, as they are responsible for the production of greenhouse gases (GHGs) that pose a long-lasting threat. The primary GHGs emitted from these fields are CH_4 and N_2O, accounting for approximately 30% and 11% of global agricultural emissions, respectively. Consequently, there is an urgent need to accurately measure the fluxes of CH_4 and N_2O in order to enhance our comprehension of these gases originating from rice fields. This understanding will enable the development of effective mitigation tactics to combat future climate change. This review aims to exclusively focus on the emission of CH_4 and N_2O in poddy fields, while also examining the impact of field and crop management activities on these emissions. Modifying traditional crop management practices could yield substantial results in mitigating greenhouse gas (GHG) emissions in poddy fields. By implementing effective management techniques, both environmental and agricultural aspects pertaining to soil can be readily adjusted. Therefore, comprehending the process of CH_4 and N_2O generation and release in poddy fields, as well as the factors governing these emissions, is crucial for devising efficient strategies to minimize emissions from poddy fields. This will assist regulatory bodies and policymakers in developing appropriate policies for agricultural farmers to enhance the reduction of GHG emissions and mitigate global climate change.

Keywords: Climate Change, Greenhouse Gases, Methane, Mitigaion, Nitrous Oxide

INTRODUCTION

Climate change, caused by the increase in concentrations of greenhouse gases (GHGs) in the atmosphere, is the most vital challenge faced by humanity. The levels of greenhouse gases (GHGs) like methane (CH4), carbon dioxide (CO_2), and nitrous oxide (N_2O) have experienced a 150, 40, and 20% increases, respectively, since the pre-industrial era. Agriculture, being a crucial economic sector, plays a vital role in ensuring food and nutritional security. However, it also has a direct or indirect impact on global climate change by releasing greenhouse gases. As a result, agriculture contributes significantly to the overall greenhouse gas emissions worldwide (Panchasara *et al.*, 2021).

Among the different GHGs, the non-CO_2 gases N_2O and CH_4 comprise a large share of agricultural emissions with relative global warming potentials (GWP) of 34 and 298 times higher than carbon dioxide (CO_2) respectively, on a 100-year time horizon (Khosa *et al.*, 2010). In contrast, N_2O contributes to the depletion of stratospheric ozone. Carbon dioxide, however, is a significant driver of global climate change and is responsible for 60% of the total greenhouse effect (Liu *et al.*, 2013).

Rice, scientifically known as *Oryza sativa*, is a significant and nutritious staple food primarily consumed in Asia. It holds the position of being the second largest cereal crop produced worldwide, according to FAOSTAT 2014. The Asian continent alone accounts for over 90% of global rice production, with 75% of it being cultivated in irrigated low land areas. In Afghanistan, rice plays a crucial role as the most important agricultural commodity among cereals, with an extensive cultivation area of 140,000 hectares, as stated by(Kakar *et al.*, (2019). However, the cultivation of rice poses a significant concern to the scientific community and poses a considerable threat to sustainable agriculture. This is due to its contribution as a major source of greenhouse gases (GHGs) such as CH_4 (methane) and N_2O (nitrous oxide), which have long-lasting effects. Rice fields alone emit approximately 30% of global agricultural CH_4 and 11% of global agricultural N_2O, as highlighted by (Hussain *et al.*, in 2015).

The GWP of rice crop is 467, which is significantly higher compared to that of wheat and maize, with increases of 169% and 169% respectively. The production of CH_4 is favored by anaerobic conditions in the soil. In the soil, N_2O is generated through nitrification and denitrification mechanisms by microorganisms under aerobic and anaerobic conditions respectively (Islam *et al.*, 2020). The highest amount of CH_4 is emitted in flooded rice fields, while intermittently flooded rice fields and transitional periods between crops produce a large amount of N_2O. It is projected that by 2030, the emissions of both GHGs may increase by 35-60% (Singh et al. 2017). However, in order to meet the growing demand from the ever-increasing population, rice production needs to be increased by 40% by 2030, which may lead to significant environmental concerns.

The application of excessive amounts of inorganic fertilizer to enhance rice production can lead to an increase in the emissions of CH_4 and N_2O from rice paddy (Gagnon *et al.*, 2011). Consequently, future rice cropping systems will need to find a balance between increased grain production and reduced GHG emissions. It is crucial to accurately measure the fluxes of N_2O and CH_4 and gain a better understanding of these gases in rice fields in order to develop effective mitigation strategies and minimize the negative impacts of climate change. This review paper focuses on identifying the main factors contributing to GHG emissions and explores potential implications for mitigating climate change by reducing agricultural greenhouse gases at their source.

MATERIALS AND METHODS

A literature review involves the investigation, analysis, evaluation, and integration of academic literature from the viewpoint of a scientific researcher, including books and journals. The resources employed for this review consisted of Google Scholar, Research Gate, and technical reports that the authors had access to. This review relies on scientific databases and the authors' knowledge, incorporating supplementary data obtained by the author.

RESULTS AND DISCUSSION

Production of GHGs from paddy fields

The primary source of CH_4 emissions is the rice paddy, however, when the paddy is flooded, it also releases a certain amount of N_2O due to the lack of oxygen in the soil. The emission of N_2O significantly rises when the rice cropping systems undergo continuous cycles of inundation and draining (Yao *et al.*, 2012). Thus, the rice-based cropping system showed a significant tradeoff between the emission of CH_4 and N_2O, and the production of both the gases is greatly influenced by water availability within the root zone of crop. Soil microorganisms play a crucial role in the generation and release of CH_4 and N_2O in rice paddy fields (Figure 1).

Methanogenic archaea are responsible for the production of CH_4 in rice paddies, while methanotrophic bacteria help in oxidizing a portion of it. On the other hand, microbial nitrification and denitrification activities contribute approximately 70% of N_2O emission. It is worth noting that denitrification is commonly linked to N_2O production (Braker and Conrad 2011). The Earth's terrestrial ecosystem harbors the largest carbon reservoir known as soil, encompassing approximately 1500-1600 Pg carbon within its organic matter (Figure 2). The rise in global temperatures, specifically a 1.1 °C increase during nighttime, due to the escalating concentration of greenhouse gases (GHGs), has the potential to diminish rice production by as much as 10% (Islam *et al.*, 2020).

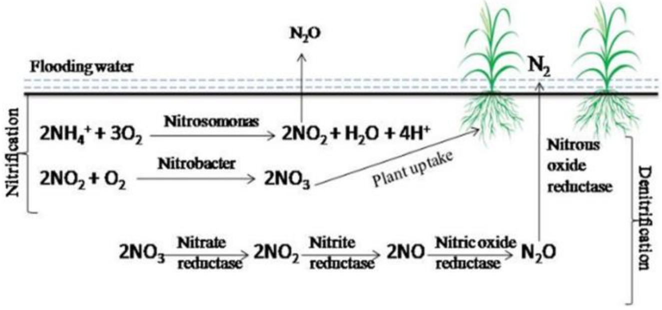

Figure. 1. Nitrous oxide production and emission from rice field (Gupta et al., 2021).

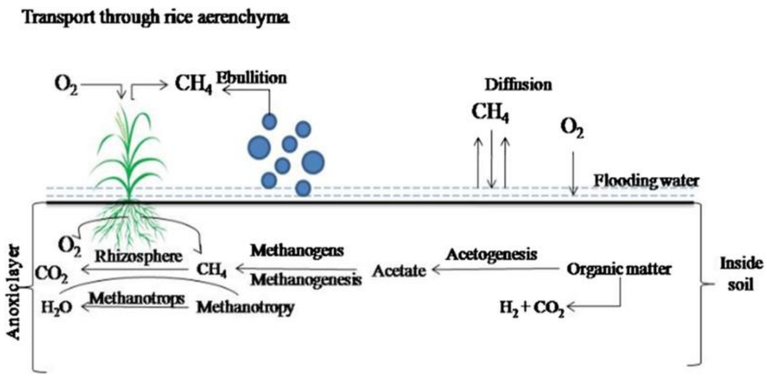

Figure. 2. Methane production and emission from rice field (Gupta et al., 2021).

Trends of GHG emissions

The anthropogenic greenhouse gases (GHGs) known as CH_4 and N_2O, which are not CO_2, have been reported to have rapidly increased in atmospheric concentrations from pre-industrial levels of 722 and 270 ppb to current levels of 1830 and 324 ppb, respectively. The CO_2 emitted from rice fields is considered neutral due to its association with the annual carbon cycles of carbon fixation and oxidation through photosynthesis. The rice sector significantly contributes to the emission of anthropogenic non-CO_2 GHGs by utilizing synthetic N fertilizer to meet the growing food demand of the increasing population (Yao *et al.,* 2012). According to Panchasara *et al.,* (2021), rice cultivation ranks as the second highest source of CH_4 emissions, following enteric fermentation. Table 1 illustrates that ruminant animals are the primary source of this fermentation, accounting for the highest contribution of 56%. Agricultural soil follows with a contribution of 23%, while paddy fields contribute 18%. The escalating concentration of greenhouse gases (GHGs) in rice fields can be attributed to various factors such as the extensive cultivation of rice, increased utilization of fertilizers and manure, and other agricultural inputs. Notably, the excessive application of nitrogen (N) fertilizers and manure in soil between 1970 and 2010 has significantly amplified the emission of N_2O (Pathak 2015). By 2030, it is projected that the use of synthetic fertilizer will result in a 60% increase in greenhouse gas (GHG) emissions compared to the levels in 1990. Developing countries accounted for over 70% of these emissions in 2010, with Asia alone contributing nearly 90% of the total emissions (FAOSTAT, 2014).

Table 1. Emanation of greenhouse gas from different sectors and subsectors of agriculture in 2010

Main sectors		Agriculture subsectors	
Sectors	GHGs emission (%)	Subsectors	GHGs emission (%)
Energies	65	Enteric fermentation	56
Agriculture	18	Agricultural soil	23
Industry	16	Rice fields	18
Waste	1	Crop residues	2
		Manure management	1

Climatic factors affecting N_2O and CH_4 emissions

Different microbial-mediated activities in soils, such as nitrification and denitrification, primarily govern the production and emissions of N_2O from rice fields. Additionally, the transport of gases through plants also plays a role in this process. Similarly, the emission and consumption of CH_4 in paddy soil are also influenced by biological factors. Consequently, the emission of CH_4 from paddy fields is influenced by various climatic factors, including soil temperature, pH, moisture content, and soil properties.

Strategies for mitigating N_2O and CH_4 emissions from rice fields

Several management practices can be implemented to minimize the emission of greenhouse gases (GHGs), particularly N_2O and CH_4, from rice fields. These practices include adjusting the irrigation pattern, managing organic additives, using appropriate rates and quantities of N fertilizers, selecting suitable cultivars, implementing tillage practices, adopting specific cropping regimes, utilizing cover crops, and incorporating nitrification inhibitors. It is important to note that in the rice ecosystem, the production of GHGs is primarily influenced by crop management practices. However, changes in the management system also present opportunities for implementing mitigation options. Below are some of the strategies that can be employed to mitigate GHG emissions.

Adjusting irrigation pattern

The GHG emissions during rice cultivation can be significantly impacted by the irrigation pattern due to its influence on the activity of soil microorganisms and the availability of substrates for N_2O and CH_4 emissions. The alteration of soil moisture through irrigation can affect the soil's redox potential, which plays a crucial role in regulating the rate of GHG release and consumption (Wang *et al.*, 2017). Various irrigation practices, including mid-season irrigation, alternate wetting and drying, intermittent irrigation, and controlled irrigation, have been observed to decrease N_2O and CH_4 emissions while maintaining crop productivity, as compared to the traditional irrigation pattern.

Combinations of tillage

The emissions of N_2O and CH_4 during rice production are significantly influenced by soil tillage. This is due to its impact on both the physiochemical and biological properties of the soil, which in turn stimulates the microbial production of CH_4 and N_2O (Oorts *et al.*, 2007). Ahmad *et al.*, (2009) found that reducing the frequency of tillage in rice paddy fields can lead to a decrease in CH_4 emissions. This is because the adoption of no tillage (NT) practices increases soil bulk density, resulting in a reduction of soil pores and ultimately slowing down the decomposition rate of organic matter.

Fertilizer management

The proper management of fertilizers has a significant impact on the reduction of greenhouse gas (GHG) emissions from rice fields, particularly N_2O and CH_4. Studies have shown that the rice crop does not fully utilize the applied N fertilizers, making it crucial to improve fertilizer efficiency in order to substantially reduce N2O emissions (Banger *et al.*, 2012). Implementing fertilizer management strategies such as adjusting application rates and quality based on crop requirements, precise timing, using slow-release fertilizers, placing fertilizers accurately in the soil, and avoiding excessive applications can greatly contribute to the reduction of GHG emissions from rice paddy soil (Wang *et al.*, 2017).

Application of biochar

In recent times, the utilization of biochar has emerged as a viable method to improve soil fertility, boost crop yield, and reduce greenhouse gas (GHG) emissions from soil (Liu *et al.*, 2013). Biochar possesses unique attributes like its highly porous structure, carbon-rich composition, and expanded surface area, which contribute to its potential as an effective approach in mitigating GHG emissions (Zhang *et al.*, 2013).

Selection of suitable rice cultivars

Exploring the mechanism of exudate and aerenchyma effects under field conditions is crucial before selecting suitable rice cultivars. This is because the variations in production, oxidation, and transport capacities of CH_4 emission have been attributed to the differences among different types of rice cultivars. Therefore, selecting rice cultivars with higher resource use efficiency can be seen as a promising and environmentally friendly approach to reduce N_2O and CH_4 in rice paddy soil (Wang *et al.*, 2017).

Reducing emissions from manure

In paddy fields, incorporating green manure crops like Cowpea, Sesbania, Azzola, and Mungbean has shown significant potential in reducing emissions of N_2O and CH_4. This is due to the improved efficiency of plant uptake and crop yield, which aligns well with the gradual release of nitrogen from decomposing green manure residue, while also minimizing N leaching losses. Studies have indicated that the application of fermented manures (pre-composted) in rice soil has the potential to decrease CH_4 emissions, as the soil organic matter (SOM) pool is rapidly depleted through the fermentation process (Hussain *et al.*, 2015).

Management of soil chemistry and microbiology

This manipulation can effectively impact the physiology of methanogenic and denitrifying bacteria, ultimately leading to the efficient reduction of emissions (Singh *et al.*, 2017). There exist various management options that can be employed to manipulate soil conditions and microorganism populations, resulting in the reduction of CH_4 and N_2O emissions or the enhancement of their conversion to N_2. These options include the application of lime, manure, biochar, integrated fertilizer residue management, controlled-release fertilizer, nitrification inhibitors, and herbicides.

CONCLUSION

Rice cultivation serves as a crucial means to sequester atmospheric CO_2, but it also contributes significantly to the emission of CH_4 and N_2O into the atmosphere. The growing population and its increasing demand for rice in the future pose a potential threat to global climate change, as it requires more water usage and resources to boost production yields. Nevertheless, implementing proper management practices in rice cultivation can play a vital role in mitigating the emission of anthropogenic GHGs from agricultural soil. By adopting practices such as selecting rice cultivars with low emissions, managing fertilizers, controlling irrigation, and understanding the factors responsible for GHG production in soil, it is possible to effectively regulate GHG emissions from rice cultivation. Through appropriate management of soils and crops, the absorption of atmospheric carbon in the soil can be enhanced, resulting in a reduction of GHG emissions.

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