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REVIEW

A Review on Impact of Different Nitrogen Management Techniques on Maize (*Zea mays* L.) Crop Performance

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Abstract

Nitrogen (N), as a primary nutrient requirement of maize (*Zea mays* L.), plays a critical role in its development and productivity. Proper nitrogen management practices involve a delicate balance between providing an adequate amount of this nutrient and mitigating potential environmental impacts. When implemented effectively, these practices can significantly improve corn production. An adequate nitrogen supply promotes vigorous vegetative growth, contributing to strong stalks and an abundance of leaves, which are essential for maximizing the plant's photosynthetic capacity. This lush foliage, in turn, leads to increased photosynthesis and carbohydrate production, providing the energy maize needs throughout the reproductive stage to develop and fill its kernels. In addition, nitrogen is closely linked to kernel development. Well-timed and dosed nitrogen applications can result in larger, well-filled ears with plump kernels, ultimately increasing both the quantity and quality of the maize yield. Environmental considerations, such as reducing nitrogen runoff and greenhouse gas emissions, are important for maintaining ecosystems and mitigating climate change. Thus, this review article highlights the need for a holistic approach to nitrogen management, combining innovative techniques with sustainable agricultural practices, to ensure food security and environmental conservation in maize production systems.

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Statement of Sustainability: This study aims to promote the Sustainable Development Goals (SDGs) by considering key issues related to sustainability. Increasing soil productivity contributes to the achievement of Goal 2 (Zero Hunger) and aims to achieve SDG 1 (No Poverty) by improving the livelihoods of farmers. In addition, by minimizing the negative environmental impacts of excessive nitrogen use and supporting biodiversity conservation, it indirectly supports SDG 15 (Life on Land). Ultimately, the goal of our research is the achievement of multiple SDGs, no poverty and zero hunger.

1. Introduction

Maize (*Zea mays* L.) is the third most important cereal crop in the world after wheat and rice (Adhikari et al., 2021). In Nepal, it is one of the major crops and is second only to rice in terms of production and area (Govind et al., 2015). It has a higher preference than other crops because it can be grown in almost all seasons and locations. Maize is grown in 957,650 ha with an average production of 28.35,674 MT and productivity of 2.96 MT/ha (Dhakal et al., 2022). Maize is consumed as a staple food by a large population. Recently, its demand has been high due to the increasing number of poultry and feed industries in Nepal (Ghimire et al., 2019). The main maize-growing areas of Nepal, i.e., the mid-hills, are still dominated by traditional practices. Thus, it has been found that the average grain yield of maize under current farming practices is 2 tons/ha, whereas better agronomic management practices improve the yield to 6.5 tons/ha (i.e., an exploitable yield gap of 4.5 tons/ha) (Dhakal et al., 2022). Under such circumstances, the growing demand can only be met by increasing the productivity of maize with the available shrunken land (Govind et al., 2015).

Maize is an exhaustive crop that requires a large amount of nitrogen (N) during the critical growth stages (25 and 40 days after sowing and before tasseling) for maximum production (Bhandari et al., 2019). The productivity of maize mainly depends on nutrient management. Among all essential nutrients, nitrogen is one of the most important for maize crop production (Sharifi and Taghizadeh, 2009). The qualitative characteristics of cereal crops, such as yield and protein content, are greatly influenced by nitrogen fertilizer (Dhital et al., 2022). Nitrogen application increases plant height by increasing internode distance and internode length, which in turn increases the number of leaves per plant and improves photosynthesis in maize, in addition to increasing leaf area, stem diameter, and dry yield of maize (Hammad et al., 2022). In today's agricultural production, nitrogen fertilizer use is an essential indicator or condition to ensure high and consistent crop yield (Evenson and Gollin, 2003). Adequate nitrogen fertilizer supply enhances overall biomass production and crop yield, whereas insufficient nitrogen fertilizer supply inhibits plant dry matter accumulation in reproductive organs and results in inferior grain yield. Therefore, optimal nitrogen fertilizer utilization by a plant is a critical determinant of high crop yield (Hammad et al., 2022). However, mineral nitrogen is primarily lost in agricultural practices through ammonia volatilization, leaching (i.e., removal in drainage water), and denitrification (i.e., conversion to gaseous forms), which not only leads to nitrogen deficit but also has negative environmental impacts (Cameron et al., 2013). That's why a common nutrient management framework known as the "Four-Rs" is considered, which includes the Right Amount - the right rate of application; the Right Source - applying the right type; the Right Placement - using the right method for application; and Right Timing - applying at the right time in the life cycle of the system, which aims at reducing applied fertilizer and increasing crop yield (Fixen, 2020).

2. Nitrogen Management Techniques

Nitrogen is one of the essential nutrients for better crop performance (Cheema et al., 2010). It is a voluminous element, consisting of 78% volume of air however practically unavailable to plants except leguminous crops. The natural source does not provide enough nitrogen for a satisfactory yield (Alam et al., 2023). Moreover, studies by Yadav et al. (2023a) have highlighted the adverse effects of high applications of NPK fertilizers, which can deplete the soil of essential micronutrients over time and disrupt beneficial soil organisms that facilitate nutrient uptake by plants. Therefore, the appropriate way to address soil fertility depletion is the combined application of organic and inorganic fertilizer that improves soil fertility management (Chivenge et al., 2011). Successful nitrogen management minimizes losses to water and air while providing the crop with sufficient nitrogen to maximize production and profitability (Figure 1). With nitrogen, it is relatively easy to achieve both economic and environmental goals. Therefore, best management practices (BMPs) are considered sound practices from an economic, production, and environmental perspective (Scharf et al., 2006).

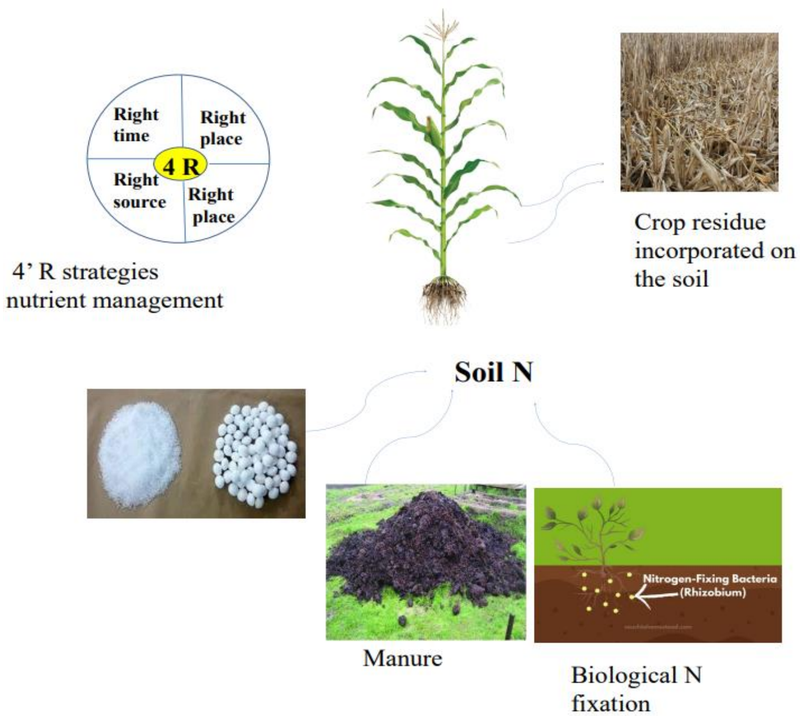

Figure 1. Nitrogen management techniques adopted by the agricultural sector.

2.1. Site-Specific Nitrogen Management

Most fertilizer management strategies do not account for field-specific variations in available soil nitrogen status. As a result, there is a risk of over-applying nitrogen fertilizer, which can result in low nitrogen use efficiency (NUE). Site-specific nitrogen management is a plant-based technique to provide nutrients to crops in the right amount and at the right time (Ghimire et al., 2015). The grain yield produced by SSNM is equivalent to a soil test-based fixed nitrogen rate, reducing nitrogen fertilizer by 20-60% (Varinderpal-Singh et al., 2023). SSNM has been recommended as one of the means to further increase nitrogen fertilizer efficiency while minimizing environmental impact (Ferguson et al., 2002). The SSNM approach takes several parameters into account when calculating the appropriate nitrogen requirement for the crop. These factors include crop nitrogen demand, desired yield, climatic conditions (temperature and solar radiation), nitrogen supply from soil, irrigation water, mineralization of crop residues, and other organic matter (Peng et al., 2010).

Soil chemical analysis is unreliable for estimating indigenous soil nitrogen supply. To obtain a field-specific estimate of indigenous nitrogen supply, grain yield measurement in the nitrogen omission plot is used. In the growing season, a chlorophyll meter (SPAD) or leaf color chart is a good indicator to estimate crop nitrogen demand on a leaf area basis (Nayak et al., 2023; Eni, 1967). Adjustments to predetermined nitrogen rates are made during the season based on SPAD or leaf color chart measurements at critical growth stages. The timing and number of nitrogen applications are fixed in this method, while the rate of nitrogen topdressing varies between seasons and locations (Peng et al., 2010).

2.2. Integrated Nitrogen Management

Integrated nitrogen management is known as the consolidation of organic and inorganic sources of plant nutrients, which improves soil nutrition, crop root system, and soil organic carbon, resulting in improved crop growth and optimal yield production (Sarwar et al., 2021). Organic sources enhance the activities of soil microbes, which play an important role in nitrogen mobilization and better NUE (Alam et al., 2023). Incorporation of organic matter, whether in the form of crop residues, organic manure such as farmyard manure (FYM), vermicompost, bio-compost, etc., or amendments, has a significant effect on bulk density, soil aggregation, soil structure, soil moisture holding capacity, soil tilth and infiltration rate (Gudadhe, 2018).

Maize is a heavy feeder and is more responsive to nutrient application; due to the low nutrient content of organic fertilizer, it alone does not give a better yield. On the other hand, inorganic fertilizers are the potential sources of higher nutrients in easily available form, so they cannot be avoided. The application of inorganic fertilizer alone degrades soil health, so sustainable crop production can be achieved by applying an appropriate combination of organic and inorganic fertilizers (Iqbal et al., 2014).

2.3. Controlled Release of Nitrogen Fertilizers

Crop growth and development vary with the form of nitrogen application (Ghafoor et al., 2021) reported that worldwide in the agricultural sector, about 0-65% of ammonia is volatilized from urea fertilizer based on environmental and soil characteristics (Figure 2). Nitrogen loss is the main problem that affects soil health conditions and causes environmental pollution. Therefore, to improve nitrogen utilization efficiency, controlled release of nitrogen fertilizer is in practice. Controlled-release nitrogen fertilizers are granular fertilizers covered with a semi-permeable membrane that slowly releases nutrients into the soil over a period and are widely used in agricultural productivity. This approach is expected to avoid excessive nitrogen input and nitrogen loss to the environment in the crop production system (Yao et al., 2021).

Coating nitrogenous fertilizers with appropriate materials reduces the solubility of the fertilizer, resulting in slow release in the soil (Beig et al., 2020). Inorganic materials and organic polymers are the two main groups of coating materials. Inorganic materials consist of sulfur, bentonite, and phospho-gypsum, while organic polymers can be either synthetic polymers such as polyurethane, polyethylene, alkyd resin, etc., or natural polymers such as starch, chitosan, cellulose, and others. Similarly, biochar, rosin, and polyphenol are used as organic materials that maintain the durability of the structure and provide resistance to weather, moisture, abrasion, chemical resistance, toughness, and aesthetic appearance (Lawrencia et al., 2021). Additionally, Yadav et al. (2023b) have confirmed that biochar exhibits a significant adsorption capacity, allowing it to absorb potassium, nitrogen, organic matter, and phosphorus within the soil.

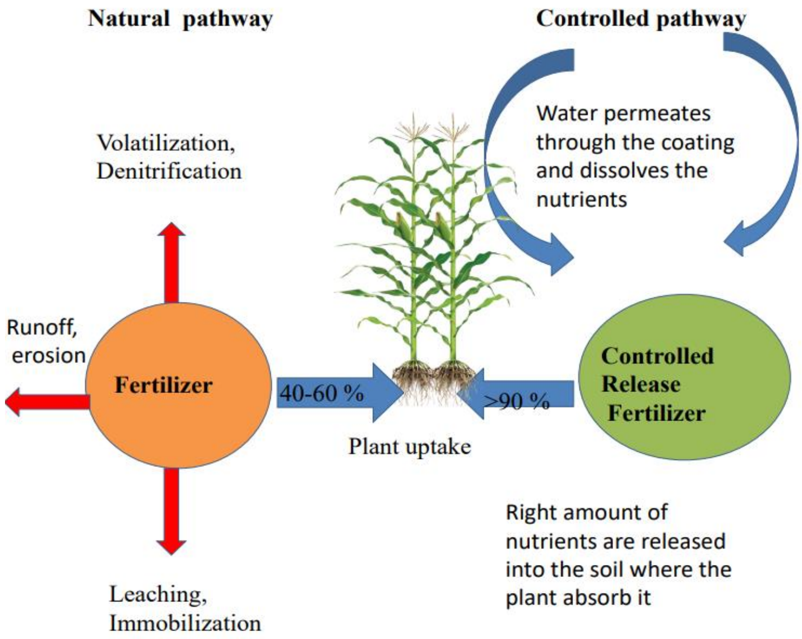

Figure 2. Pathway of nitrogen fertilizer dynamics and uptake by plants through various mechanisms.

2.4. Use of Nitrification Inhibitors

N fertilizer can be easily lost to the environment through leaching and runoff in the form of dissolved organic N, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and nitrous oxide (N_2O), as well as gaseous emissions in the form of ammonia (NH_3), nitric oxide (NO), nitrous oxide (N_2O), and dinitrogen (N_2) (Sharma and Bali, 2018). These nitrogen losses not only increase production costs but also pose a significant threat to global environmental quality. Reducing nitrogen losses from farms is an important step towards increasing nitrogen agronomic efficiency and reducing the environmental impact of nitrogen fertilizers. Therefore, the use of nitrification inhibitors (NIs) is one of the potential ways to suppress nitrification in soil for the optimal use of nitrogen fertilizers (Sun et al., 2015). Nitrification inhibitors slow down the rate of conversion of ammonium to nitrite and nitrate by inhibiting ammonia-oxidizing bacteria (AOB) and ammonia-oxidizing archaea (AOA) (Wang and Wang, 2022) (Misselbrook et al., 2014). The efficiency of nitrification inhibitors is determined by soil factors, management factors, and crop type (Yang et al., 2016). N-(n-butyl)-thio-phosphoric tri-amide (NBPT), dicyandiamide (DCD), 2-chloro-6-(tri-chloro-methyl)-pyridine (CP, N-serve), and 3, 4-dimethylpyrazole phosphate (DMPP) are the most commonly available nitrification inhibitors (Sun et al., 2015). NBPT decreases the process of hydrolysis of nitrogen fertilizer, resulting in a reduction of NH3+ volatilization and accumulation of NO_2- in the soil (Bremner, 1990).

3. Effect of Nitrogen on Maize Crop Performance

3.1. Effect on Growth and Phenology of Maize

Nitrogen plays an important role in plant growth and constitutes about 1 to 4 percent of the dry matter of the plant (Asif et al., 2013). The application of nitrogen during the early stages of plant growth increases the cell number and volume per leaf, accelerates chlorophyll formation, and increases plant biomass (Amanullah et al., 2009). The growth parameter such as the number of leaves per plant is increased by nitrogen application, which improves plant height by increasing the distance between internodes and length of internodes. As a result, the application of nitrogen fertilizer is also good for increasing the height, leaf area, and stem diameter as well as the fresh and dry yield of maize (Hammad et al., 2022). Furthermore, the study by Yadav et al. (2022) underscores the pivotal role of nitrogen and potassium as the key elements influencing leaf count and leaf area in plants. Higher nitrogen concentration in the root zone during early growth stages is favorable for achieving high crop yield (Hammad et al., 2018). Various stages of maize such as days to tasseling, days to silking, physiological maturity, and seed filling stage are affected by nitrogen application rate (Karki et al., 2020) (Begizew and Desalegn, 2019). Nitrogen plays a critical role in crop phenology, which is one of the most important components in determining yield and yield attribution characteristics of maize (Sharifi and Namvar, 2016).

Table 1. Key finding for the impact of nitrogen application on the maize grain yield.

Study	Key Findings
Karki et al. (2020)	Nitrogen fertilizer enhances chlorophyll content, enzymes, and photosynthesis rate, improving yield and yield parameters such as cob length, cob diameter, kernel row, kernel/row, kernel/cob, test weight, and shelling %.
Hammad et al. (2022)	The application of nitrogenous fertilizer has a positive and significant effect on the number of ears per plant, the weight of ears, and the mass of a thousand seeds.
Marahatta (2020)	Increasing nitrogen levels reduces maize sterility and bareness percentage.
Dawadi and Sah (2012)	Nitrogen levels show significant effects on grain production, stover yield, harvest index, and grain stover ratio.
Sandhu et al. (2021)	Nitrogen availability influences grain yield through factors such as radiation interception, effective use of radiation, and nitrogen participation in reproductive organs.

3.2. Effect on Yield of Maize

Nitrogen fertilizer has a great influence on grain quality by changing the amount of protein and mineral content and crop yield (Table 1). Application of nitrogen fertilizer increases chlorophyll content, enzymes, and rate of photosynthesis which improves yield and yield parameters such as cob length, cob diameter, kernel row, kernel/row, kernel/cob, test weight, and shelling % (Karki et al., 2020). Hammad et al. (2022) and Demari et al. (2016) reported that the application of nitrogen fertilizer has a positive and significant effect on the number of ears per plant, weight of ears, and mass of thousand seeds. Increasing nitrogen content also reduces the sterility and barren percentage of maize (Marahatta, 2020). Similarly, nitrogen content shows a significant effect on grain production, stover yield, harvest index, and grain stover ratio (Dawadi and Sah, 2012). The physiological components such as interception and effective use of radiation and nitrogen participation in reproductive organs are used to determine the availability of nitrogen on grain yield (Sandhu et al., 2021).

4. Conclusion

This review indicates that appropriate nitrogen management plays a critical role in improving the growth, phenology, yield, and quality of maize. From this review, it was found that increasing maize productivity through nitrogen use is difficult because nitrogen is susceptible to loss in many forms. To mitigate these losses and optimize maize production, some existing best nitrogen management approaches are discovered through rigorous discussion and interpretation of the result. Some of the approaches that help to improve the efficiency of nitrogen use and productivity of corn crops include site-specific nitrogen management, integrated nitrogen management, controlled fertilizer release, and nitrification inhibitors.

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