A Seminar Paper
On

Tackling Nitrogen Loss in Agricultural Fields: Strategies for Enhancing Nitrogen Use Efficiency and Minimizing Environmental Impact

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Tackling Nitrogen Loss in Agricultural Fields: Strategies for Enhancing Nitrogen Use Efficiency and Minimizing Environmental Impact[1]

By

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ABSTRACT

Although being the most crucial agricultural macro nutrient, nitrogen (N) suffers from substantial losses when used as fertilizer. Annually, 413 Tg (Tera gram) of reactive nitrogen (Nr) from global nitrogen fixation enters terrestrial and marine ecosystems, with 210 Tg N coming from human activities. For 79%-94% and 0.2%-9.9% of the total nitrogen losses in composting, respectively, NH_3 and N_2O emissions are responsible. Such losses degrade the environment and boost greenhouse gas production, which ultimately lowers N uptake, lowers crop output, and raises fertilization costs for agricultural fields. The development of enhanced efficiency fertilizers (EEFs) will control the release of nitrogen (N) from fertilizers, enabling improved uptake and usage by plants, reducing losses, and raising agricultural output. The inorganic, biological, or organic coatings of the EEFs as well as their modes of action on various N forms are used to categorize them. By adsorbing NH_3/NH_4^+, lowering the pH of the composting pile, producing struvite, and promoting nitrification, additives can limit nitrogen loss during composting. Based on their traits and methods for conserving nitrogen, the additives in this review are divided into three groups: physical, chemical, and microbial. Future study on nitrogen management additives, EEFs, and inhibitors was emphasized. Further research is needed of these topics to check their economic viability before they can be applied widely in composting.

Keywords: Environment, ecosystems, additives, inhibitors, composting.

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CHAPTER I

INTRODUCTION

Nitrogen is one of the essential macronutrients required for plant growth and development, and it is often supplied in the form of fertilizers to increase crop productivity. However, a significant amount of nitrogen is lost from the agricultural system, and this has detrimental effects on the environment. Nitrogen losses not only reduce the efficiency of fertilizer application but also have significant environmental consequences such as eutrophication, greenhouse gas emissions, and nitrate pollution of drinking water (Zhang et al., 2021).

The usefulness of nitrogen lies in its ability to enhance crop productivity, increase yield, and improve food quality. Nitrogen is a critical component of chlorophyll, the green pigment found in plants, which is necessary for photosynthesis, the process by which plants convert light energy into chemical energy (Li et al., 2019). It is also a vital component of amino acids, the building blocks of proteins, which are essential for plant growth and development. Adequate nitrogen supply can improve plant growth, increase photosynthesis, and enhance plant resistance to stress, such as drought and disease. Moreover, nitrogen losses from agricultural systems contribute to greenhouse gas emissions, particularly nitrous oxide, a potent greenhouse gas that contributes to global warming and climate change (Robertson et al., 2017).

The present status of N loss is a growing concern for agricultural scientists and policymakers. The demand for food is rapidly increasing, and nitrogen use has become a crucial factor in meeting this demand. However, the negative environmental impacts of nitrogen losses cannot be ignored, and efforts are being made to address this issue (Ju et al., 2016). Therefore, reducing nitrogen losses has become a crucial area of research in agricultural science.

Considering the facts present study was undertaken with the following objectives:

i) To identify the various factors that affect nitrogen loss in the agricultural field.

- ii) To discuss the different nitrogen management practices and technologies that can mitigate nitrogen losses to minimize economic loss and environmental degradation.

CHAPTER II

MATERIALS AND METHODS

The purpose of this seminar paper is to provide a review, and all information presented here was obtained from secondary sources. The sources used included books, journals, reports, internet searches, and resources from the Bangabandhu Sheikh Mujibur Rahman Agricultural University library. I was fortunate to receive sufficient guidance from my primary professor and course instructors, which proved helpful in completing my seminar report. To acquire knowledge, I conducted searches on similar websites on the internet. The collected information was then compiled to create this seminar paper, which drew from a variety of publications, journals, and websites.

CHAPTER III

REVIEW OF MAJOR FINDINGS

3.1 Available sources and forms of nitrogen

Nitrogen is an essential nutrient for plant growth, and there are different sources and forms of nitrogen that can be used as fertilizers (Figure 1). The nitrate form of nitrogen is essential during the early stages of growth, but it is not commonly used as a fertilizer on its own due to the risk of nitrogen loss through nitrification (Robinson et al., 2011). Urea is the most commonly used nitrogen fertilizer because of its high nitrogen content and cost-effectiveness (Meyer et al., 2007). While the mechanism by which plants absorb and utilize urea is not fully understood, it can be

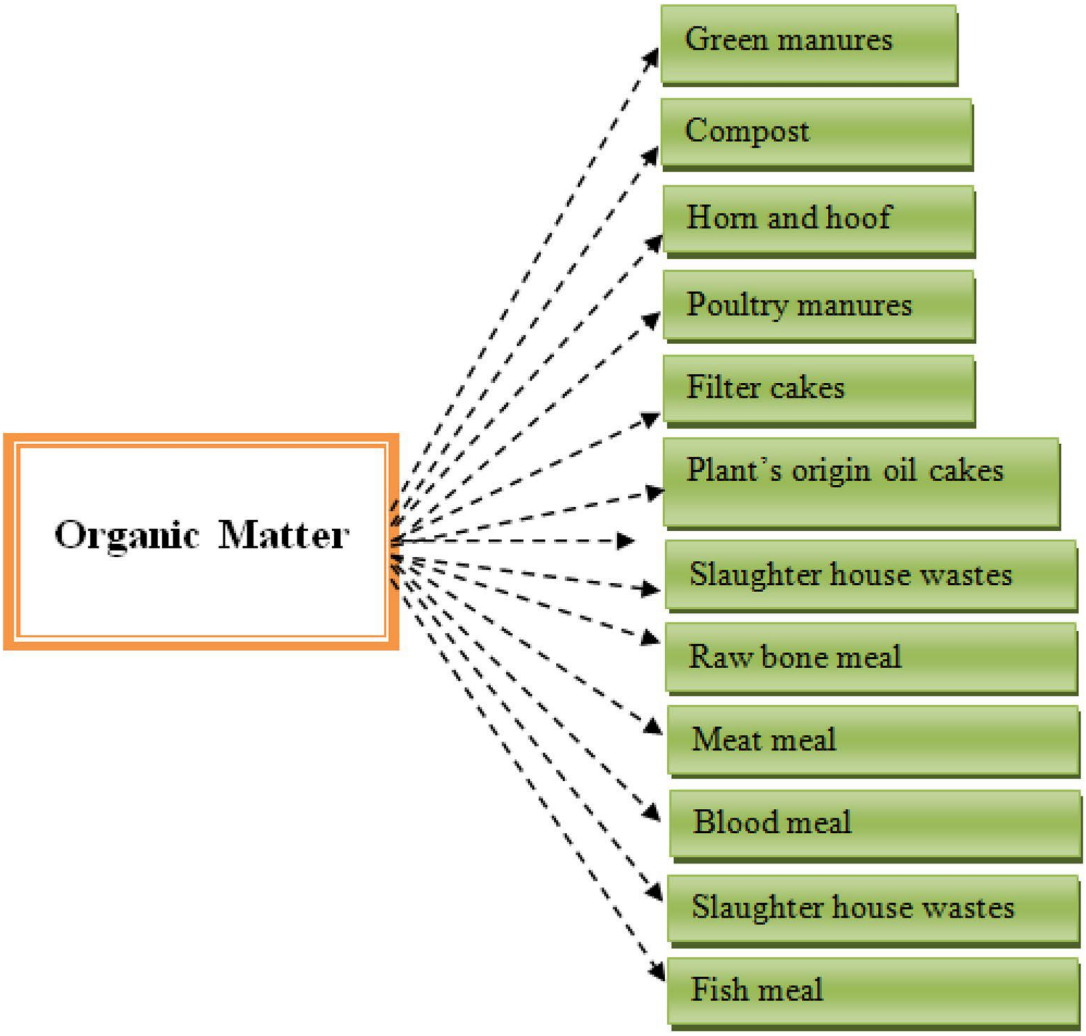

Figure 1: Sources of organic nitrogen available for mineralization in soil.

(Source: Leghari et al., 2016)

converted into both nitrate and ammonium forms after application in soil. Nitrogen uptake by plants is primarily derived from the soil rather than from the fertilizer itself, and the level of soil nitrogen needs to be monitored to assess the effectiveness of nitrogen usage in agricultural field conditions. Nitrogen assimilation has been directly linked to crop growth, development, biomass production, and yield (Fenilli et al., 2007). Plants can also take in more NO3-nitrogen than they actually need for assimilation and keep it in unassimilated reserves such as the vacuoles of leaves. The provision of both nitrogen and phosphorus to soil can lead to alterations in its chemical, physical, and biological characteristics (Yokoyama et al., 2017). Nitrogen fertilizer has a synergistic impact on phosphorus, and when used together, they produce more positive effects than either of them used alone. However, excessive use of nitrogenous fertilizers can increase production costs, environmental pollution, and decrease nitrogen use efficiency (Duncan et al., 2018). Therefore, it is crucial to develop sustainable fertilization strategies to minimize environmental impacts while ensuring optimal crop growth and yield.

3.2.1 Losses of nitrogen in the ecosystem

Nitrogen fertilizer excessive use can lead to adverse economic and ecological consequences such as eutrophication, air and water pollution, soil acidification, soil degradation, and disruption of biological communities (Figure 2)) (Zhang et al., 2013). The use of synthetic nitrogen fertilizers is unsustainable and environmentally damaging and can result in about 50% of the nitrogen fertilizer being unused by crops during the growing season (Socolow et al.,1999).

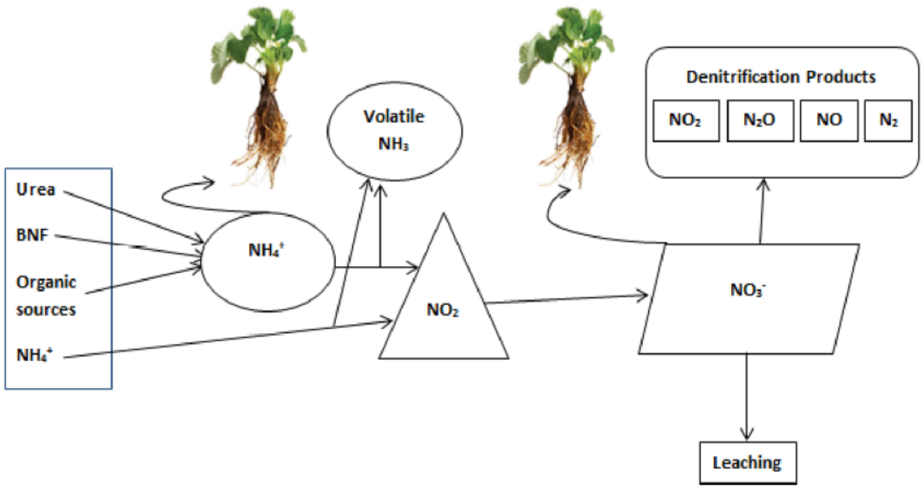

Figure 2: Summary of nitrogen sources and their conversion, availability to plant, and losses within/outside soil.

(Source: Anas et al., 2020)

Additionally, overfertilization can make plants more vulnerable to lodging, which can degrade the quality of the grain (Zhang et al., 2007). The primary nitrogen fertilizer used in the field is urea, which is also the primary source of ammonia gas emissions resulting from agricultural practices. Nitrogen losses can occur through leaching, direct emissions to the air, denitrification, and percolation (Skocaj et al.,2013). Legume crops can be adopted in cropping systems, for minimizing the leaching process resulting in up to 50% more leaching reduction than in conservative systems (Drinkwater et al., 1998). Biological nitrogen fixation by soybeans can reduce the demand for nitrogen by 50-60%. There is competition between plants and microorganisms for mineral nitrogen, particularly NH_4^+, which can lead to variations over time. Gaps in sugarcane fields during the ratoon season can reduce crop response, but well-established ratoon crops can respond well to nitrogen fertilizer. The use of synthetic fertilizers can decrease soil nitrogen stocks, while long-term application of organic fertilizers can increase both soil carbon and nitrogen levels (Ladha et al. 2011).

3.2.2 Altered precipitation patterns and agricultural N losses

Changes in precipitation patterns can have negative impacts on nitrogen losses in agriculture (Castellano et al., 2012). Heavy precipitation events during the spring and early summer can increase denitrification and nitrate leaching, resulting in losses of nitrate through leaching, especially on saturated soils (Figure 3). Extended periods of drought can lead to high levels of nitrogen loss through denitrification and leaching, while more intense and prolonged droughts can have delayed impacts on nitrogen losses in agriculture. Hydrological disconnections can result in nitrogen retention in landscapes, leading to higher nitrogen concentrations during subsequent flushing events (Greavere et al., 2016).

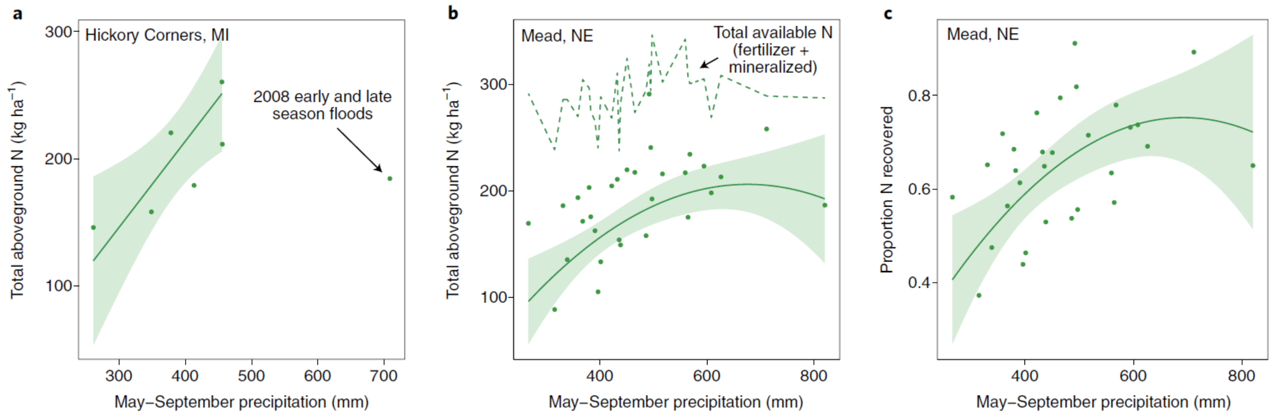

Figure 3: Total aboveground N uptake in maize at harvest increases with total growing season precipitation.

(Source: Bowles et al., 2018)

An increase in the occurrence of extreme drought-to-flood transitions is expected (Loecke et al. 2017), leading to poor water quality after pulses of nitrate losses (Figure 4). Additionally, drought stress will remain a significant threat to rainfed crop production, even in a world with higher concentrations of CO_2.

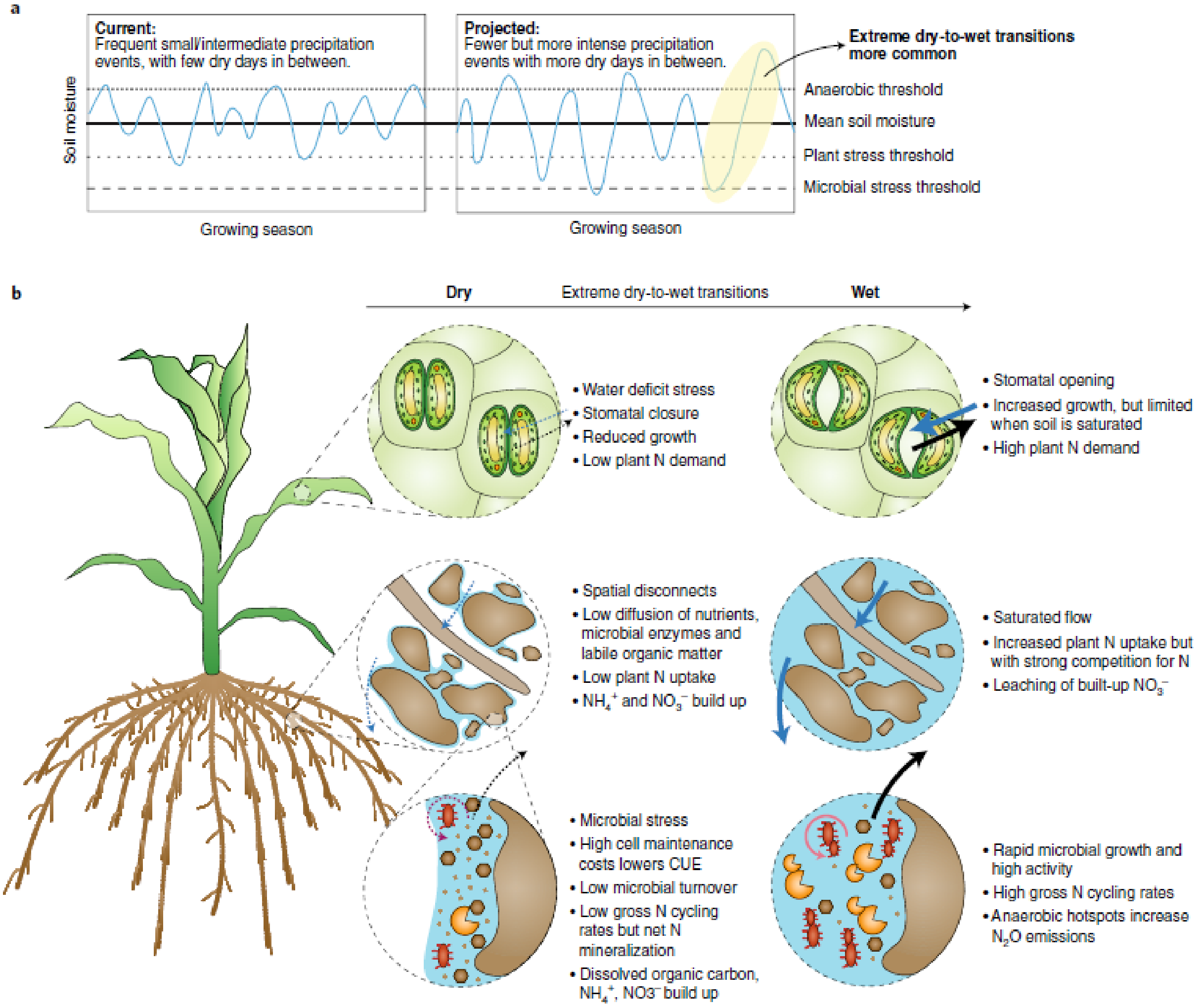

Figure 4: Conceptual diagram of the response of plant-soil-microorganism N cycling in soil moisture dynamics resulting from intense rain.

(Source: Bowles et al., 2018)

The physiological stress of dry soil can lead to a decrease in the carbon use efficiency of microorganisms, resulting in an increase in nitrogen mineralization and losses through denitrification and leaching.

Table 1: Hypothesized increases in agricultural N losses during specific time periods due to changing precipitation pattern, along with potential mechanisms

N loss pathway	**Time period**	**Potential mechanism**	**Uncertainty**
Nitrate leaching	Spring and summer	Larger rainfall carries nitrate below the root zone	Low
Nitrate leaching	Autumn or spring following summer droughts	Higher residual soil inorganic N due to decreased plant N uptake during drought period	Low
N2O emissions	Spring	Soil drying following longer periods of saturated soil conditions could increase N2O emissions	Medium
N2O emissions	Summer	More intense wet-dry cycles may increase cumulative N2O emissions from both nitrification and denitrification	High

(Source: Dimkpa et al. 2020)

3.3 Conversion of nitrogen loss in compost

During composting, nitrogen undergoes several transformations, including ammoniation, nitrification, denitrification, and biological immobilization (Lu et al., 2018).

1. Organic nitrogen break down through microorganisms' compounds through ammoniation or deamination, resulting in the generation of ammonia, which can be released into the atmosphere (Figure 5) (Wang et al., 2017).

2. Nitrification converts ammonium nitrogen into oxidized nitrogen, minimizing ammonia volatilization (Wang et al., 2019. However, the sensitivity of nitrifying microorganisms to high temperatures can inhibit their growth and activity during the thermophilic phase of composting, resulting in weak nitrification (Figure 5).

3. Denitrification is a process where microorganisms convert nitrate to different forms of nitrogen, facilitated by four different reductase enzymes, which occurs in an oxygen-limited environment within composting (Li et al., 2016).

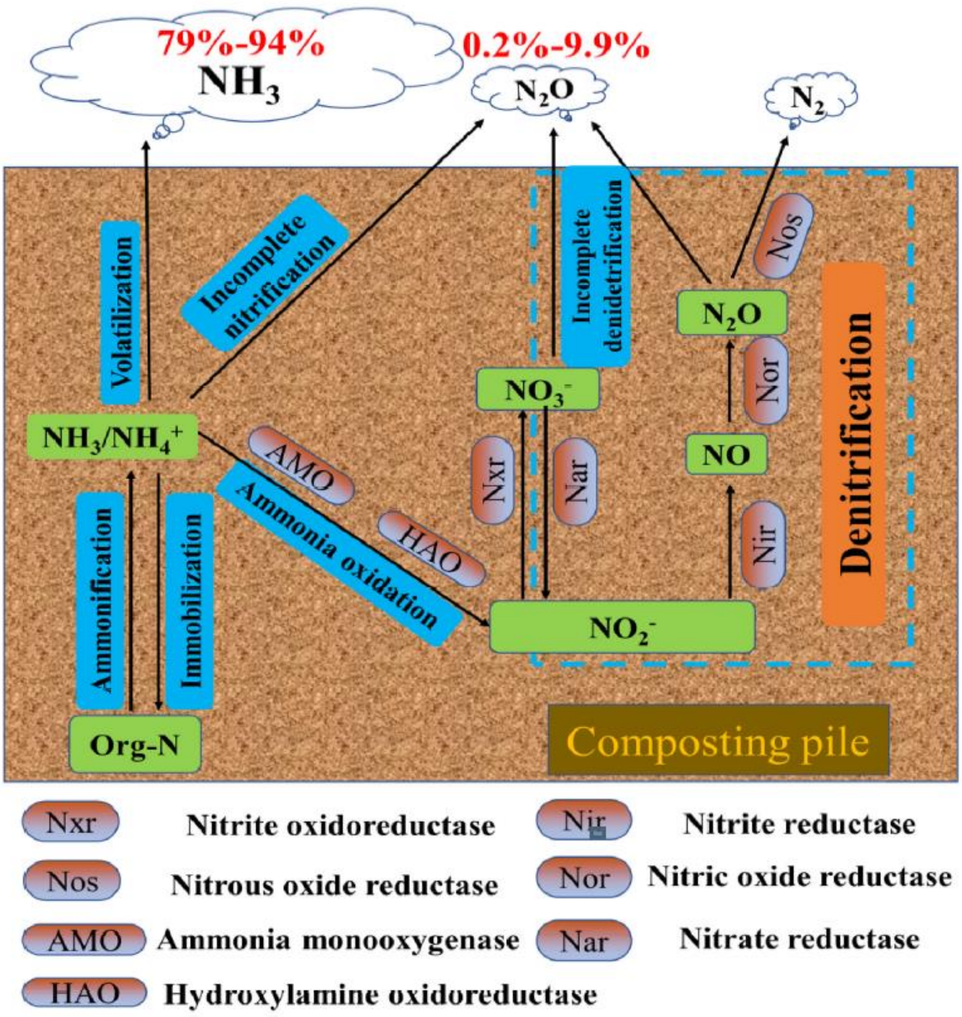

Figure 5: Nitrogen conversion process in compost.

(Source: G. Shan et al., 2021)

4. Biological immobilization is the process of converting inorganic nitrogen compounds into organic nitrogen compounds (Hart et al., 1994), where microbial protein is generated as microorganisms utilize nitrogen to create proteins (Figure 5).

These transformations of nitrogen are important in composting as they can impact the release of ammonia into the atmosphere and the availability of nitrogen for plant uptake.

3.4.1 Approaches to Enhance Nitrogen Use Efficiency

Irrational application of nitrogen is a major problem of low nitrogen use efficiency (Zhang et al., 2014). Therefore, agronomic principles and practices should be utilized in modern techniques to enhance nitrogen use efficiency, so as the reduced application rate of fertilizer inputs without yield reduction is key factor. Soil characteristics and agro-climatic conditions highly force the application level of fertilizer. Crops can use only up to 35% of the supplied N during its complete life cycle (Meyer et al., 2007) and the remaining is escaped to the environment by various mechanisms and functions. Improvements in NUE by decreasing nitrogen dose may delay leaf senescence which results in no yield loss. Late-season leaf senescence due to low nitrogen application rate provides relatively higher photosynthetic capacity to crop and ultimately increase yield production. N mineralization in soil is positively regulated by synthetic nitrogen fertilizer. Nitrogen fertilizer application dose can be minimized by 20% without yield loss in Australia (Rochester et al., 2009). The N fertilizer in China has possibility to use moderately at low rate by integration management practices. The reports from different regions/countries suggest that N use efficiency can increased by decreasing N application rate.

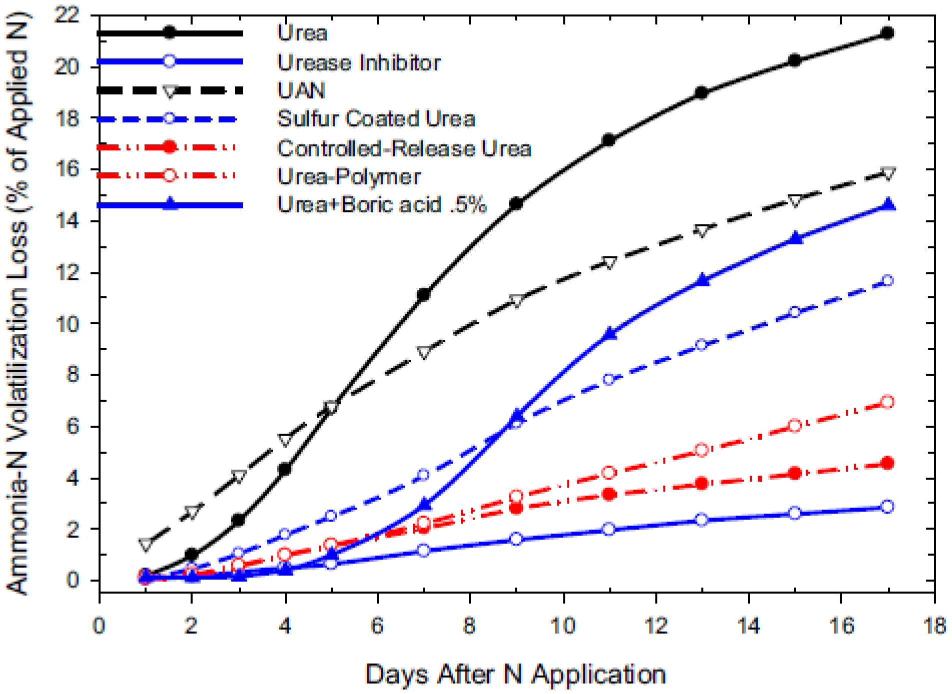

Figure 6: Temporal volatilization of NH3 during rice growth from conventional urea fertilizer and mitigation by EEF products.

(Source: Singh et al., 2010)

3.4.2 Polymer coating for enhanced fertilizers

Urea coating with organic polymers is a widely adopted technique for enhancing nutrient use efficiency in crop production. Various synthetic polymers such as polyolefin, polyurethane, and aldehydes have been reported to be effective in controlling the release of nitrogen (Azeem et al., 2014). Additionally, biodegradable polymers such as polyvinyl alcohol and cellulose acetate have also been studied as alternatives to synthetic polymers to mitigate potential environmental hazards associated with the latter (Chen et al., 2018).

Polymer coatings can control the release of nitrogen by diffusion of moisture through their variably permeable membranes (Table 2). The degree of polymer permeability, composition, thickness, soil temperature, and soil moisture affect the rate of nitrogen release. Polymer coatings have been shown to reduce NH_3 volatilization and N_2O emission.

Table 2: Generalized overview of the effects of polymer coating, urease inhibitor, nitrification inhibitor on plant N uptake and reductions in NH_3 volatilization, N_20 or NO emission and NO_3^- leaching from N fertilizers.

EEF system	Plant N uptake (% increase)	NH_3 volatilized; N_20 or NO emitted: NO_3^- leached (% reduction)
Polymer coating	45	35 (N_20)
	16	31 (N_20)
	121	68 (NH_3)
	25	40 (NH_3)
		29 (NO_3^-)
Urease Inhibition	12.9	54 (NH_3)
	6	55-90 (NH_3)
Nitrification Inhibition	11	38 (N_20)
	44	46 (NO)
	13	36(N_2O)
		37 (N_20)
		26 (N_20)
Urease and nitrification inhibition	13-100	13-87 (NH_3)
	3-8	26(N_20)
	8	

(Source: Dimkpa et al. 2020)

3.5.1. Urease inhibitors for nitrogen management

Efforts to increase the efficiency of nitrogen use in agriculture have led to the development of enhanced efficiency fertilizers (EEFs) that inhibit the activity of soil bacteria enzymes responsible for urease and nitrification (Table 2) (Timilsena et al., 2015). Phillip et al. (2015) described a urease inhibitor formulation consisting of a urease inhibitor and dialkyl sulfones, polymethylene, or cyclic sulfones, which could improve the storability of coated urea.

3.5.2. Nitrification inhibitors for nitrogen management

Nitrification inhibitors are used in the fertilizer industry to retard the rate of nitrification by inactivating nitrifying bacteria, thereby prolonging the nitrification period and synchronizing nitrogen release with crop demand (Table 2). DCD and DMPP are common nitrification inhibitors that reduce N2O emissions and NO3− leaching. DCD is more effective in promoting yield in rice than DMPP or neem, but DMPP (3,4,-dimethylpyrazole phosphate) is better at inhibiting nitrification (Harty et al., 2016). The combination of a urease inhibitor and a nitrification inhibitor can further enhance the benefits of enhanced fertilizers (Forrestal et al., 2016). Neem oil-coated urea (NOCU) is a biologically derived nitrification inhibitor that can be easily applied in resource-limited conditions (Akiyama et al., 2010). However, the use of synthetic additives in EEFs can lead to environmental deposition of potentially hazardous residues with reduced biodegradability, affecting soil microbial systems and potentially leading to negative outcomes (Marsden et al., 2015). Therefore, understanding the full scope of the potential effects of various synthetic additives on soil microbial life is critical for sustainability. The European
Union Commission has proposed new fertilizer regulations that include biodegradability requirements for controlled release fertilizers.

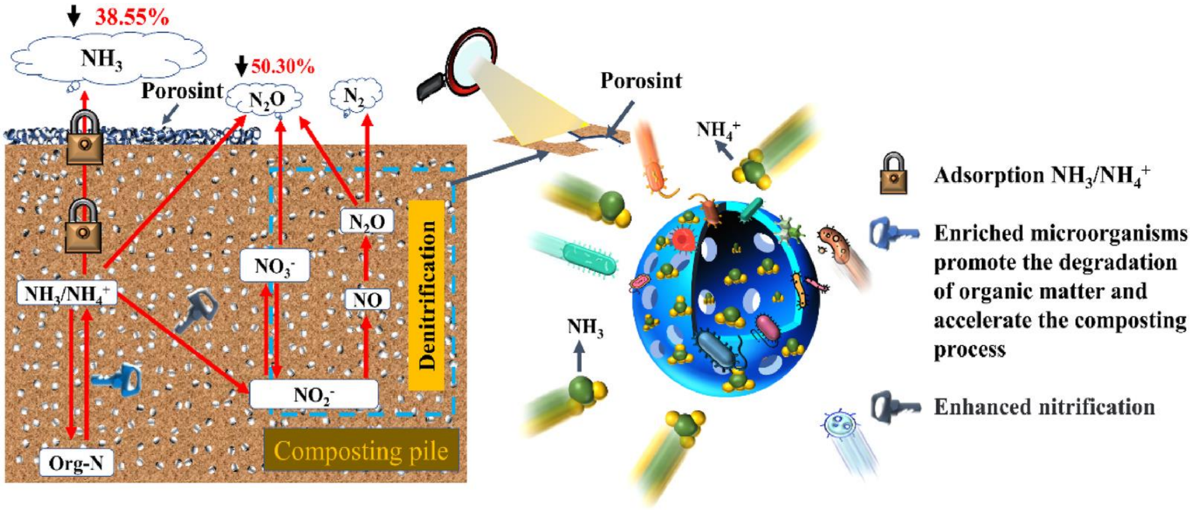

Figure 7: Mechanism by which porous materials reduce nitrogen loss during composting.

(Source: G. Shan et al., 2021)

3.6 Physical and Mineral Additives for nitrogen management

Organic physical additives such as biochar, apple pomace, and mature compost have been studied for their nitrogen conservation effects in composting (Sanchez-Monedero et al., 2018).

Biochar is a popular physical additive due to its high specific surface area, adsorption ability, and microporosity. Studies show that adding biochar to composting can effectively absorb NH$_3$/NH$_4^+$ and reduce nitrogen loss, especially in livestock manure composting (Steiner et al., 2010). However, excessive addition of biochar can increase the pH of the composting pile, enhance the conversion of NH$_4^+$ into NH$_3$ (gas), and reduce the nitrogen-preserving effect of biochar in the compost (Xiao et al., 2017). Mineral physical additives, such as zeolite, bentonite, clay, vermiculite, and medical stone, can reduce nitrogen loss and NH$_3$ emissions during composting (Table 3) (Awasthi et al., 2016). Zeolite, in particular, has been found to effectively reduce nitrogen loss during composting by adsorbing NH$_3$/NH$_4^+$ and capturing cations through ion exchange (Turan and Ergun et al., 2008). Other additives such as bentonite, clay, vermiculite, and medical stone have similar adsorption properties to zeolite and can be used to retain nitrogen in compost through cation exchange and physical adsorption (Table 3). However, it is important to consider the appropriate dosage of these additives as excessive use may have negative effects on the quality of the final product.

Table 3: Overview of the major impacts on N losses of mineral physical additives in organic solid waste composting

Feedstock	**Additive**	**Impact on N conservation (% respect to control)**		
		Total N **(% increase)**	NH$_4^+$ **(% increase)**	NH$_3$**(% decrease)**
Dairy slurry, sawdust	Zeolite (6.25%)			**↓50.0**
Food waste, barley straw	Zeolite (Gas adsorbent)			**↓41**
Leftover food, rice hulls	Clinoptilolite (31.5%-41.2%)			↓20
Food waste, sawdust	Zeolite (10%), MgO (0.05 M/kg), K2HPO4, (0.1 M/Kg)			↓18
Municipal solid waste	Natural zeolite (15%)		**↑64.5**	
	Mg-Modified zeolite (15%)		**↑109.7**	
Cattle manure	Zeolite (10%)	↑16		
Sewage sludge, wheat straw	Zeolite (30%), lime (1%	**↑50.34**		
	Zeolite (15%), lime	**↑43.17**		
	Zeolite (10%), lime	**↑41.12**		
Cattle manure	Vermiculite (10%)	↑8.99		
	Vermiculite (20%)	↑24.46		
	Vermiculite (30%)	**↑47.84**		
Chicken manure, rice husk	Montmorillonite (5% ^{2}	**↑79.48**		
Cattle manure	Lignite (4.5 kg/m2)			**↓66**
Cattle manure	Lignite			**↓54**

(Source: Shan et al., 2021)

3.7 Microbial additives

Microbial additives are effective in reducing nitrogen loss during composting (Li et al., 2017). The addition of exogenous microorganisms can reduce ammonia emissions and preserve more nitrogen nutrients by changing the metabolism of carbon and nitrogen. Microbial agents used include thermophilic ammonium-tolerant bacteria, nitrifying bacteria (Zhao et al., 2020), Azotobacter, and nitrogen-retaining microbial agents (Figure 8). Nitrification is a key step in accelerating the conversion of ammonium nitrogen into nitrite and nitrate, reducing NH3 volatilization (Wang et al., 2019). Bacillus species can reduce nitrogen loss during composting, and a multifunctional microbial agent is better than a single strain. Inoculation of nitrogen-retaining microbial agents and Thiobacillus thioparus can significantly decrease NH_3 losses and increase the TN and nitrate contents of compost products. The addition of chicken manure-integrated microbial consortium could reduce cumulative NH_3 and N_2O emissions during the composting of chicken manure and wheat straw (Chen et al., 2020a).

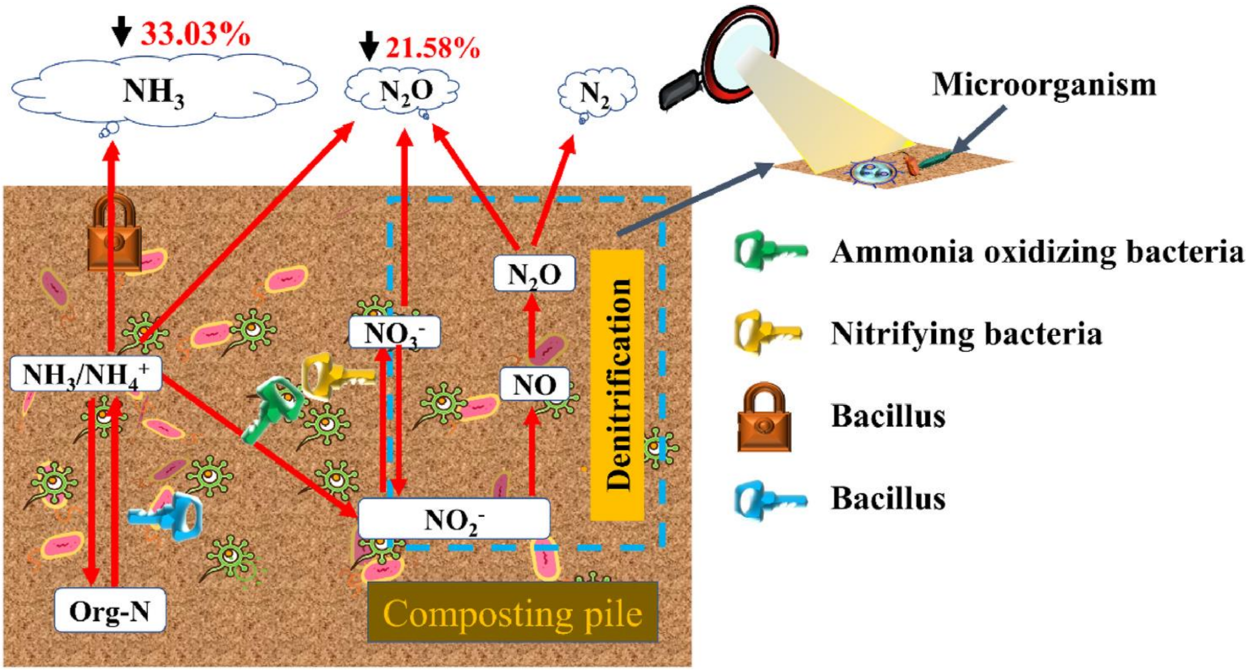

Figure 8: Mechanism of reducing nitrogen loss during composting by inoculating microorganisms.

(Source: G. Shan et al., 2021)

Table 4: Overview of the major impacts on N losses of microbial additives in organic solid waste composting

Feedstock	**Additive**	**Impact on N conservation (% respect to control)**		
		Total N	**NH_3**	**N_2O**
Food waste, straw	Mature compost (rich in nitrifying microorganisms) (28%)		↓36	
Chicken manure, mushroom residues	Thiobacillus thioparus 1904 (5% v. w)	↑28.20		
	Thiobacillus thioparus 1904 (5% v. w), sulfur (0.25% net weight)	↑70.94		
Layer manure, sawdust	Bacillus stearothermophilus (S g/kg)		↓11.23	
Chicken feces, rice husk and bran, mushroom residue	Ammonia-oxidizing archaea (5% w/v)		↓82.12	↓.57
Chicken manure, wheat straw	Chicken manure integrated microbial consortium (CMMC) (1096")		↓21.8	↓44.5
	Chicken manure biochar (CMB) (2%), CMMC (10%)		↓24.2	↓21.0
	CMB (4%), CMMC (10%)		↓37.8	↓18.2
	CMB (6%"), CMCC (109")		↓39.3	↓15.2
	CMB (10%"), CMCC (10%)		↓41.4	↓9
Chicken manure, rice husks	Nitrogen-retaining microbial agent (10%)		↓58.8	

(Source: Shan et al. 2021)

3.8 Future perspectives

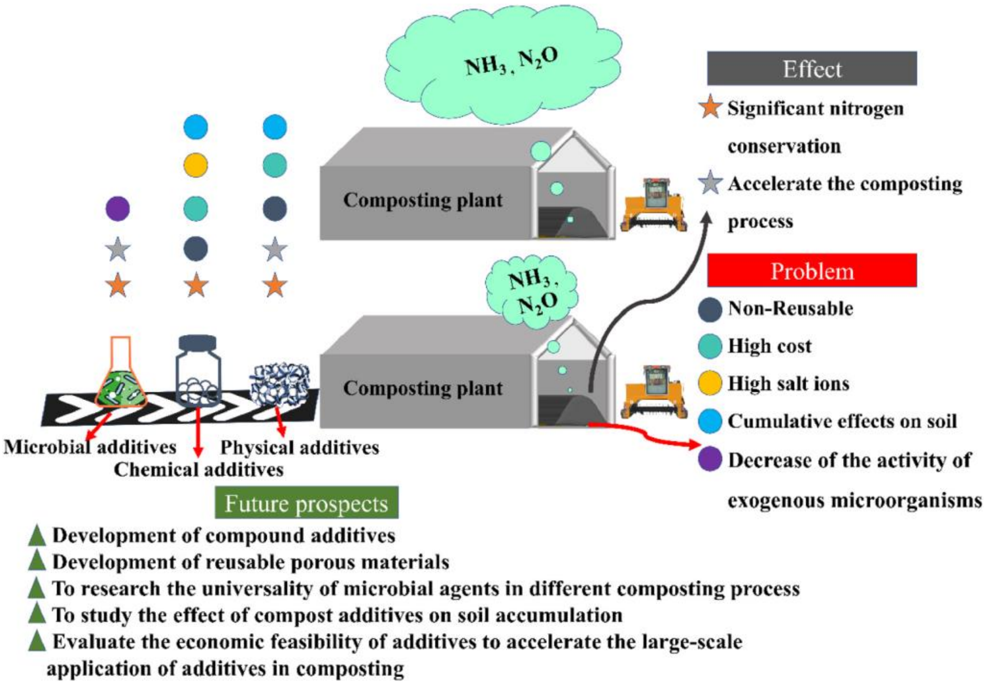

Figure 9: Schematic illustration of the effects, problems, and future perspectives of different types of additives in organic solid waste composting.

(Source: G. Shan et al., 2021)

The review emphasizes the importance of combining N-fertilizer with other nutrients to improve efficiency and mitigate climate effects while addressing nutrient depletion and its impact on produce quality and human health (Bindraban et al. 2020).

Different approaches, such as the use of multi-nutrient minerals, advanced biological materials, and nanotechnology, can be employed to achieve this. Solid fertilizer briquettes that contain multiple nutrients have several benefits, including balanced nutrition, reduced labor and input costs, and decreased pollution by residues from organic coating materials (Figure 9).

However, physical and chemical additives have limitations, such as high cost and non-reusability. Future studies should focus on developing reusable porous materials, compound additives, and evaluating the long-term and economic impacts of different additives on composting. Research on the universality of microbial additives to different composting systems should also be strengthened.

CHAPTER IV

CONCLUSION

The results show that among the three major forms of N loss, there are several factors that further accelerate or reduce the loss of N in agricultural fields. N availability can increase dramatically with growing-season precipitation but decrease with extended flooding conditions. Nitrate leaching can occur both in high rainfall conditions and during droughts. N2O emissions are more intense during alternate wetting and drying periods. To ensure sustainable crop production and reduce environmental impact, it is crucial to control nitrogen loss in agricultural fields.

Using effective enhanced nitrogen fertilization techniques such as using polymer-coated fertilizers and urease inhibitors, nitrification inhibitors can significantly reduce nitrogen loss and increase N availability as well as crop productivity. Adding physical and microbial additives to nitrogen management can further improve nitrogen use efficiency and reduce environmental degradation. Achieving a sustainable balance between agricultural production and environmental stewardship will require further research and acceptance of these solutions.

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