

Nitrogen Loss Pathways in Anaerobic Soils and Mitigation Approaches Through Inhibitors - A Review

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Abstract: Nitrogen (N) is the largest yield limiting nutrient in rice cropping. Therefore, efficient N fertilizer management is critical for rice production. Nevertheless, the complex nature of N transformation in soils, has led to low N use efficiency. The lower N use efficiency of fertilizers is a result of multiple loss mechanisms such as volatilization and denitrification and it is a major problem in rice system. Low efficiency of N is not only responsible higher cost of crop production, but also a major threat to environmental quality. The use specially formulated form of fertilizer by supplemented with inhibitors have a great prospect to reduce N losses, improve fertilizer N efficiency and produce positive impact to the environment. This review discusses the N losses pathway in anaerobic rice soil, the effectiveness and mechanism of urease inhibitors as well as nitrification inhibitors to minimize the N loss.

Key words: Nitrification • Denitrification • Urease • Rice soil.

INTRODUCTION

Rice cultivation has a high nitrogen (N) demand to boost growth and yield. There are a variety of nitrogenous fertilizers available in the market; however, urea is extensively been used as a sources of synthetic N in rice cropping and it is the cheapest source of N in addition to its ease of handling. Unfortunately, recovery of applied urea is low and overall efficiency of applied fertilizer in most crop field have been lower than 50 % [1] and specifically in lowland rice system the average recovery efficiency of applied N is typically less than 40 % [2] meaning that large portion of the applied N is not being used for productive purposes. The inefficient use of N in rice cultivation can be attributable to the unsynchronized release of N from fertilizers with the plant demand due to the N losses *via* various pathways such as volatilization, nitrification and denitrification.

Nitrogen losses resulted in a significant yield loss and environmental consequences with respect to the emissions of gases such as nitrous oxide (N₂O), ammonia (NH₃) and aquatic pollution through nitrate (NO₃⁻)

leaching [3; 4]. Yield loss also poses economic implication to the farmers and increases the expense for the rice production. Recent report revealed that N export to the environment from rice fields accounted for 13.1–31.7 % of the N input [5]. Due to substantial N losses and environmental concern, the development of technologies that accelerated urea use efficiency must contribute to the reduction of NH₃ volatilization and both denitrification losses. Various approaches have been used to improve the availability of N and mitigate the economic and environmental impacts of N loss. One such approach is the use of nitrification and urease inhibitors [6].

Ammonium Diffusion in Flooded Rice System: Is important to understand the process of N diffusion in anaerobic soil and the mechanism in alleviating N loss through the use of inhibitors. In flooded rice system, mineral N is more unstable than in aerobic condition. The instability of mineral N in flooded condition is presumably as a result adjoining aerobic zones that supports nitrification and anaerobic zones that promotes denitrification. These nitrification and denitrification can

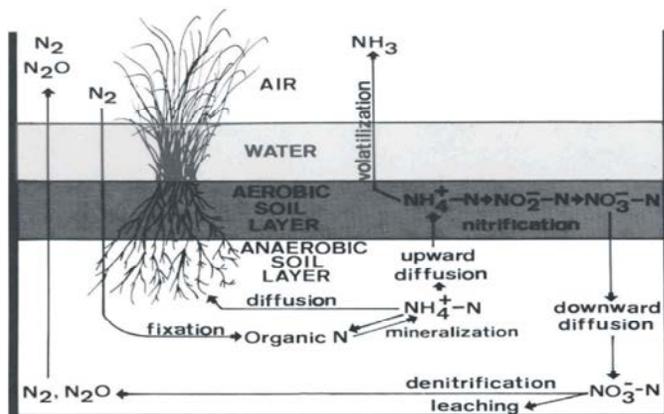


Fig. 1: Schematic diagram of N transformation in rice soil [8]

proceed concurrently. Flooded rice soil is characterized by two distinct layer; a thin aerobic layer (oxidized zone) normally ranging from few mm to 1-2 cm depth located at soil surface and underlying anaerobic (reduced) zone beneath of the aerobic layer (Fig. 1). The thickness of the oxidized zone depends on organic matter content that links to the biological activity since this resulted in O_2 consumption respiring organism and soil structure that influence the O_2 diffusion through the soil profile [7].

Ammonium released from urea fertilizer, will be oxidized to NO_3^- may leach move down into the aerobic layer at the soil surface, afterward due to the gradient in concentration, NO_3^- quickly move down into the anaerobic soil layer where the denitrification take place and transform NO_3^- to N_2O or N_2 . Nitrification in rice soils also occurred in the zone around the roots' rhizosphere. An oxidizing ability of rice roots has been known for many years. In rice plant system, O_2 can be adsorbed from atmosphere and transported from shoot to root through porous internal aerenchyma tissue. Oxygen then diffuse out into the rhizosphere root area and the resulting aerobic zone surrounding root tissue [7].

Nitrogen Fertilizer Loss Pathway: By far, N is the most complex and yield limiting nutrient to manage for fertilizer use efficiency in flooded environment; flooded soil which is anaerobic soil are very unique in terms of chemical and biological properties and involve in complex transformation processes [9] as discussed above. Urea when dissolved in the soil, is exposed to loss; the main N loss pathway in rice cultivation are NH_3 volatilization and nitrification denitrification [10]. Basically, leaching is not to be a major N loss pathway in rice cultivation as rice soils remain flooded and have low water infiltration [11].

Hydrolysis of Urea in Soil: The conversion urea to plant available NH_4^+ form in soil is termed urea hydrolysis. The N fertilizer losses problem related to the application of urea is dependent on the rate of urea hydrolysis. The hydrolysis of urea is promoted by a high biological activity at the soil surface [12] and the hydrolysis rate is influenced by soil urease activity which is present in many plants and plant litter and in most species of bacteria, yeast and fungi [13]. The urea fertilizer is usually hydrolyzed within a few days [6].

Surface application of urea may subjected it to hydrolysis process catalyzed by urease enzyme action in soil. Urea react with H_2O and soil urease enzyme to release NH_4^+ hydroxyl (OH^-) and carbonate (CO_3^{2-}) ions. Urea hydrolysis is summarized as follow:



The process of hydrolysis leads leading to a very high concentrations of NH_4^+ around the urea granule and increasing soil pH at the fertilizer microsite [14]. Furthermore, the OH^- formation can trigger the soil's pH around the applied urea particle to increase as high as around 9.0 which proliferate NH_3 volatilization [15]. Ammonium may transform to NH_3 , which can escape into the atmosphere depending on the pH. In addition, other than NH_3 volatilization, NH_4^+ that is produced through hydrolysis may undergo nitrification and denitrification which is subjected to N losses as well.

Ammonia Volatilization Losses: One of the disadvantages of urea is its volatile property which causes enormous boom losses of NH_3 to the atmosphere. Ammonia loss from urea have intensively been studied in

the laboratory and in the field [16-19]. Ammonia volatilization following urea applications is a major pathway by which N is lost from rice cultivation with submerged soils [10]. The potential of NH₃ volatilization is regulated by many factors such as soil pH, cation exchange capacity (CEC), temperature, water content, wind speed, the presence of free NH₃ near the soil surface [14].

About 50% of all the NH₃ emission worldwide is derived from agriculture sector [20]. The volatilization loss of NH₃ is highly influenced by the urea hydrolysis rate. Ammonium ion provided from urea hydrolysis will dissociate into NH₃ with the presence of OH⁻ as described in following equation:



The rapid accumulation of NH₄⁺ arising by hydrolysis and accompanying rise in pH liberate a volatilization gaseous loss of fertilizer as NH₃ [Eq 3]. Ammonia is formed because of the equilibrium between NH₄⁺ and NH₃. Equation 3 illustrated a simple reaction of the physical process of NH₃ transfer across a water surface (in contact with the atmosphere) when NH₃ is present in a soil solution [21]:



The pH is the virulence factor that accelerate NH₃ volatilization loss. It was stated that the magnitude of NH₃ volatilization is directly correlated to microsite soil pH around the fertilizer, which largely determines the ratio of NH₃ to NH₄⁺ in the soil solution [22].

Ammonia volatilization losses following urea application is a very serious in rice cropping and is likely the mechanism responsible for variation in urea performance [23]. Ammonia volatilization also can take place in acidic soil as reported previously by [16] due to the rise in microsite pH. The sharp rise in microsite pH increases the likelihood of NH₃ volatilization. The magnitude of NH₃ volatilization loss from flooded soils is associated with the volume of aqueous NH₃ or partial pressure of ammonia (pNH₃) in water at the interface with the atmosphere [10]. In flooded soil, high NH₄⁺ derived from urea hydrolysis can accumulate in floodwater; this coupled with elevated pH of floodwater during daytime due to photosynthesis process by aquatic plant and temperatures raises or favors the conditions for NH₃ volatilization [11]. The volatilization of NH₃ in rice flooded soil was reported to reach almost 60 % of applied N [24].

[4] mentioned that urea containing fertilizers losses nearly 30% or more of their N as NH₃ except they are rapidly incorporated into the soils.

Environmental Consequence of NH₃ Volatilization Loss:

Heavy emission of NH₃ from the agricultural sector, can both negatively impact the economy and environmental. Ammonia has a short lifetime in the atmosphere, but it can extend its life in the atmosphere by reaction with sulfuric acid (H₂SO₄) and nitric acid (HNO₃) in cloud droplets [25]. Emitted NH₃ may be returned to the soil surface in gaseous or dissolved form through dry deposition (attached to particulate matter) and wet deposition (dissolved in rain water). The deposited and dissolved NH₃ in downwind terrestrial and aquatic ecosystems causes water pollution problems like eutrophication.

Eutrophication is characterized as an over enrichment of nutrients in water bodies that bring adverse impact to aquatic life, such as algae bloom that will deplete dissolved oxygen (O₂) in the water, thus decreasing water quality as well [26]. Furthermore, high rates of photosynthesis associated with eutrophication can raise the pH to extreme levels during the day time [26]. Ammonia itself is not a greenhouse gas, unfortunately, it is a secondary sources of N₂O in the atmosphere and indirectly contributes to global warming. Therefore NH₃ volatilization have been identified as a source of N contributing to losses to the environment.

Nitrification and Denitrification: Apart from NH₃ volatilization loss, the coupled nitrification and denitrification processes are considered as one of the major contributing factors the losses of N in anaerobic rice field. Besides, the emissions of nitrogenous gas from nitrification and denitrification are of outstanding importance for the atmospheric.

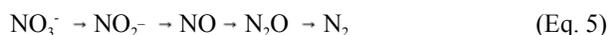
Nitrification: The remaining NH₄⁺ from hydrolysis, will undergone nitrification process. Nitrification refer to the two successive processes whereby in the first step NH₄⁺ is transformed to nitrite (NO₂⁻) which is further oxidized to very highly mobile NO₃⁻ (Eq 4). Nitrification is performed by two different group of bacteria known as ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB) [27]. The NO₂⁻ formation is carried by AOB while the latter is responsible for the conversion of NO₂⁻ to NO₃⁻. Ammonia oxidizing bacteria belong to the genera *Nitrosomonas* and *Nitrosococcus*. The second step of nitrification is mediated by bacteria of the genus *Nitrobacter* [28].



Nitrification does not only provides NO_3^- as substrate for denitrification but it also serve as a source for N_2O in soils [29]. When O_2 is limited, NO_2^- will accumulated in soil, alternatively nitrifiers using NO_2^- as an electron acceptor, NO_2^- is reduce rather than further oxide to NO_3^- and yielded in N_2O formation [30].

Nitrification happen in soil having adequate supply of soil water and air; maximum nitrification occurs when there is nearly 60 % of water filled pore space. In rice flooded soil, nitrification is regulated primarily by O_2 , temperature, soil and floodwater pH, NH_4^+ concentration and microbial population [9]. Generated NO_3^- from nitrification is subjected to: removal by plants, loss through leaching, immobilization by soil microorganism, reduction to N_2O or N_2 *via* denitrification [28] and dissimilatory reduction to NH_4^+ which occur in highly reduced soil [30].

Denitrification: More than 70% of the total rice cultivation area in the world is under flooded system [31]. Floodwater in rice soils provide anaerobic condition which facilitate denitrification, result into lowering of N fertilizer use efficiency in rice soil and emissions of nitrogenous gas losses to the environment. [11] reported denitrification loss from flooded rice soil was in range < 10 % of urea and can be as high as 33 %. Denitrification is a stepwise microbial mediated process by which NO_3^- is reduced into N_2 via intermediary products such as NO_2^- , nitric oxide (NO) and N_2O . Denitrification pathway is shown in equation 5 [32].



It was carried out by facultative anaerobic and catalyzed by nitrate reductase and nitrite reductase which are a major enzyme involved in denitrification [33]. Contrary with aerobic medium, NO_3^- is highly unstable under anaerobic condition. Oxygen is an electron acceptor for denitrifying organisms (in aerobic soil), but when there is a lack of O_2 concentration (in anaerobic soil) and adequate organic substrate, denitrifying bacteria may be alternatively use NO_3^- as an electron acceptor to reduce NO_3^- to NQ and N [9], in other words denitrifying microorganism obtain O_2 from NO_3^- . The more anaerobic the soil, the greater is the N_2 production. Denitrification pathway in soil governed by O_2 supply which is directly

correlated with water supply, temperature, pH and the presence of NO_3^- [7]. Denitrification process is faster at pH 6-8 [28]. Denitrifying microbial activity is temperature depended, it is negligible at temperature 3°C to 10°C.

Environmental Consequence of Nitrification

Denitrification Loss: Increase in global temperature have occurred in past years and have been connected to proliferate in greenhouse gas concentration in atmosphere. Among greenhouse gases, N_2O is of primary importance; it is a long live trace gas in the atmosphere for up to 114 years and has a global warming potential of 310 times greater than carbon dioxide (CO_2) [34]. The atmospheric N_2O have a strong capacity to absorb the infrared radiation and have raised the global temperature. On top of that, N_2O is the largest stratospheric ozone (O_3) layer depleting substance by oxidizing it into N-oxide (NO) in the stratosphere [35]. It has been known that O_3 layer protects the biosphere from harmful solar ultraviolet variation [24].

Nitrous oxide is originated by biological nitrification and denitrification reaction in soil. Denitrification is the main source of N_2O in water filled pore space (WFPS) higher than 70%, but nitrification is the main process when the WFPS decreases to 60% [36]. The agriculture activity account for roughly 87 % of total N_2O emissions, mainly from agricultural soils and animal waste management [37]. It is estimated that about 1.5 million tonnes of N is injected annually into the atmosphere as N_2O as a result of fertilizer application [6]. Particularly, emitted N_2O in rice field was due to the N fertilizer rate, anaerobic condition and cropping system [38]. Considering the importance of N_2O as a greenhouse gas and how much agricultural soils contribute to originate it, the development of strategies to decrease N_2O in the atmosphere should necessarily include agricultural practices.

Accumulation of NO_3^- in ecosystems are a cause for great concern, mainly from health and environmental issue. Nitrate is predominately produced as a result of nitrification and is prone to be lost into N_2O by denitrification and loss via leaching if drainage occurs. It is easily repelled from soil exchange sites due to its negative charge [39]. Rainfall intensity, evaporation rate, quantity and frequency of irrigation, soil texture and structure affect NO_3^- leaching potential [28]. Increased urea application rate, rainfall and temperature have raised NO_3^- leaching [40]. Build up of NO_3^- to aquatic systems

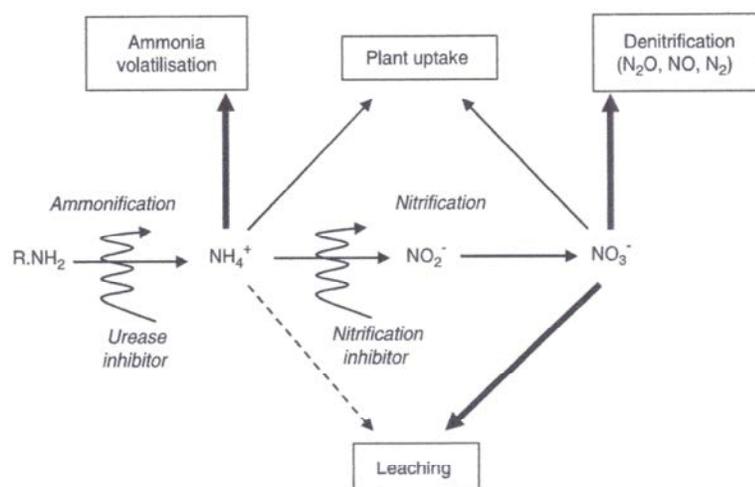


Fig. 2: The role of inhibitors in controlling nitrogen transformations and losses [6]

through leaching contributes to water pollution. Nitrate leaching makes its way into ground water; contaminated ground water by NO₃⁻ is hazardous if use as drinking water. As a result of health and environmental concerns, permitted NO₃⁻ concentration in drinking water have been set to less than 10 mg of NO₃⁻NL⁻¹ [41]. Excess NO₃⁻ when discharge into surface water such as stream, river and lakes will create an eutrophication and fish poisoning [42].

Inhibitors in Agriculture: In agriculture, nitrogen inhibitors are compounds used in controlling N dynamics in soils in order to minimize N losses and mitigate nitrogenous gases emission. Nitrogen inhibitor can be classified into two group: urease inhibitors and nitrification inhibitors. In general, the theory for using nitrification and urease inhibitor is they will slow N transformation by slowing the oxidation of applied N to NO₃⁻, causing N to stay in the more available form of NH₄⁺. [6] demonstrated the role of inhibitors in controlling N transformations and losses as described in Fig. 2.

The urease inhibitors are used to control urea hydrolysis through their effect on urease enzyme while the nitrification inhibitor is used to control the oxidation of NH₄⁺ ions to NO₂⁻. Both inhibitors are recommended for the purpose of minimizing N losses in soils which in turn increases yield, nitrogen use efficiency [43] and consequently produced positive impact toward to environment. Nitrification inhibitors do not inhibit nitrification indefinitely, but usually between 4 and 10 weeks depending upon soil temperature and pH [6].

Urease Inhibitors: A major potential associated with urea is loss of N gasses *via* NH₃ volatilization especially under dry soil condition, high temperature, high pH and high wind speed. As the urea efficiency is depends on hydrolysis process, the efficiency of fertilizer can be improved by slowing down the hydrolysis process. The use of urease inhibitor has thus been considered one effective strategy to slow down the hydrolysis of urea, by inhibiting the activity of urease enzyme, thus slow the transformation of urea to NH₄⁺ ion, reduce NH₄⁺ in soil solution or floodwater therefore lowers the potential of NH₃ volatilization and improve N efficiency of urea fertilizer [4]. The use of urease inhibitors can decrease the localized zones of high pH common with urea application [44].

Inhibition Mechanism of Urease Inhibitor and Class of the Inhibitor: The inhibition mechanism of urease inhibitor is mostly based on the binding of the enzyme and substrate. The mechanism can be classified into two categories based on the binding activity with urease enzyme either in a non competitive or a competitive manner. The competitive inhibitors compete with the substrate molecules for the active site and resembles with the substrate structure closely while in the non competitive mechanism the inhibitors affect the enzyme structure and induce inhibition. In non competitive inhibition, the mechanism is not specifically on the active site in the enzyme [45]. Many compound are capable of inhibiting of urease activity and can be broadly classified into two main categories as follow: organic compounds, such as acetohydroxamic acid, humic acid

and 1, 4-benzoquinone [46; 47] and heavy metal ions, such as Cu, Zn, Pd, Cd and Hg [48]. Urease enzyme have been tested highly sensitive to metal element [49]. The inhibitory effect of metal ion is stated as a consequence of the interaction of metals ion with a sulfhydryl group at the active center of the urease enzyme; the reaction is analogous to the formation of a metal sulfide [50]. Despite their performance as good inhibitors toward urease, some of them are heavy metals which have restriction for soil if their application exceeds the permitted level.

Urease Inhibitors Performance on N Losses and Fertilizer Efficiency: Thousands of chemicals both synthetic or natural compound have been identified and evaluated as soil urease inhibitors [51, 25, 52]. Of all the identified urease inhibitors, N-(n-Butyl) thiophosphoric triamide (NBPT), phenylphosphorodiamidate (PPD) and hydroquinone are the most thoroughly studied urease inhibitors [53]. N-(n-Butyl) thiophosphoric triamide is commercialized under trade name of Agrotain.

By slowing down the rate at which urea is hydrolyzed in the soil, volatilization losses of NH_3 can be minimized. Accordingly, the efficiency of urea is enhanced and any adverse environmental impact from their use is reduced. The application of urease inhibitor (Agrotain) reliably cause a reduction effect on NH_3 emission in laboratory experiments [54] and simultaneously improve plant production in rice cropping [55]. Instead of reducing loss and increasing plant production, Agrotain coated urea also improve grain quality [56]. The increment in yields attributable to the increase in N availability resulted in N uptake. The tested urease inhibitor slows down the urea hydrolysis process, which reduces the rapid increase of NH_4^+ and thus reduced increases in soil pH localized around fertilizer granule. N-(n-Butyl) thiophosphoric triamide was very effective in small concentration, approximately 50 % inhibition was observed with 0.01 % concentration [57]. Urease inhibitor NBPT have a potential in abating N_2O associated with lower NH_4^+ release [58], in contrast [25] reported that NBPT has no effects on N_2O abatement.

Urea amended with urease inhibitor (Agrotain) may delay urea hydrolysis and allow urea to move away both vertically and laterally from the surface soil layer to the sub surface soil layer. Urease inhibitor allowed more time for rainfall or irrigation to move urea granule from the surface layer to the sub soil layers where it is likely to make good contact with plant roots. The principal advantages of urease inhibitors as concluded by [59]

included: a drastically reduction in NH_3 volatilization loss thus yielding in an increase in available N for plant uptake; an improvement the efficient use of N fertilizers; a reduction effect in the emission of N_2O and lower the potential of seedling damage.

Some of the metal ion are micro elements beneficial for plant growth. The application of micronutrients and urea at rate compatible with nutrient recommendations may have double advantages if the micronutrients show urease inhibitory effect [60]. Zinc coated with urea not only accelerate Zn uptake and N uptake but also have a marked effect on grain protein content of rice [61]. With regards to NH_3 volatilization aspect, the outcome in laboratory experiment proved that Cu coated urea can reduce 30-67 % of NH_3 loss from soils [18]; the same author also reported the similar observation with respect to urea hydrolysis. Increase of 20% - 60 %, 77% have been recorded by the application Cu coated urea in maize dry matter yield and maize N uptake respectively, in pot experiment [62]. As well as Cu coated urea and micronutrients (Cu in combination with Zn) coated urea enhanced grass yield and N uptake up to 50% in field study [63].

Nitrification Inhibitor: The nitrification inhibitors have played a vital role in the controlling N loss during nitrification denitrification processes and recommended by IPCC as a potential mitigation option for N_2O emissions [64]. A large number of chemical; synthetic or natural compound have been found to have nitrification inhibiting properties including plant derived product [65; 66]. Hundreds of nitrification inhibitors are known; only a few gain practical importance as nitrification inhibitors. To the date, Nitraphyrin, 3, 4-Dimethylpyrazol-phosphate (DMPP) and (dicyandiamide) DCD have emerged for commercial use [60].

Mechanism of Nitrification Inhibitors: Nitrification inhibitors are compounds that delay the oxidation of the NH_4^+ to NO_2^- ; the first step of nitrification by depressing over a certain period of time the activity of ammonia monooxygenase (AMO) enzyme of the AOB and renders it inactive [67]. Specifically, DMPP act by indiscriminately binding to the complex of membrane proteins inclusively AMO as presented in Fig. 3 [68]. Nitrification inhibitor reduce N_2O directly by inhibiting the nitrification process and indirectly reducing N_2O emission by suppressing NO_3^- release, the substrate for denitrification; hence both major pathways of N_2O in soils are blocked [29].

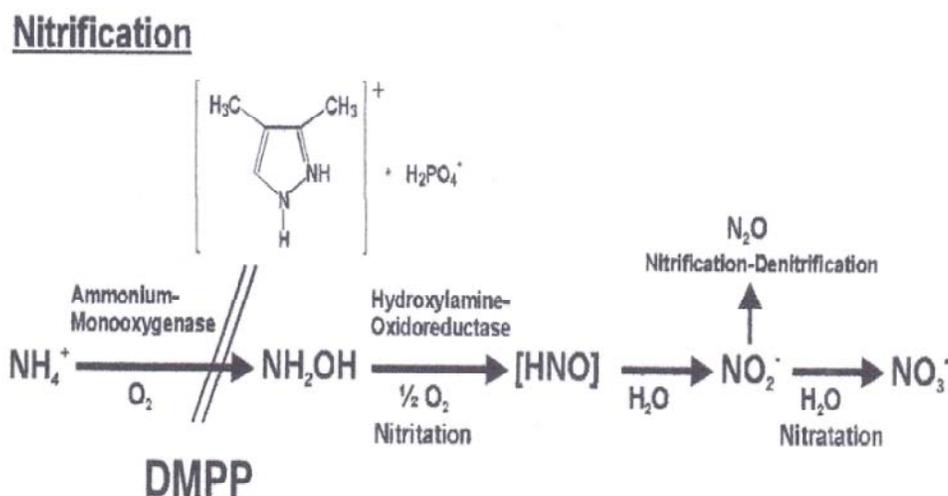


Fig. 3: Chemical formula and mechanism of DMPP [68]

Nitrification Inhibitor Performance on N Losses: The main purpose of nitrification inhibitor is to mitigate the emission of N_2O by denitrification and control NO_3^- leaching thereby prolonging the persistence of N in the NH_4^+ form in soil thus increasing efficiency of N fertilizers. Analysis on DCD and DMPP, both nitrification inhibitors were effective in reducing N_2O ; the inhibitory effect for DCD was 42.3% and for DMPP was 40.2%, with emission factors for N fertilizer amendment with DCD and DMPP of 0.41% and 0.7%, respectively [69]. Inhibitory effect for DCD and DMPP was 26.5% on rice field [69]. The nitrification inhibitor diminish the availability of NO_3^- and its vulnerability to escape mechanisms.

[70] synthesized the results of multiple nitrification inhibitor in field studies and concluded that inhibiting nitrification process by inhibitor reduces N_2O emission with average of 44%, decrease dissolved inorganic N leaching with average of 48% and this represented reduction of 16.5 % in total N that escaped to the environment. Moreover nitrification inhibitor are also efficient in improving plant N recovery (58%), productivity of grain and straw amounting to 9% and 15% increment respectively. However, nitrification inhibitor also yielded negative impacts, such as increase in NH_3 volatilization loss with an average of 20 %.

Dimethylpyrazol-phosphate produced with distinct advantages over other nitrification inhibitors. Field studies revealed that DMPP is superior to DCD in the mitigation of NO_3^- leaching and N_2O emissions and its inhibitory effect was long lasting [68]. It is highly effective at very low rates, even at application of $0.5\text{--}1.5 \text{ kg ha}^{-1}$ it was able to suppress nitrification over a period of 4–10 weeks under field conditions [67]. It has no phytotoxic reaction and highly plant compatible. Various toxicology

test carried out proved that DMPP revealed no toxic and ecotoxic side effect [67]. A further advantage of DMPP is their performance at higher temperature. Under temperature as high as $26\text{--}32^\circ\text{C}$, DMPP stabilize NH_4^+ and delay NO_3^- leaching for a period of several weeks [71;72]. The mobility of DMPP within the soil is lower than NH_4^+ and consequently the tendency of DMPP being leached into the groundwater is very low [67]. Dimethylpyrazol-phosphate also have affected the activity of nitrate reductase and nitrite reductase enzyme; the enzyme that catalyze the formation of N_2O during denitrification [33].

Future Prospects of Inhibitors in Agriculture: The use of urease and nitrification inhibitors is one of the mitigation options to mitigate NH_3 volatilization, N_2O emission and to control N dynamics in soils. For positive economic benefit in rice production, the N saved from gaseous losses by using the inhibitors would have to result in an improvement in rice production with a value greater than the cost of the inhibitors. [70] reported that the cost and economic analysis exhibited that the economic benefit of reducing N environmental impacts offsets the cost of inhibitor application. The economic benefits of reduced environmental pollution and destruction to our environment from gaseous emissions are of higher significance over the long-term than the productivity gains [6]. Therefore, in future application of urea emended with urease and nitrification inhibitor have a potential in reducing N gaseous emissions and improving N efficiency of fertilizers in anaerobic soils as global warming is one of the priority issue nowadays which has become more and more serious in recent years. Nevertheless, findings such as the observed effect of inhibitor of the experimental soil, consider that more

studies under tropical conditions are necessary to confirm these results and to study the influence of urease and nitrification inhibitors on NH_3 , N_2O for anaerobic soil.

CONCLUSIONS

Nitrogen fertilizer losses through ammonia volatilization, nitrification and denitrification processes may reduce fertilizer N use efficiency, cause economic loss, environmental pollution and health problems. Although these problems cannot be alleviated completely, there are research findings that these problems can be minimized by the used of urease and nitrification inhibitor. Application of urease inhibitors or nitrification inhibitors amended with N fertilizers, improves the availability of N in soil, effective in reducing N losses, resulting in increased N use efficiency and crop yield. Such increases result from the delayed urea hydrolysis by urease inhibitors and retention of N in NH_4^+ available form by nitrification inhibitor. The economic benefits of reduced environmental pollution, improved fertilizer N efficiency and future reduce damage to our environment as a result of the use of urease inhibitors and nitrification are of higher significance to the production of gains over the long-term.

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