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Research Article

BIOTECHNOLOGICAL STRATEGIES FOR NITROUS OXIDE EMISSION REDUCTION IN AGRICULTURE

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ABSTRACT

Throughout the industrial revolution began, the amount of greenhouse gases in the troposphere has increased. One particularly strong greenhouse gas is nitrous oxide (N_2O), with agriculture being the main source of N_2O emissions. This gas has a notable effect on global warming and unquestionably plays a big role in the ozone layer's depletion. A substantial portion of these greenhouse gas emissions is caused by bacterial and fungal denitrification and nitrification processes in soils, which are mostly caused by the use of nitrogenous fertilizers. The denitrification and nitrification processes are significantly affected by factors such as temperature, oxygen levels, carbon presence, nitrogen content, and moisture levels. After reviewing many literary works, then concluded that N_2O emissions may be significantly decreased with applying nitrogen (N) supply (30–40%, with peaks as high as 80%). The impacts of tillage and irrigation techniques also varied, whereas the application of extended-release fertilizers and nitrification suppressors led to reductions of up to 50%. Whereas 50% reduction was received by crop rotation schemes. Integrated nutrient management also played a role in reductions. In conclusion, the most effective and straightforward method for significant N_2O reduction is increasing N supply.

Keywords: Nitrous oxide; Greenhouse gas; Emission ; Agriculture, Bio-Carbon, Fertilizers, Nitrification Suppressor.

INTRODUCTION

The long-term profitability of farming activities is critical for crop output maintenance, particularly during harsh climatic conditions. Several nations throughout the world are employing intensive farming practices to secure their food supplies in the face of global population growth and sufficient supply of food for all (Tilman *et al.,* 2002). However, the increased number of agricultural operations, as well as the pesticides and fertilizers employed in them, have a negative influence on the environment (Hassan *et al.,* 2021). It significantly contributes to the release of greenhouse gases (GHGs) to the environment around it, including as CO_2, N_2O, and CH_4. It additionally accounts for approximately 10-12% of the overall greenhouse gas emissions caused by human activities globally (Malyan *et al.,* 2021) . Nitrous oxide releases currently account for a major component of the global GHG inventory (Yoro and Daramola 2020). Projections show that this contribution will rise in the twenty-first century due to causes such as industrial activity, organic sources, and the expected growth of the global population (Yoro and Daramola 2020). Nitrous oxide is a long-lasting greenhouse gas with a climate change impact (GWP) 298 times more than the impact of carbon dioxide. Furthermore, it has the potential to disrupt the stratosphere's ozone layer (Anenberg *et al.,* 2012) . This reactive gas stimulates the creation of tropospheric ozone, which has effects on health and agricultural yield. Nitrous oxide emissions presently constitute a significant portion of the world's greenhouse gas inventory (Yoro and Daramola 2020). Projections indicate the aforementioned contribution will increase in the 21st century due to ctors including manufacturing activity, organic matter, and the predicted growth of the world population (Yoro and Daramola 2020). Agriculture is a major source of N_2O emissions, accounting for 60% of worldwide output due to its intensive use of nitrogen -based fertilizers. Legumes, which exhale nitrogen at the conclusion of their life cycle, increases the quantity of nitrogen generated by the agricultural sector (Avnery *et al.,* 2011). The process of recycling animal manure into soil has led to in an rise in N_2O emissions. This rise in emissions is anticipated to result in a 20% increase in atmospheric N_2O levels during the next century, with a rise of around 0.2-0.3%. Additionally, N_2O emissions are probable to rise by 35-60% in the next few years This increase is mostly attributable to inefficient organic waste handling and amplified use of fertilizers made up of chemicals (Haider *et al.,* 2020). In addition, improper timing as well as excessive nitrogen use can cause N leaching, reducing water quality and increasing N_2O emissions from landscape-draining rivers (Kammann *et al.,* 2017). N_2O is predominantly generated in soil by microorganisms converting reactive Nitrogen. Whether N is derived by either biological or synthetic fertilizers (NH4+ and NO_3), a variety of mechanisms contribute to N_2O generation. However, the significance of these methods is not well known. The principal sources of N_2O emissions include nitrification, denitrification, as well as dissimilatory nitrate reduction. The relevance of each step may be evaluated by components such as soil texture, pH, microbial activity, precipitation, and temperature. To minimize N_2O emissions from agriculture, implement crop management strategies that involve tilling, irrigation, nitration inhibiting agents, the use of arbuscular mycorrhizal fungus , and appropriate crop rotation methods, which substantially modify soil particles and hence effect N_2O emissions (Seleiman and Hardan 2021a). Reducing N_2O emissions can be accomplished by employing suitable irrigation as well as tilling methods, applying fewer applications of nitrogen fertilizer, and implementing organic amendments, manures, as well as Effective crop rotation strategies.

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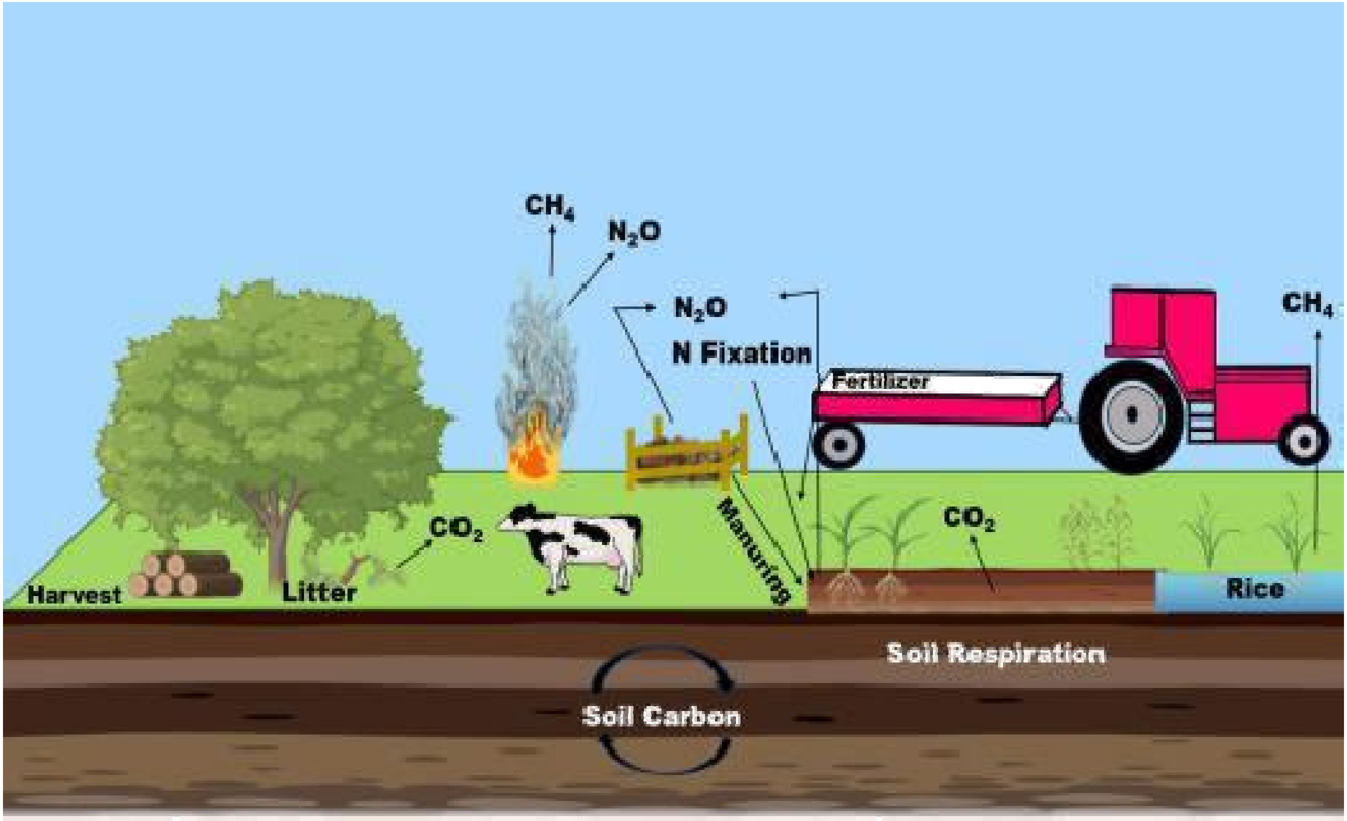
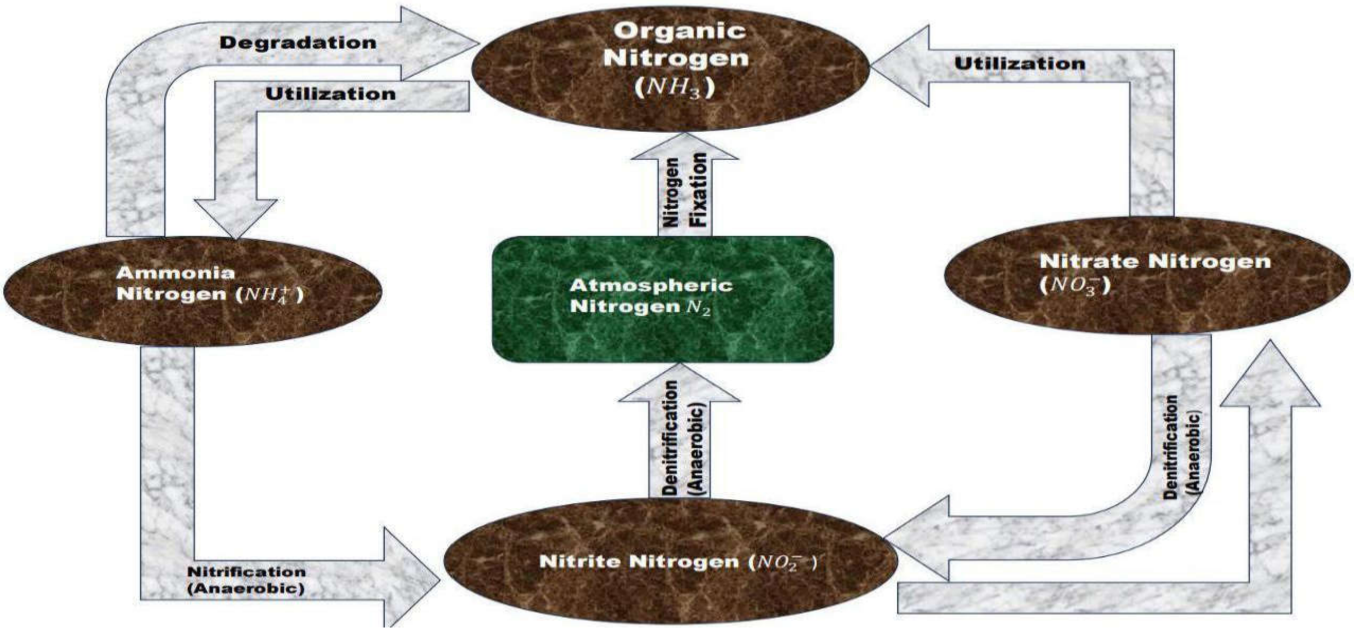


[Fig 1: - Depicts Emission of Greenhouse gases from agricultural field]

Nitrous Oxide: -

Figure 2 depicts the nitrogen cycle, in which atmospheric N_2 is converted to ammonia (NH_3) with the help of diazotrophs, which are free-living as well as symbiotic bacteria as well as archaea. These microorganisms employ the nitrogenase enzyme for breaking the N_2 triple bond. In soil, NH_3 may be transformed to ammonium ion (NH_4+), which is subsequently reduced to nitrate ion (NO_3-) by a procedure that involves three stages known as nitrification. Nitrite (NO_2-) along with NO_3- ions are produced during nitrification but can be decreased during denitrification. Denitrification is the innovative process by which four enzymes convert NO_3- to N_2, producing intermediate particles like NO_2-, N_2, and N_2O in the process. Furthermore, N_3-- reduction might take place during NO_3- ammonification to NH_4+, leading to the generation of N_2O (Thomas *et al.,* 2004).



[Figure 2: - Depicts nitrogen cycle]

N2o Production And Emission :-

Numerous concurrent mechanisms contribute to the emission of nitrogen gases in soils used for agriculture. The biological processes of denitrification and nitrification are the primary source of N_2O emissions. The principal microbe-based processes controlling the nitrogen cycle in soil are autotrophic aerobic nitrification, which is aided by ammonia-oxidizing as well as nitrite-oxidizing bacteria and anaerobic denitrification which is conveyed by denitrifying bacteria .

Under anaerobic circumstances, anammox bacteria may convert NH_{4+} and NO_{2-} into N_2, some fungi contribute to N_2 and N_2O generation by denitrification and nitrification. Archaea mediate nitrification in marine habitats and have been shown to induce denitrification in soil (Seleiman and Hardan 2021a). Nitrification is regarded as a vital part of the global cycle of nitrogen. Autotrophic bacteria primarily aid in the change of nitrogen during nitrification. The primary step of nitrification is the oxidation of NH3 into hydroxylamine (NH_2OH). This technique is performed out by ammonia-oxidizing archaea (AOA) along with ammonia-oxidizing bacteria (AOB). In a variety of soil types, AOA is more prevalent than AOB, suggesting that AOA abundance might perform a significant role in limiting nitrification rates. As a result, N_2O emissions may be lower in soils with a higher concentration of AOB (Lehtovirta-Morley et al. 2016) . This tendency is especially noticeable in acidic soils, where AOA dominate because to their distinct adaption strategies. Despite these observations, the exact extent to which AOA vs AOB effects N_2O emissions is unknown, possibly dependent on the destiny of NH_2OH (Seleiman *et al.,* 2013a)

Both nitrification and denitrification processes are critical in the creation of N_2O in soils and require additional investigation due to their importance. Nitrification includes the aerobic oxidation of NH_{4+} to NO_{3-}, mediated by chemoautotrophic bacteria in two sequential phases. Nitrification is the oxidation of NH_{4+} to NO_{2-} by bacteria such as Nitrosomonas sp., Nitrosospira species and Nitrosococcus species. Nitratation occurs when NO_{2-} is further oxidized to NO_{3-} by bacteria such as Nitrobacter sp., Nitrosospira species as well as Nitrococcus species (Pilegaard 2013) .Denitrification, on the other hand, is a reduction process that converts NO_{3-} to N_2, aided by facultative anaerobes that make about 0.1-5.0% of the overall bacterial society in the soil. This method might be full, leading to the generation of N_2, or incomplete, resulting in the emission (Pilegaard 2013). These microbial activities account for over 70% of worldwide N_2O emissions (Syakila and Kroeze 2011) . Furthermore, many metabolic activities may contribute to N_2O generation in soils:

- Hydroxylamine breakdown takes place throughout both autotrophic as well as heterotrophic nitrification activities.
- Soil NO_2 undergoes chemical DNF, while ammonium nitrate decomposes abiotically in amid conditions of light, dampness, and reactive surfaces.
- Nitrifier denitrification occurs within nitrifying bacteria produces N_2O
- Different microorganisms participate in coupled nitrification-denitrification; nitrite oxidising agents create nitrate, that is then denitrified by in-situ denitrifying agents.
- Denitrification is carried out by microorganisms that may use nitrogen oxides like alternate electron receivers when oxygen is lacking.
- The co-denitrification of organic nitrogen molecules along with NO, nitrate ammonification, and dissimilatory nitrate reduction to ammonium are all promoted (Butterbach-Bahl *et al.,* 2013a)

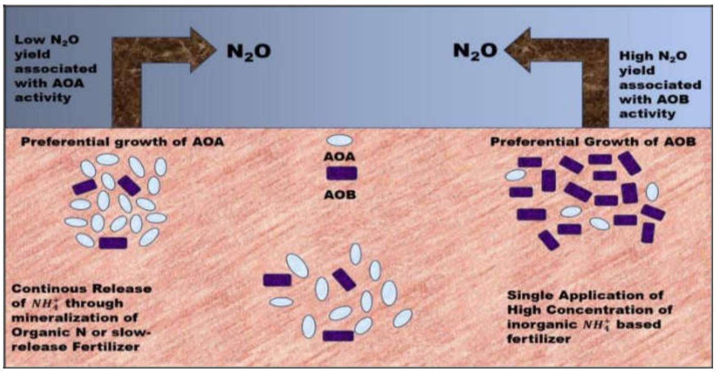


Fig 3: - Shows a comparative study between anaerobic archaea and anaerobic bacteria

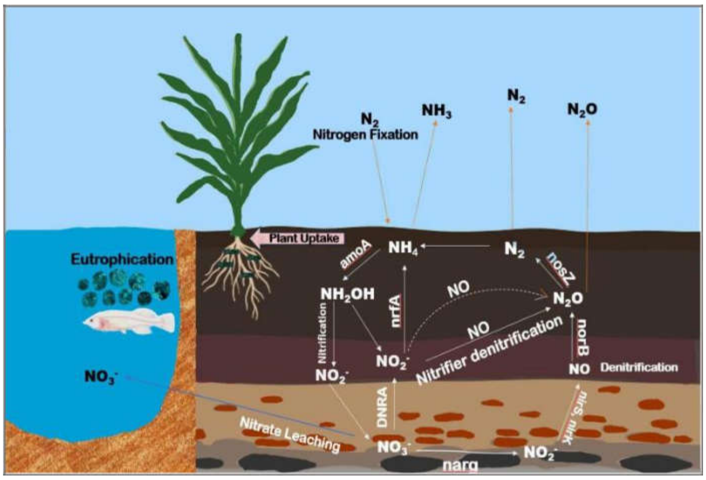
Microbial Pathways for N2O Production :-

Various microbial processes inside the nitrogen (N) cycle of aquatic as well as terrestrial environments create nitrous oxide.

Soil :-

Nitrogen enters the soil in inorganic as well as organic forms from sources such as fertilizers, compost, biological fixation, residues from crops, and atmospheric deposition. Inorganic forms, such as ammonium (NH_4) and nitrate (NO_3), are easily available for many N_2O producing activities. Nonetheless, organic N supplies are as important due to their propensity to be mineralized into NH4. Nitrification and Denitrification are considered major source of N_2O production. Apart from this several microbes also play crucial part in N_2O production like DNRA

Dissimilatory Nitrate Reduction to Ammonium, employs NO3 as an electron acceptor in the reduction process, this results in the creation of NO_2 and eventually NH_4 (Cole and Brown 1980), it has lately emerged as a source of N2O emissions in soil. Dissimilatory Nitrate Reduction to Ammonium (DNRA) has been hypothesized as a possible source of N_2O in the rhizosphere, where root-derived carbon supplies and periods of increased oxygen and nitrate demand may produce favourable circumstances (Baggs 2011). However, new tests using 15N labelled NH_4 and NO_3 in a sandy soil (Kool et al. 2011) suggest that DNRA's contribution to N_2O may be insignificant. As a result, the importance of DNRA as a source of soil N_2O is questionable, and the links between the quantity and diversity of DNRA microorganisms (as defined by the nrfA, nirB, narG, and nap genes) and the release of N_2O are not thoroughly understood.

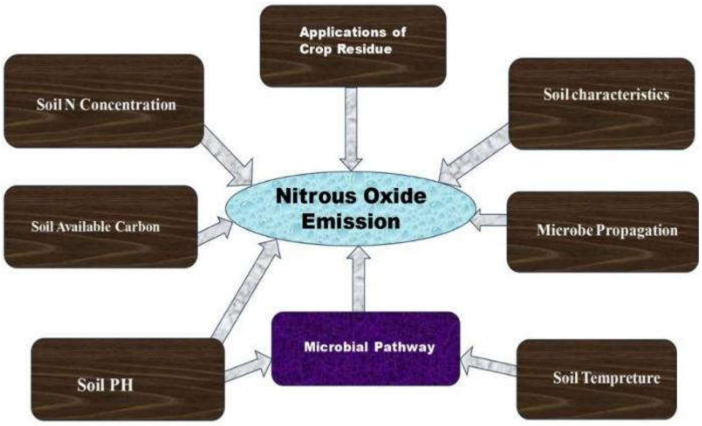


[Fig 4: -Shows Nitrogen cycle significance in Agroecosystems]

Manure :-

Cattle and pigs produce fresh feces and urine, which include microbe produced proteins and urea as their principal nitrogenous components, respectively. Poultry and birds emit both urine and feces, with unprocessed proteins along with uric acid being the main nitrogenous components (Groot Koerkamp et al. 1998) . The term 'manure' will refer to feces, urine, poultry excreta, and their mixes, as well as other items commonly found in animal facilities such as straw, wood shavings/chips, sand, peat, as well as manure fiber. This combination might be liquid, often known as slurry, or solid, sometimes known as manure from farms or solid/stackable manure.

Factors Influencing N_2O Emission from Agriculture: -



[Figure 5 :- Shows schematic representation of Factors affecting N_2O emission]

I. ***PH of Soil :-***

Soil pH comes up as a crucial factor influencing N_2O emissions.(Figure 2) improving soil pH has been linked to lower N_2O emissions (Sun *et al.,* 2012a) . However, some sources argue the contrary, stating that raising pH leads to increased N_2O emission (Baggs *et al.,* 2010) . This supports the idea that denitrifying bacteria flourish in situations with relatively high pH values, which facilitates their activities. The alkaline pH is known to promote nitrification in addition with denitrification processes (Khan *et al.,* 2011) . Overall PH of soil has a significant impact on microbial populations and activity, that affect Nitrous oxide emissions (Tate *et al.,* 2007a).

Microbe Propagation : -

Soil microorganisms have an important role in both denitrification and nitrification (Williams *et al.,* 1992). An autotrophic bacteria, like Nitrosomonas and Nitrobacter, serve as the primary nitrifiers (Parton *et al.,* 2001) . Phototrophs, lithotrophs, as well as organotrophs are all microorganisms that denitrify. These creatures derive energy from light, inorganic nitrogen, and organic carbon. Organotrophs, specifically Pseudomonas species, emerge as the major de-nitrifiers in soils, most likely due to their versatility and competitive advantage for substrates made of carbon within the group. Other soil de-nitrifiers include a large number of Alcaligenes species, that are directly linked to Pseudomonas (Abdalla *et al.,* 2011). Microbes in the soil have the ability to influence N_2O emissions via changing the denitrification method's nitrogen products ratio, like the N_2/N_2O ratio (Chen *et al.,* 2018). solitary Pseudomonas de-nitrificans G1, which has a remarkable ability to remove 90%-98% of NO_3 as well as 97%-99% of N_2O in one day under anaerobic environments. Pseudomonas de-nitrificans G1 grew at a moderate rate in anaerobic settings than in aerobic circumstances. Despite the delayed development, effective denitrification occurred, resulting in the eventual formation of N_2 as the end product.

II. ***Soil Moisture and Tempreture:-***

Nitrous oxide levels rise when there is a lot of water in the pore space. This is due to the effect of moisture in the soil on the release of N_2O during the breakdown of biomass. Adequate moisture of soil can promote organic carbon petrification, controlling microbe based metabolism as well as activity (Bolan *et al.,* 2011). As the water - filled pore space (WFPS) surpasses 60%, available oxygen is displaced in the soil pores, resulting in anaerobic conditions of soil moisture that favour N_2O generation. In this setting, facultative anaerobic bacteria like Pseudomonas citronellolis help reduce the nitrite in the soil to nitrates , N_2O and finally nitrogen gas (Ghimire *et al.,* 2020). Higher carbon levels drive microorganism activity by growing surface accessibility that raises nitrous oxide production. Moisture content soils lead to longer N_2O emission periods because of the greater supply of carbon substrate for microbial activity. Furthermore, the lack of tillage (NT) may increase pore spaces filled with water in comparison with traditional cultivation (CT), potentially leading to higher N_2O emissions under NT circumstances. Temperature of soil, in combination with moisture levels, affects nitrous oxide production. Bacterial populations increase with rising temperatures within a particular scale of (25-35 $_o$C) (Stres *et al.,* 2008; Braker *et al.,* 2010).

III. ***Soil N Concentration :-***

Various nitrogen inputs into soils used for agriculture, include inorganic N fertilizers and organic N sources such as manures, slurry, legumes, and post-harvest crop residues, have the ability to contribute to nitrogen substrates for nitrous oxide emissions (Smith 2017). Nitrification involves the oxidation of NH_4 to NO_3. Then, denitrifying bacteria convert NO_3 to N_2O. The presence of nitrate molecules is critical for denitrification. The concentration of soil NO_3 varies and is determined by factors such as net mineralization as well as nitrification rates, plant nitrogen intake, microbial immobilization rate, and NO_3 transport by means of the soil via leaching and lateral flow (Cameron *et al.,* 2013).

IV. ***Soil Available Carbon :-***

Soil carbon often acts as a source of energy for soil microbes increasing microbial activity (Mehnaz *et al.,* 2018; Signor and Cerri 2013). Nitrifying and denitrifying bacteria use a readily accessible C source to oxidize ammonium (NH4) and reduce nitrate (NO3). Soil denitrification and nitrification are more likely to occur when soil organic carbon concentration increases, particularly water-soluble C content. This soluble C supply is most easily available to microorganisms, resulting in enhanced microbial activity (Butterbach-Bahl *et al.,* 2013b; Steinbach ; Alvarez 2006; Dalal *et al.,* 2003). The quantity of organic carbon is critical in deciding whether denitrifies create N_2 or N_2O (Stein and Yung 2003. Weier *et al.,* 1993) examined impact of readily access with the carbon on the released N_2/N_2O ratio in a California sand and silt loam soil, using various glucose-C treatments .

V. ***Application of Crop Residues*** :-

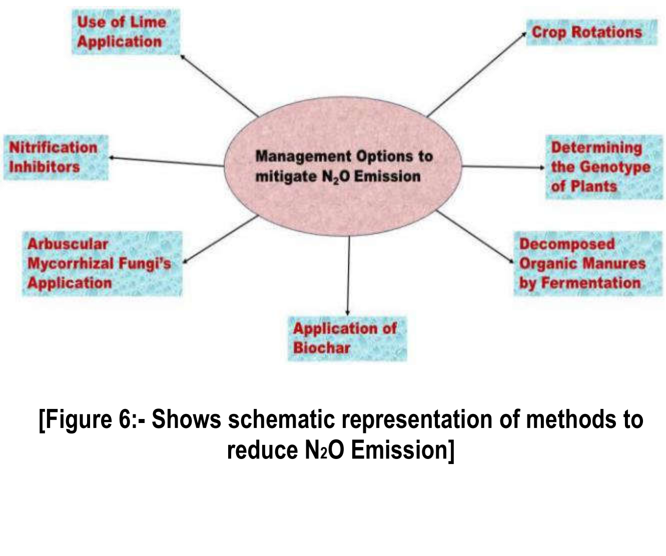
Crop wastes and straw provide an easily accessible source of carbon and nitrogen, potentially contributing to N_2O emissions (Lemke *et al.,* 1999). The emission of Nitrogen and Carbon as a result of agricultural residue mineralization is mostly determined by the ratio of carbon and nitrogen in the remanants (Eichner 1990a). Rate of denitrification is determined by the quantity of freely accessible carbon provided to the colony of de-nitrifying microorganism (Patten *et al.,* 1980). Notably, adding chaff along with a low ratio of carbon and nitrogen in loamy soil resulted in a significant increase in N_2O emissions (Eichner 1990b). Sandy soil, on the other hand, produced less N_2O when cereal chaff with a high ratio of carbon and nitrogen was applied than vegetable scrap along with low ratio of carbon and nitrogen (Baggs et al. 2000). As a result, the properties of agricultural residues that have been absorbed into the soil have a significant impact on N2O emissions.

VI. *Soil Characteristics :-*

Soils having finer textures release more N_2O, which is due to the existence of more capillary holes inside soil aggregates than sandy soils (Lesschen *et al.,* 2011a). Fine-textured soils contain larger pores that may store more water, resulting in extended anaerobic conditions. When compared with sandy soils, this protracted anaerobic condition produces a significant increase in N_2O emissions (Parton *et al.,* 1996). As soil texture as well as water-filled pore space (WFPS) increase, so does denitrification (Lesschen *et al.,* 2011b). In contrast, as WFPS drops, the DNF process slows. In clay-based soils, it has been observed that N_2O emissions rise significantly with increasing WFPS, peaking at WFPS values greater than 70% (Lesschen *et al.,* 2011b). Furthermore, soil texture influences N_2O emissions through changes in soil nitrogen availability, organic carbon content, and population of microbes (Meurer *et al.,* 2016). Field surface shape is also important; N_2O emissions were shown to be higher in depressions than in ridges and sloping fields, owing to the greater amount of moisture in depressed regions (Xu *et al.,* 2013. Hefting *et al.,* 2003). Additionally, reduced pressure in the air at higher elevations promotes greater N_2O emissions by reducing the counter pressure applied on the soil (Xu *et al.,* 2013; Hefting *et al.,* 2003).

Management Options to Mitigate N2O Emission: -

In spite of the impact of meteorological conditions on N_2O output, soil management methods that alter the previously listed parameters and increase the activity of microbes can also contribute to N_2O production. Notably, activities like soil tillage, nitrogen recycling from agricultural leftovers, and the use of mineral or organic nitrogen fertilizers are all important (Groffman *et al.,* 2009).



[Figure 6:- Shows schematic representation of methods to reduce N_2O Emission]

a) Using Slow-Release Fertilizers or Nitrification Inhibitors: -

It has been demonstrated that nitrous oxide and methane emissions may be significantly reduced by nitrous oxide inhibitors or slow-release N fertilizers (Huérfano *et al.,* 2016). In addition to having an indirect influence on crop output by reducing the available supply of nitrate for denitrification, the NI directly lowers N_2O emissions by blocking nitrification factors (Ruser and Schulz 2015; Gilsanz *et al.,* 2016).

The chemical components of NI, notably ammonia mono-oxygenase, deactivate the enzymes that cause the first stage of NF. This deactivation aids in the long-term retention of ammonium in soils (Tenuta And E. G. Beauchamp 2003). Thus, NI causes NF rates to drop and denitrifier substrate availability to decrease, which in turn causes a decrease in the release of N_2O from fertilizers (Burton et al. 2012). Controlled-release fertilizers are the main example of slow-release fertilizers (Wu *et al.,* 2018). The granule-coated formulations in these fertilizers are intended to release nutrients gradually, improving the efficiency of nutrient absorption (Jarosiewicz and Tomaszewska 2003).

When there is a significant risk of nitrogen losses, it is advised to apply controlled-release fertilizer. When used in conjunction with other tactics, using CRF might be seen as an ideal to reduce loss of nitrogen (Chen *et al.,* 2017) or as a good substitute for urea (Cui *et al.,* 2016). In conclusion, using CRF and nitrogen inhibitors together offers a viable strategy to reduce N_2O emissions and other N loss routes while also increasing crop yield as well as efficiency in using nitrogen (NUE).

b) Use of Lime Application: -

Lime application can have a substantial impact on soil N_2O production, taking into account organic material mineralization, nitrification as well as denitrification (Tate *et al.,* 2007b; Yamulki *et al.,* 1997). However, there have been conflicting findings about the influence of lime on the release of N_2O. The increased mining of both carbon and Nitrogen, which results in greater NH and NO3 concentrations, acts as the foundation for heightened NF and DNF. This, in turn, has the ability to reduce N_2O emissions (Čuhel *et al.,* 2010; Cornelissen *et al.,* 2013a).

The release of soil N_2O is controlled by pH, with a linear reduction with a rise in pH between 4 and 7, irrespective of the kind of soil (Shaaban *et al.,* 2020). Furthermore, choosing the type of liming material has a substantial effect on mineral Nitrogen concentration. The summation of lime decreases NH4 as well as accelerates the nitrification processes process, hence increasing NO_3 concentration. The increased NO_3 concentration at higher levels of pH causes bacteria to use N_2O as an acceptor of electrons rather than NO_3 (Hussain *et al.,* 2015). Liming has undeniable benefits, but it must be used carefully to reduce residual NO_3-. Excessive NO_3- levels in adverse situations might feed N_2O releases.

Table-1 Shows Comparison of Nitrogen Sources and N_2O Emission in Different agricultural fields and Soil Types Across Various Countries.

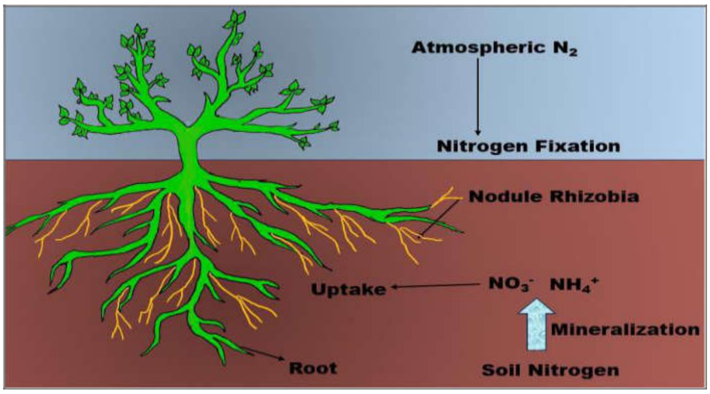
CROP	Nitrogen(N) Sources	N2O Emission (kg ha−1)	Soil type	Country
Rice	Control (no fertilizers)	0.04	rice- clay loam	India
Corn	Mineral N	0.6-1.5	Loam	USA
Rice	Control (no fertilizers)	0.67	rice- clay loam	India

Maize	Control (no fertilizers)	1.53(kg N Mg−1)	rice- clay loam	India
Winter wheat	Mineral N	0.17	Silty loam	China
Maize	Control (no fertilizers)	0.16	rice- clay loam	India
Rice	Control (no fertilizers)	0.64	rice- clay loam	India
Corn	Organic N	1.18	Loam	Brazil
Rice	Urea (100 kg ha−1)	0.15	rice- clay loam	India
Sugarcane	Mineral N	3	Sandy loam	Australia
Rice	Urea (100 kg ha−1)	1.39	rice- clay loam	India
Maize	Urea (100 kg ha−1)	0.30	rice- clay loam	India
Wheat	Mineral N	0.71	Silty clay	China
Maize	UAN (150 kg ha−1)	1.92(kg N Mg−1)	rice- clay loam	India
Rice	Ammonium Sulfate (AS) (100 kg ha−1)	0.17	rice- clay loam	India
Cotton	Mineral N	1.1	Clay	Australia
Rice	NPK (210:105:240 kg ha−1)	6.51	rice- clay loam	India
Maize	CAN(150 kg ha−1)	1.81(kg N Mg−1)	rice- clay loam	India
Corn	Mineral N	0.66	Clay loam	USA
Maize	Ammonium(AN) (150 kg ha−1)	0.29	rice- clay loam	India
Winter wheat	Mineral N	2	Clay	China
Corn	Organic N	0.74	Sandy loam	Germany

c) Arbuscular Mycorrhizal Fungi's Application: -

A crucial class of microorganisms known as arbuscular mycorrhizal fungi, or AM forms symbiotic relationships with most plants (Tellez-Rio *et al.,* 2017; Seleiman *et al.,* 2019a). Though they have their own needs for nitrogen, it is known in general that Arbuscular Mycorrhizal Fungi actively engages in the nitrogen cycle, helping host plants digest this vital nutrient (Oertel *et al.,* 2016; Seleiman *et al.,* 2013b) (Cavagnaro *et al.,* 2015). Furthermore, recorded data emphasizes the function of AMF in reducing NO_3-leaching from the ground (Köhl and Van Der Heijden 2016; Hodge and Storer 2015).

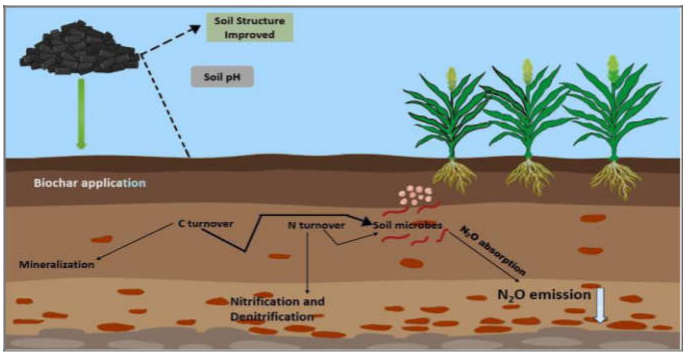
In general, these fungi affect the generation of nitrous oxide by decreasing the supply of sources of nitrogen in both fertilized (DNF) and non-fertilized soils. AMF show a preference for NH_{4+} because to its superior energy efficiency, even though they can absorb both nitrate and ammonium (Seleiman and Hardan 2021b; Seleiman *et al.,* 2019b). Nitrous oxide producers have less nitrogen available to them due to competition between these fungi and other microbes for inorganic nitrogen, which lowers N_2O emissions (Bender *et al.,* 2014). Furthermore, by absorbing nutrients and transmitting some to host plants, AMF affect the nitrogen cycle (Dungan et al. 2021). It is abundantly evident that AMF significantly contribute to limiting N_2O emissions by their interactions with their host plant as well as the soil environment. AMF works as a buffer, controlling nitrogen levels in the soil profile. This reduces the amount of nitrate sensitive to fertilized soils (DNF)



[Fig 7: -Depicts nitrogen fixation by rhizobium bacteria]

d) Application of Biochar :-

A product rich in carbon, biochar is made by pyrolyzing various sources of organic matter. Biochar improves soil qualities and sequesters carbon when it is mixed into the soil (Prosser and Nicol 2012) (Kunhikrishnan *et al.,* 2016; Wu *et al.,* 2013). This integration causes a variety of physical, chemical, and biological changes in the soil , all of which have an effect on the generation of nitrous oxide (Case *et al.,* 2012). The use of biochar may help reduce soil greenhouse gas emissions (Gupta *et al.,* 2020). By promoting the full conversion of nitrous oxide to nitrogen gas and raising soil pH, applying biochar helps to reduce release of nitrous oxide (Cornelissen *et al.,* 2013b). However, the impact of biochar on N_2O emissions depends on a number of variables, including the amount of biochar that is applied and different soil characteristics like pH, ratio of Carbon and Nitrogen, organic carbon content, status of water, microbial as well as enzymatic activity. Both biotic and abiotic routes contribute to the decrease in N_2O emissions made possible by biochar (Sun *et al.,* 2012b). The important impacts of biochar, which include improving PH of soil, increasing aeration, as well as increasing capacity of holding water are accountable for the observed decrease in N_2O emissions (Bakken *et al.,* 2012a). Low soil pH inhibits this enzyme's ability to assemble and function (Obia *et al.,* 2015a). The addition of biochar raises the pH of the soil, which restores N_2O as normal operation. This mechanism provides an explanation for the significant decrease in N_2O emissions seen following the use of biochar (Van Zwieten *et al.,* 2010). By raising the pH of the soil by the application of biochar, nitrous oxide is completely reduced to nitrogen gas hence reducing N_2O emissions (Cornelissen *et al.,* 2013c). However, effect of biochar on release of Nitrous Oxide depends on a number of variables, including the amount of biochar that is applied and different soil characteristics particularly PH, ratio of carbon and nitrogen, organic carbon content, state of water, and microbial and enzymatic activity. Both the abiotic and biotic mechanisms are involved in the reduction of N_2O emission caused by biochar (Sun *et al.,* 2012c).



[Fig 8: - Depicts use of bio carbon in agricultural field]

Reducing N2O emissions is mostly dependent on the main impacts of biochar, which include changing the pH of the soil, increasing aeration, and improving water-holding capacity (Bakken *et al.,* 2012b). Additionally, biochar immediately absorbs N2O, offering still another way to lower emissions (Obia *et al.,* 2015b). Furthermore, NH4+ and NO3- have been shown to adsorb significantly on the surface of biochar due to its strong adsorption potential (Pereira *et al.,* 2020). This thus reduces the amount of nitrogen available for the synthesis of nitrous oxide (Clough *et al.,* 2013). The quantity of soil genes, such as nirK and nosZ, is impacted by the use of biochar (Levy-Booth *et al.,* 2014). These genes are especially responsive to a Ph below 7 because they are essential for denitrification (DNF). Nitrous Oxide reductase, that triggers the conversion of N2O to N2, is linked to the nosZ gene (Song *et al.,* 2014). As such, the use of biochar leads to a significant decrease in N_2O emissions (Shaaban *et al.,* 2022; Feng *et al.,* 2003). Beyond just lowering N_2O emissions, using biochar also increases soil organic carbon, boosts crop productivity, improves soil fertility, and modifies N_2O emissions.

e) *Decomposed organic manures by Fermentation*: -

In a research it was discovered that applying decomposed organic matter noticeably reduced N_2O emissions and increased carbon sequestration (Nayak *et al.,* 2015) . They also saw an increase in emissions of CH_4. When compost was applied instead of urea in rice farming. (Zhang *et al.,* 2012) observed that N_2O emissions were reduced by more than 50%. Furthermore, compared to the use of fresh straw, the use of organic material from the aerobic composting of rice straw showed a significant reduction in greenhouse gas emissions, particularly CH_4 and N_2O (Doan *et al.,* 2015). This implies that using organic material by aerobic composting is a sustainable method.

The body of research indicates that organic compounds that are produced by the fermentation of organic debris are not toxic. This might be explained by the possibility of using more regulated dosages as opposed to OAs that come from animal slurries as well as manures. Concerns are raised in climate-resilient agro ecosystems by the problem of increased N_2O emissions in soils altered with manure, especially in irrigated settings (Shakoor *et al.,* 2022). Furthermore, after applying fermented manures, there may be a noticeable rise in N_2O emissions due to increased rainfall. In order to achieve maximum productivity while reducing N_2O emissions, it is thus advised to apply manure with caution in areas with more rainfall and on irrigated soils.

f) Determining the genotypes of plants: -

The selection of appropriate cultivars is a fundamental requirement for achieving desired crop production (Hassan *et al.,* 2018), while simultaneously contributing to greenhouse gas reduction. In the context of rice plants, there are active pathways facilitating the transport of N_2O through aerenchyma cells to water-submerged soil (Subbarao *et al.,* 2013). Additionally, during daylight hours, N_2O moves from the root system to the shoot system by the stream of transpiration and is slowly released by stomata (Byrnes *et al.,* 2017). In the case of Brachiaria humidicola certain cultivated varities have the capacity to yield specific chemicals that immediately restrict nitrification factors (Pappa *et al.,* 2011), leading to a substantial reduction in N_2O emissions. It is true that plant cultivars with high nitrogen absorption have shown the capacity to lower the N pool, especially nitrate availability. As a result, there is less substrate available for denitrifiers, which lowers nitrous oxide emissions.

g) Crop Rotations: -

The effect of rotation of crop diversification on greenhouse gas release via various plant species within rotations has not been well studied. Similar CH_4 emissions from both crops were noted in a three-year study of a maize–soybean cycle (Omonode *et al.,* 2011). Non-significant changes in N_2O emissions between cowpea, wheat, as well as soybean in rotation were discovered in another four-year research (Barton *et al.,* 2013). Crop rotations along with mono-cropping were compared, and the results showed that rotated corn had lower N_2O as well as CO_2 emissions whereas wheat emissions were similar in both cases (Cai *et al.,* 2013). As demonstrated by the differences in N_2O emissions between maize crops and grasslands, effective crop selection is essential (Shakoor *et al.,* 2021). The observed changes suggest that soil and climatic variables, in addition to crop diversity, influence the impact of rotation of crop diversification on greenhouse gas emissions. Cropping schemes as well as rotations do not consistently have an impact, which emphasizes the relationship among N_2O emissions as well as the possibility of mitigating them with certain crop management elements. Two of these factors—nitrogen fertilizer and the planting system—have been covered in-depth in particular subsections.

The function of regulatory bodies in establishing eco-friendly approaches of governance to minimize greenhouse gas emissions The function of regulatory bodies in establishing eco-friendly approaches of governance to minimize greenhouse gas emissions: -

Recent considerable increases in the level of greenhouse gases have intensified the effects of climate change as well as global warming. Globally, governments have enacted a range of policies, strategies, and tactics aimed at reducing greenhouse gas emissions. Standards, incentives, and permits are just a few of the several strategies used to encourage eco-friendly behaviours that decrease release of GHG. Worldwide release of greenhouse gas has been the subject of international efforts to address emissions and fight climate change and global warming for the past 20 years. GHGs are a major factor in climate change.

Many nations have gone through many cycles of development since the 1990s in an effort to reduce greenhouse gas emissions. The Kyoto Protocol's Annex-1 group was created as a result of early attempts to reduce emissions from wealthy and industrialized countries. Furthermore, by 2030, the European Commission has suggested a 55% decrease in GHG emissions from 1991 levels. However, the concurrent adoption of climate change legislation in the USA, UK, and EU-27 has highlighted the importance of heavy industries to the GDP of each country. Socio-economic and demographic changes, coupled with technological advancements, are strategically employed to reduce climate change and decrease release of greenhouse gas within a market-oriented framework. A widespread global practice involves embracing renewable energy sources while concurrently reducing reliance on coal and petroleum. This shift is accompanied by the promotion of effective generation of energy as well as expenditure methods.

The necessity of incorporating environmental protection into corporate operations is being increasingly recognized in the modern period. Environmental conservation may have several benefits, including reduced costs and resource usage as well as increased employee satisfaction and loyalty. Environmental Management Systems, including those described in ISO and EMAS standards, aim to enhance the protection of the environment. They help organizations get an edge over others by making enhancements.

CONCLUDING REMARK:

Three primary categories environmental variables, management factors, as well as measurement factors are used to organize the factors impacting N_2O emissions in this research. The rate at which the nitrification and denitrification processes occur is mostly determined by environmental conditions. However, management considerations are important because they determine how much nitrogen is added to soils, which in turn affects the environmental factors discussed earlier. It is predicted that putting the strategies covered in this paper into practice would successfully cut N_2O emissions without sacrificing output. We have been able to define the function of several management strategies that may be used separately or together to deal with N_2O emission reduction thanks to the literature debate. It has been demonstrated that using fertilizers that have a low N_2O emission potential—such as ammonium fertilizers—will lower N_2O emissions more than Nitrate-based fertilizers. Promoting the deep application of nitrogen Nitrogen fertilizers is another suggested tactic for reducing N_2O emissions.

Moreover, genotypes that have improved Nitrogen absorption, nitrogen fixation skills, as well as capacity to maximize carbon-nitrogen relations in the rhizosphere should be the main targets of plant breeding initiatives in order to reduce N_2O emissions. Future studies must look at how irrigation affects the hydraulic properties of the soil since these characteristics are critical to water distribution and, in turn, affect N_2O emissions. Further research is needed to determine the effect of nitrogen fertilizer percentage, frequency, and type on N_2O emissions. This is especially important for sprinkle as well as drip systems for irrigation, as these watering methods are usually combined with fertilizer treatments.

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Conflict of Interest

The Authors declare that they have no conflict of interest.

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