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The Most Important Factors affecting Nitrogen Use Efficiency: A review

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أهم العوامل المؤثرة على كفاءة استخدام النيتروجين (مراجعة)

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ABSTRACT

Nitrogen is basic and necessary element contributing to plant growth and development. It is one of the most nutritious fertilizers used in agriculture. Adding a sufficient amount of Nitrogen will increase production, but the excessive use of nitrogen fertilizers has led to environmental pollution and the deterioration of the ecosystem. The plants use 50% of the added nitrogen and the remaining portion is lost to the environment in various ways, and thus it will affect the farms and pollute the soil, air, and water. Consequently, it has negative effects on humans and animals, as the emission of NH_3, N_2O, and NO in gaseous form through denitrification and volatilization, which causes dangerous environmental problems, as well as an increase in the value of production due to the loss of fertilizers from the ecosystem. Therefore, nitrogen use efficiency (NUE) must be developed and enhanced through agricultural management to improve plant production. This review describes several factors that participate in the loss of nitrogen from soil-plant systems, such as nitrification, volatilization, filtration, denitrification, ammonium fixation, surface runoff, and stabilization, plant factors, temperature, rainfall and irrigation, tillage, soil texture, Crop residues and soil quality, nitrogen management.

Keywords: Nitrogen, Soil, plant, Fertilizer.

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INTRODUCTION

Nitrogen is an essential and necessary element, and improving the use of nitrogen (NUE) is an important process to increase food and energy production per unit area to keep pace with increasing population growth and greater pressures on fertile lands. Therefore, agricultural practices must work to increase productivity as well as protect human and animal health and the environment [1, 2]. N is essential for plants, as it contributes to their growth and development, as it is a major component in cells. Nitrogen fertilizers are the second most needed fertilizer behind water in plant production [3]. To achieve high productivity and healthy growth, plants such as wheat, corn, and rice need high amounts of nitrogen [4]. Organic nitrogen constitutes the largest portion of the existing nitrogen and is not directly available to the plant, while biological fixation provides nitrogen additionally [5]. 50% of the added nitrogen is converted into an available form for the plant, and the remaining forms of nitrogen available in the plant are nitrate (NO_3^-) and ammonium (NH_4^+) [6]. The NUE yield is affected by the physiological activity of plants, their interactions, and environmental factors. Biochemical N transformations in the soil are complex, and the physical losses of nitrogen from the soil and plants affect and reduce the use of NUE. Nitrogen is lost in major ways, namely the leaching of dissolved NO_3, the volatilization of ammonia gas (NH_3) and Surface runoff of dissolved forms. Rainfall also affects enzymatic and biological activity rates, as do changes in temperature. While photosynthesis rates, leaf expansion, and root characteristics, which are mainly responsible for absorbing nitrogen and NUE are affected by low nitrogen [7]. Nitrogen is the primary element of plant proteins, chlorophyll, and nucleic acids [8]. Although nitrogen is abundant in the atmosphere, it needs to be converted into a usable form by soil microorganisms. This conversion process, known as nitrogen fixation or nitrification, is conveyed through nitrogen-fixing bacteria in the soil, such as *Nitrosomonas* and *Nitrobacter* [9]. However, nitrogen can be lost through leaching and denitrification, causing environmental contamination. Maintaining the soil's microbiome is crucial to ensuring nitrogen availability to plants, but it can be expensive and time-consuming [8]. Nitrogen fertilizers play a crucial role in modern agriculture by enhancing crop yield and supporting soil fertility. However, their use can lead to soil and environmental degradation [10, 1]. The effect of fertilizers on soil fertility depends on several factors, such as nutrient content, type of soil, management practices, and climate [11]. Fertilizers can cause changes in the physical, chemical, and biological properties of the soil. For example, nitrogen fertilizers can contribute to soil acidification and lessen soil organic matter content, reducing fertility and productivity. However, appropriate fertilizer application can help maintain soil fertility and promote healthy plant growth. This review aims to elucidate the factors

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that are accountable for nitrogen loss, reduce NUE and the harm of NUE and their influence on the environment.

Nitrogen loss pathways

Globally, 50% of NH_3 gas is lost due to agricultural activities through volatilization into the atmosphere [12]. The two main sources of NH_3 emissions in agriculture are the use of natural fertilizer and animal activity. Chemical nitrogen fertilizers are the cause of 34% of nitrogen loss [13]. Especially urea, due to the increase in soil acidity as a result of hydrolysis, when the soil pH rises to 7.5 and temperatures rise to 45 degrees Celsius, and due to sufficient air movement, NH_3 is removed at the surface between the atmosphere and the soil [11].

Hydrolysis ofurea

The final step in organic nitrogen mineralization is the hydrolysis of urea. A large number of organisms in the environment have the ability to produce urease enzymes, for example, bacteria, plants, and fungi [14]. The enzyme is present in most types of soil and is sufficient and free in solution to decompose urea into NH3 [15]. Therefore, urease must be inhibited to prevent the conversion of urea into NH3 and the loss of nitrogen by volatilization so that urea can be safely added to the soil [3].

Leaching process

Nitrate is affected by leaching because of the negative charge of NO_3^-, This prevents their binding to the negative charge of colloids in soil, while $NH4^+$ is protected from leaching and is electrostatically attracted to the colloids because of its positive charge [16]. So heavy rains, irrigation, and slow cropping periods eliminate nitrates from the system [3].

Nitrification

Nitrification results from autotrophic bacteria that occur through oxidation to convert ammonium into nitrate [17]. It takes place in two stages: The first is accomplished by bacteria such as *Nitrosospira* and *Nitrosomonas*, which oxidize NH_4^+ to negative nitrite (NO_2^-) [18]. The second stage converts NO_2^- into NO_3^- by *Nitrobacter*. The second step is more efficient and rapid than the first, which prevents nitrite from assembling in the soil [19].

Denitrification

The process of denitrification is also mediated by microbes, where nitrite is reduced to nitrogen gas [20]. It is produced by facultative anaerobic bacteria by nitrite and nitrate reductase enzymes [21].

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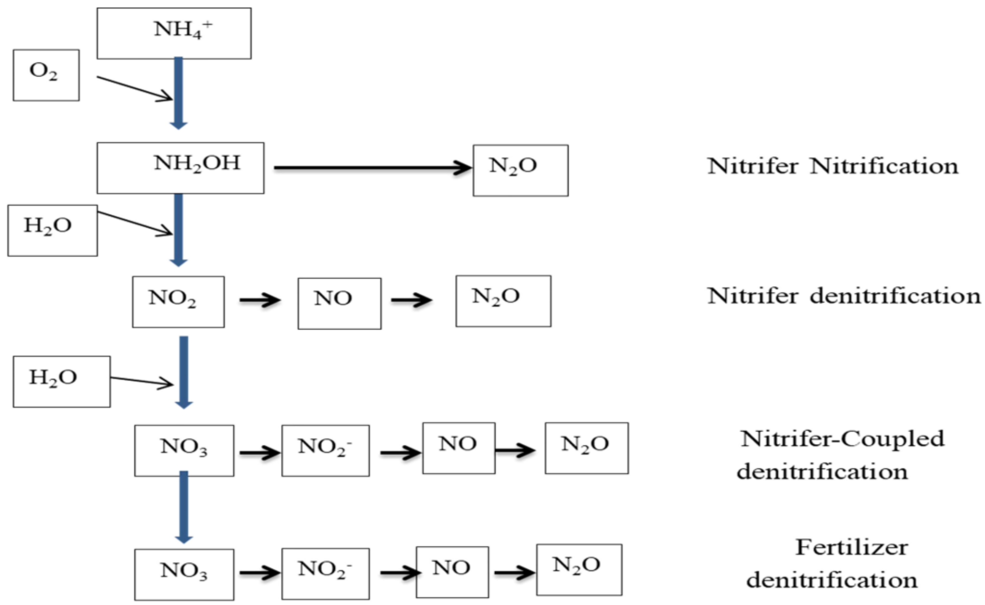

Figure. Different pathways of N_2O production in soil [22].

Soil erosion and surface runoff

The principal determinants of soil and nutrient loss and transport are soil type, rainfall intensity, and vegetation [23]. Nitrogen and organic matter concentrations are often found in soil near the surface; they are easily transported by erosion and runoff and can lose approx. 70% of the nitrogen fertilizers added to the surface in the event of rainfall and surface runoff occurring within twenty-four hours [24].

Plant factors

Plants differ in their ability to absorb nitrogen. Plant growth rate, productivity, nitrogen absorption, and achieving agricultural NUE in plants can be increased by supplying optimum soil humidity [25, 26]. High growth rates of crop plants require sufficient nitrogen during vegetative growth [27]. Conversely, if nitrogen is not released during the vegetative growth stage, crop production can decline. One of the main pathways for nitrogen retention in the soil is nitrogen fixation [28].

Environmental factors

The agricultural use of plants is affected by environmental factors, including temperature, rain, and radiation [29]. The possibility of obtaining nitrogen from the roots at low temperatures decreases significantly [30]. Nitrogen is lost at high temperatures, as a result, NUE decreases [31]. The intensity, duration, and frequency of rainfall during the growing season also affect the loss and absorption of nitrogen [32]. Plant growth and nitrogen uptake are also affected by photosynthesis [33].

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FACTORS OF MANAGEMENT

Fifty percent of the nitrogen utilized is lost to the environment, resulting in resource loss and an increase in greenhouse gas emissions [34]. Low nitrogen efficiency is a result of selecting plants and varieties with poor nitrogen uptake and inefficient use of nitrogen [35]. In addition to the loss of nitrogen from plant residues after harvest and from the soil [36]. Likewise, intensive plant cultivation reduces the efficiency of the nitrogen used, the efficiency of nitrogen use is also weak due to synthetic nitrogen fertilizers instead of symbiotic nitrogen fixation [37]. In addition, flood and uncontrolled irrigation lead to NO_3^- leaching because of the high solubility and negative charge, which causes a lack of oxygen that leads to an increase in denitrifying microorganisms, High temperatures and wind speeds also high the danger of NH_3 volatilization [38]. High soil temperature increases the rate of nitrification, leading to loss of nitrogen and weakening of NUE [39].

THE HARMS OF NUE AND THEIR IMPACT ON THE ENVIRONMENT

The atmosphere has been affected, drinking is polluted, and the ecosystem deteriorates as a result of nitrogen fertilizers that are lost to the environment [40]. Additionally, nitrate-containing groundwater is a serious hazard [41]. Since nitrogen oxides are highly reactive and harmful for the environment, they are formed nitric acid, that leads to acid rain, affecting infrastructure and microbial communities in the soil [12]. As a result of the combination of volatile organic materials with nitrous oxide, ozone pollution in the atmosphere occurs [42]. Consequently, it has negative effects on humans and animals, such as the emission of NH_3, N_2O, and NO in gaseous form through denitrification and volatilization, which causes dangerous environmental problems, as well as an increase in the value of production due to the loss of fertilizers from the ecosystem [43, 44]. also the phenomenon of world warming because of one of the powerful greenhouse gases, nitrous oxide [45]. Increased NO_3^- leaching as a result of adding large amounts of nitrogen to the soil, thus reducing NUE [46]. Nitrogen loss varies greatly between fields due to different soil types, Plant growth stages, rainfall, and management strategies, especially fertilizers, irrigation, etc. [47, 48].

NUE AND CONSERVATION TILLAGE SYSTEM

Factors that improve NUE, for example, the rate, timing, and source of adding fertilizers, as well as using modern technologies [3]. That is, the proper source, rate, time, and place, which reduces nutrient losses, increases fertilizer efficiency and reduces environmental risks [49]. Sustainable management of soil nitrogen depends largely on soil analysis [50]. This approach offers agricultural, environmental, and economic benefits, improving production costs and fertilizer doses, improving crop quality and productivity, and reducing nutrient loss to the atmosphere and water. The controlled release of nitrogen fertilizers by packaging these fertilizers with types of synthetic or natural products [51, 52] These fertilizers control the slow release of nutrients so that the nutrients reach their target locations in plants and are absorbed and used in a longer time compared to other fertilizers [50, 53].

Nitrogen sources

Nitrogen represents 78% of the atmosphere, but it is not available to plants except legumes, which are added through nitrogen fixation by lightning, rainfall, and thunderstorms, by heterotrophs (*Azospirillum*, *Azotobacter*) and autotrophs Cyanobacteria (blue-green algae) which provide multiple benefits such as increased NUE, reduced nitrate leaching and urea application, and increased soil organic carbon and post-harvest soil N [54]. One of the basic elements of nitrogen in the soil is organic matter. Adding organic fertilizer from plant or animal sources does not provide sufficient nitrogen for the plant to obtain appropriate production [50].

The rate of NUE

Environmental problems and economic losses to farmers resulting from excessive use of fertilizers and insufficient nutrients cause poor soil productivity for a long period of time because of low soil fertility that leads to nutrient extraction (degradation) [55]. [56] observed in a study on corn with nitrogen highest grain production, nitrogen accumulation in grains, improved dry weight of shoots, and increased NUE and nitrogen metabolism enzymes.

The placement

The appropriate equipment that the farmer owns contributes to multiple applications at low rates, increases production, and reduces losses, according to the appropriate time and quantity [3]. To reduce nitrogen losses, fertilizers are placed near the root area of plants. Fertilizers are combined with tillage, injections via broadcasting, or it is used during planting and placed under the seed. This increases NUE and reduces nitrogen losses through ammonia volatilization [57]. Nitrogen is also added with irrigation, which is considered another option, adding nitrogen to a depth of 15 cm increased nitrogen uptake and grain yield in corn [58].

The timing

To avoid loss of nutrients, the time of nutrient use must coincide with the requirement of plants for nutrients as much as possible. For example, agricultural nitrogen efficiency, the efficiency of physiological, seed productivity, and nitrogen absorption improved when nitrogen is added to maize in 4 stages: the seed stage, the sixth leaf stage, the twelfth leaf stage, and the Seed silk [59]. Nitrogen fertilizers are characterized by slow release and the ability to improve the synchronization and release of nitrogen and its absorption according to plant needs and reduce nitrogen losses through filtration and denitrification [60].

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Root uptake and effect of plant

Plants' uptake of nitrogen is affected by root morphology, which plays a crucial role [61]. It can reduce nitrogen losses in plants with rapid root growth [62]. In the barley plant, [63] observed an increase in the NUE value due to the increased root dry weight compared to normal plants. Due to improvements in root traits such as root length, root surface area, root radius, and number [64]. The absorption and use of nitrogen during plant growth are divided into 2 stages: synthesis and post-synthesis [65]. In the first stage, plants absorb nitrogen, at the beginning of the stem elongation stage, and it is used by the entire plant system. In the second stage, when the grains appear, the available nitrogen is divided by the plant to obtain high grain productivity [66]. Nitrogen use is related to physiological conditions more efficiently and to an increase in leaves during the vegetative growth stage [65]. Usually, in the post-synthesis stage, nitrogen is pulled from the stem and leaves towards the grains, and in some plants, nitrogen is slowly provided to the grains to maintain nitrogen within the framework of provide and request [67]. The movement of auxin is regulated by proteins and leads to the development of the lateral root. NUE is controlled by physiological, agronomic, genetic, and environmental traits that evolve the NUE of the plant [68].

Soil texture

Soil texture is affected by clay content, which is a key regulator that affects nitrogen immobilization [69]. The large reactive surface area that clay particles have, facilitates abiotic N immobilization through enhanced aggregation in soil [70]. Meanwhile, clay particles can facilitate microbial growth through microbial biomass preservation, prompting closer interactions, and the retention of more microbial decay products in the vicinity of surviving cells [71]. Therefore, high clay contents would result in the immobilization of high N proportions into microbial biomass. In addition, soil texture can influence soil aeration/moisture status and affect the distribution of organic matter in the soil, and, in turn, the decomposition potential, and provide some degree of protection for organic matter through the combination of organic matter with clay particles [72]. The effect of soil texture on N immobilization is complex. Therefore, fine-textured soils (such as clay and clay loam) generally immobilize more N than coarse-textured soils (such as sand and sandy loam) [70]. In N-limited soil, microbial activity is facilitated by increasing the availability of nitrogen and thus stimulating biological processes. Also, the availability of nitrogen is affected by the pH of the soil [73].

Crop residues and soil quality

Crop residues affect nitrogen immobilization through their decomposition [27]. Plant remainders contain highly labeled organic compounds and by stimulating microbial growth, they increase biogenic nitrogen immobilization and subsequent increases in microbial nitrogen requests for metabolism [74]. Microorganisms preferentially

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assimilate NH4+ in the form of inorganic nitrogen into cellular components [28]. While microorganisms convert NO_3^- into NH_4^+ before they are assimilated [75]. In soils with high concentrations of $NO_3^-$and carbon, microbial fixation of nitrate occurs with low concentrations of NH_4^+ [76]. Because microbes have the ability to quickly convert NO_2^- gases into nitrogen or NO_3^-, therefore microorganisms fix nitrite at a relatively low rate [77]. In general, processes of abiotic control the immobilization of NO2- and NO3-, while biotic and abiotic processes control the immobilization of NH_4^+ [78, 79]. Soil pH affects the nitrogen content in the soil (pH less than 8.4), Due to the metabolism of microbes stimulation on NH_4^+ immobilization [80]. In acidic soils (pH less than 6.2), reactions of abiotic favor NH_3 and NH_4^+ and replace them in clay elements [81]. While alkaline soils do not prefer to immobilize NO_3^- [82].

Save nitrogen and reduce losses

The tillage

Soil tillage systems greatly affect the nitrogen content in the soil [83]. Aerobic conditions are created by conventional tillage and promote the decomposition of organic matter and plant residues in the soil, thus making nitrogen readily available and increasing the potential for nitrogen loss [84]. Tillage improves NUE and reduces nitrogen loss, the chemical, biological and physical characteristics of soil are affected by deep tillage [85].

Management of Irrigation

Water has a major role in regulating reduction and oxidation through the soil, and thus affects the availability of nutrients through the soil, their movement, and their absorption by plants [86, 87]. Therefore, multiple methods were adopted, including controlled irrigation, drying, midseason drainage and humidifying, and intermittent irrigation, in order to increase nitrogen extraction without affecting grains, increasing the efficiency of water use and reducing greenhouse gases emitted [88,85].

CONCLUSION

Our study showed that nitrogen must be provided in sufficient quantities that are suited to the requirements of plants, considering the factors affecting nitrogen use efficiency (NUE), which include the soil, plant, and environment. N Fertilizer is concerning as it causes a detrimental impact on the environment and production costs. To improve nitrogen, use for soil and plants, modern agricultural strategies, breeding, and biotechnology must be integrated to complement the management of essential nutrients. Techniques used in agriculture, include the use of nitrogen fertilizers, precise timing, conservation tillage, nutrient management, planting high-biomass plants, and retaining plant residues under different soil and climate conditions.

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