

# IMPROVING FERTILIZER- EFFICIENT METHOD AND STRATEGIES FOR THE FUTURE

Pallavi Kumari<sup>1</sup> and Sweta Ranjan<sup>2</sup>

<sup>1</sup>MBA (Agribusiness) and <sup>2</sup>Associate Professor

Amity Institute of Organic Agriculture, AIOA, Amity University, Uttar Pradesh, India

Corresponding author: pallavidubey2508@gmail.com

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## ABSTRACT

Our Special Issue, "Improving Fertilizer Use Efficiency Methods and Strategies for the Future," is introduced in this editorial. The potential of an applied fertilizer to boost the production and utilization of the nutrients present in the soil/plant system is measured by the fertilizer usage efficiency (FUE). The primary purpose of FUE indicators is to evaluate how well fertilization with nitrogen (N), phosphorus (P), and potassium (K) works. The low effectiveness of NPK fertilizers, their negative environmental effects, and the scarcity of natural resources in relation to P are the causes of this. The plant genotype and the environment, which includes both biotic and abiotic elements, interact to produce the FUE. The foundation for appropriate fertilization in agricultural practices, which aims to maximize the FUE, is a thorough understanding of these elements. A few important subjects in crop fertilization are the focus of this special issue. Owing to particular objectives, they can be categorized as follows: eliminating obstacles that prevent plants from absorbing nutrients; enhancing and/or preserving sufficient soil fertility; accurately calculating fertilizer dosages and application schedules; applying fertilizer topically; utilizing cutting-edge fertilizers; and implementing effective genotypes.

**Keywords:** Ammonia volatilization, crop genotypes, elemental sulphur, magnesium, nitrogen efficiency indices

## INTRODUCTION

By 2050, there will be 9.7 billion people on the planet, and by 2100, there will be around 10.4 billion (Thomas et al., 2019). There are currently enough resources in the globe to feed eight billion people (Borlaug et al., 2004). Therefore, in order to address the issue of the constantly rising need for food, the best possible solutions must be sought in both the political and economic spheres (Friedmann et al., 1993). It is either too costly or too dangerous for the ecology and the health of the global ecosystem to expand

agricultural regions at the expense of forests, shrubs, or even bare ground (Falkenmark et al., 2007). Hence, maximising yields from the space that is currently used by agricultural activities is the only logical path for agricultural expansion (Kremen et al., 2012). Breeding advancements, efficient use of mineral fertilizers and crop protection techniques, and the knowledge and expertise of farmers and their advisors are some of the elements thought to be essential in efforts to boost production.



Consuming nitrogen fertilizers is critical in accomplishing this goal (Zhang et al., 2015). The most significant of these are related to things like greenhouse gas and ammonia emissions, the loss of the ozone layer, environmental eutrophication, or the decline of plant and animal species' environments (Necula et al., 2022). Enhancing N fertilization technique, including the use of inventive approaches in fertilizer manufacturing technology and chemical composition, can raise the NUE value (Shoji et al., 2001).

The right amounts and types of minerals in the soil, which facilitate the intake and processing of nitrogen into plant crops, have an important role in deciding the NUE. P, K,

#### **TECHNIQUES FOR IMPROVING FERTILIZER USE EFFICIENCY**

Integrated Nutrient Management refers to the use of local resources such as agricultural wastes, organic manures, chemical fertilization, and biological nitrogen fixation (Al-Suhaibani et al., 2020). Simply said, it is the use of nutrients from a variety of sources, including biological, inorganic, and organic sources (Palm et al., 1997). The benefit of integrated usage is that it increases the delivery of nutrients and creates a physio-chemical environment that promotes greater root growth and development (Abro et al., 2023). The efficiency of fertilizer use, and output might be significantly increased by the interaction of nutrients with a few other macro and micronutrients in Integrated Nutrient Management (Kumar et al., 2022). Consequently, increased production results from the optimal and prudent use of nitrogen from all accessible sources (Hire et al., 2011).

While nitrogenous fertilizers containing amide and ammonium are more likely to volatilize, nitrogen fertilizers containing nitrate are more likely to leach; slow-release

Mg, S, and other fertilizers can be used alone to accomplish this goal, or they can be combined with N to create compound fertilizers (Olson et al. 1982; Wakefield et al., 1971). Therefore, the idea of fertilizer usage efficiency (FUE) may be included within the term "NUE." Such a concept is not restricted to just one nutrient and permits a broader remedy to the problems pertaining to the efficacy of the application of all fertilizers (Srinivasarao et al., 2021). Sharing the most contemporary information and research findings on the enhancement of the FUE/NUE in the cultivation of diverse plant species is the goal of this Special Issue (Barlóg et al., 2023).

nitrogen fertilizers increase nitrogen recovery and decrease nitrogen losses, which raises the efficiency of nitrogen use (Jat et al., 2012). Because of its delayed nitrogen release pattern, which synchronizes soil nitrogen the accessibility with crop demand, slow-release nitrogen fertilizers can lower nitrogen losses. The popular slow-releasing fertilizers in India are coated fertilizers, however their restricted use is caused by their high manufacturing costs and unavailability (Kaur et al., 2021).

Nitrification is a natural process in which *Nitrosomonas* and *Nitrobacter* convert ammonium to nitrite, which in turn changes  $\text{NO}_3^-$  to  $\text{NO}_2^-$ . Nitrification is the conversion of ammonia to  $\text{NO}_2^-$  and subsequently  $\text{NO}_3^-$  to nitrate (Bhattacharya et al., 2021). By reducing leaching and denitrification, ammonium may be absorbed by the soil's colloids and retained for extended periods of time, improving the efficiency of nitrogen usage. Inhibitor amendment may provide a bigger amount of ammonium in the soil, where FUE and agricultural output rise, and



can also check the process of  $\text{NH}_4^+$  conversion to  $\text{NO}_3^-$ . A commercially available inhibitor that is appropriate for rice cultivation is DCD (Dicyandiamide) (Fitts et al., 2014)

Crop rotation is the practice of switching up the crops grown on the same plot of land at the same time period each year (Tanveer, et al., 2019). Legumes are traditionally added to cereals as an old-fashioned method of making best use of available resources. As a result of the legume crops fixing atmospheric nitrogen in the soil and increasing its amount, later crops will naturally require less fertilizer to be supplied external. Crop residue is the portion of the crop that is left in the field after it has been cut. Crop residue has the potential to provide nutrients for a longer period. According to reports, the leftovers of different cereal crops can provide 40–100 kg/ha of nitrogen in a season. This boosts soil organic carbon and improves soil health. Compared to cereal crop residues, legume crop residues have a higher nitrogen content and a lower C/N ratio, making them the most effective sources of nitrogen (Sarkar et al., 2020).

### **FACTORS INFLUENCING FERTILIZER USE EFFICIENCY (FUE)**

One of the most important metrics in contemporary agriculture is Fertilizer Use Efficiency (FUE). It calculates the percentage of fertilizer nutrients that genuinely support plant growth and development. In addition to being financially responsible for producers, optimizing FUE supports sustainable farming methods. Currently, we'll take a look at the components that affect FUE and the methods for maximizing soil health and FUE.

The soil's current nutrient levels affect how well plants absorb fertilizers. As a way for gardeners to customize fertilizer treatments

Adopting conservation farming methods may increase the soil's capacity to deliver nutrients since healthier soil makes more nutrients available to plants. Due to a greater rate of oxidation, intensive tillage techniques accelerate the depletion of soil organic carbon and significantly enhance the soil's vulnerability to erosion (Olson et al., 2016). Modern ideas like bed planting with residue assimilation and zero tillage have gained popularity; if these technologies are used over an extended period of time, soil health will improve. Long-term use of these technologies enhances the soil's biological, chemical, and physical properties, notably its carbon content. The ability of legumes to fix atmospheric nitrogen in the soil renders it better than non-legumes in green manuring crops. Green manuring legume crops need to have certain qualities, such as quick growth, short duration, higher biomass production, fixing nitrogen in the air, and above all the least number of cultural techniques (Brandjes et al., 1989). Legumes can conserve among 20 and 300 kg of nitrogen per acres annually.

to match the demands of certain plants, soil testing are essential for identifying nutrient deficits (Viera et al., 2016). By developing a baseline for nutrient content through routine soil testing, producers can use fertilizer strategically and prevent overapplication. The pH of the soil influences nutrient availability. Even if certain nutrients are present in the soil, plants may not be able to absorb them as well if the pH is outside of the ideal range. To establish an environment where plants can easily get fertilizer nutrients, adjust the pH of the soil as necessary. Applications of sulphur or lime



can be used to adjust pH imbalances (Hodges et al., 2010).

The soil's microorganisms are essential to the availability and cycle of nutrients. By functioning as extensions of plant roots, mycorrhizal fungi enhance the availability and absorption of nutrients, particularly phosphorus (Jansa et al., 2010). Use soil management techniques, such as adding organic matter and using cover crops, that encourage the diversity and activity of soil microbes. The availability and absorption of fertilizer nutrients are influenced by environmental conditions like as temperature and precipitation. Soil structure and nutrient retention can be affected by extreme weather events (Costa et al., 2022). When scheduling fertilizer treatments, take seasonal

fluctuations into account. Modify nutrient management plans according to the weather to reduce losses and improve nutrient absorption.

Nutrient availability is influenced by fertilizer selection and application technique. Certain fertilizer formulations or application methods may work better for some crops than others. For nutrients to be transported throughout the plant, there must be enough water. Both too much and too little water can affect how nutrients are absorbed. Use effective irrigation techniques to guarantee the ideal soil moisture content for nutrient uptake. To stop fertilizer nutrient leaching, take into account water management techniques.

### IMPROVING FUE BY OPTIMIZING N UPTAKE AND RATE

The proper fertilizer dosage selection for particular soil and climate conditions, the used agrotechnics, and the plant needs in crop rotation are among of the most crucial actions meant to improve the FUE. Analytical techniques include soil testing, plant tissue analysis, fertilizer rate response modeling, nutrient absorption dynamics, and digital and information technologies can all be used to do this. Information on the mineral nitrogen (N<sub>min</sub>) content of the soil serves as the foundation for the standard approach for assessing the demand for N fertilizers. Therefore, determining and categorizing the variables influencing the organic nitrogen mineralization processes and the soil's N<sub>min</sub> concentration is crucial (Wogi et al., 2021). The yield level may be shaped by consciously controlling N<sub>min</sub> using the information acquired in this field. The first article in the subchapter addresses how different ploughing techniques affect the amount of different types of nitrogen in

fluvo-aquic soil from China's Huang-Huai Hai Plain (Wenchao et al., 2016). Using rotary tillage (RT), deep tillage (DT), and shallow rotary tillage (SRT), the experiment assessed the impact of five treatments.

Wheat was the test plant. The findings demonstrated that, in comparison to RT-RT-RT, rotation tillage combined with deep tillage enhanced both the overall amount of nitrogen and the content of mineral nitrogen forms. The NO<sub>3</sub>-N and NH<sub>4</sub>-N content in 0–40 cm was particularly enhanced by them, with the maximum value under DT-SRT-RT. But with time, deep tillage's impact on dissolved organic N in deeper layers drastically decreased. 2018 and 2019 saw the greatest wheat yields with DT-SRT-RT, at 6346 and 6557 kg ha<sup>-1</sup>, respectively. The wheat yield and N partial productivity showed a similar pattern, with higher values of 28.98 and 29.94 kg<sup>-1</sup>, respectively. In addition, the scientists found that the DT-SRT-RT therapy had the lowest apparent



nitrogen loss values. It was recommended as an effective tillage technique to raise crop production and NUE.

Plants compete with one another for nutrients and water in the field. To reduce these impacts and intentionally mix yield components to achieve the highest N productivity, it is crucial to determine the proper sowing density (SR). In Jiangsu province (China), Guo et al. 2017 examined the issue of the NUE's reliance on the sowing density in winter wheat farming. In order to achieve balanced high yields and an increased NUE in wheat, the authors proposed the theory that there is an ideal seed rate to offset the adverse impacts of declining N. The findings showed that when N levels rose and seeding rates decreased, there was a considerable increase in net photosynthetic rate, stomatal conductance, chlorophyll content, and metabolic enzyme activity. The combination treatment of N235 and SR180 produced the maximum levels of plant tillers, grain yield, dry matter prior to anthesis and N translocation, N agronomic efficiency (NAE), N recovery efficiency (NRE), and N uptake efficiency (NUPE). N levels over 235 kg ha<sup>-1</sup> considerably reduced the NAE, NRE, and NUPE, however. The authors concluded that an increase of around 0.6 kg ha<sup>-1</sup> SR might replace 1-kilogram N ha<sup>-1</sup>. Additionally, the NUE parameters may be improved, and the maximum winter wheat yield can be achieved by combining N and SR (N235 + SR180). The N dose was evaluated at four different levels. A regression curve was used to calculate the ideal N rate. 20 and 40 g N plant<sup>-1</sup> treatment resulted in an N-sufficient environment, which led to excellent growth and yield performance because of a high rate of carbon absorption.

## BALANCED USE OF FERTILIZERS

The quality of soil, one of the most important elements of an ecosystem, is the result of integrated management of the majority of soil characteristics that affect agricultural production and sustainability. Constantly applying too little and in the wrong amounts of fertilizer causes the soil's organic matter to decrease, which has a negative impact on the soil's quality. As a result, one of the main issues facing Indian agriculture is the unbalanced use of nutrients, which has affected soil fertility and health and produced low crop yields.

The amount of nutrients (NPK) that are removed by crops and then added by fertilizers is about 10 million tons. For macro-level monitoring, the N:P: K ratio of 4:2:1 is regarded as optimal and adequate. Globally, the NPK usage ratio is 3.4:1.3:1. However, according to reports for 2020–21, India's current NPK utilization ratio (using K as a basis) is 6.5:2.8:1.

### • ORGANIC CARBON IN SOIL

The primary determinant of soil quality, soil organic carbon (SOC), influences most soil characteristics. Therefore, it is crucial to preserve and improve it through improved management techniques, such as balanced and INM. SOC improved with the use of balanced (100% NPK) and INM (100% NPK+FYM) practices over unbalanced nutrient application, according to the results of the LTFEs carried out in various soil types and main cropping systems across the nation.

### • PRODUCTIVITY OF CROPS

Across all LTFE sites, crop productivity increased with balanced fertilizer and INM usage. Compared to years of uneven nutrient administration, the balanced fertilizer use—100% NPK with the addition of lime and zinc—improved production. It was discovered that applying 100% N in the form





of urea significantly decreased yield and had a negative impact on soil quality and general soil health. There has been excessive wear and tear on the acid soils (Alfisols) in Bengaluru, Palampur, and Ranchi in recent

### • THE BIOLOGICAL HEALTH OF SOIL

The microbial activity in soil is reflected in its biological health. Because it influences the breakdown of organic materials in soil, the dehydrogenase enzyme is one of the most important markers of soil respiratory activity. According to the study, unbalanced fertilizer use has a negative impact on dehydrogenase activity (DHA). Therefore, the alternative to restore the biological health of soil is balanced and INM.

years. Thus, in recent years in Palampur, the yield of maize and wheat decreased to nearly nil due to 100% N, which was even lower than the unfertilized control.

### • EFFICIENCY OF NUTRIENT USAGE

The majority of crops' nutrient usage efficiencies (NUE) for applied N, P, and K showed that the efficiency increased progressively when each nutrient was added. INM, or NPK+FYM, further increased efficiency in important crops and soils throughout LTFE locations. However, because to uneven fertilizer application, NUE had sharply decrease

## FUE AND INNOVATIONS ON THE FERTILIZER MARKET

Mineral fertilizers have been utilized for many years to

- (i) guarantee a healthy supply of nitrogen to plants, particularly at key stages
- (ii) minimize the frequency of applications
- (iii) lower the nitrate content in plants
- (iv) minimize nitrogen loss and lessen its adverse effects on the environment.

These fertilizers fall into two categories: controlled-release fertilizers (CRFs) and slow-release fertilizers (SRFs). By coating the granules with a different kind of protective layer, N fertilizers from the CRF group have the effect of delaying N release.

Using two CRF fertilizers—calcium ammonium nitrate (CAN) fertilizer coated with modified conventional polyurethane and CAN coated with vegetable oils—(Lu et al., 2022). evaluated the potential for

increasing Nf efficiency and lowering its adverse environmental impact (N leaching). The CRF fertilizer's impact was contrasted with that of the traditional CAN. For both coated fertilizers, three treatment options were evaluated: a single application of coated CAN, a single application of CAN with coated CAN (1:2), and divided application (CAN, coated CAN). Winter oilseed rape served as the test plant. When compared to the usage of traditional CAN fertilizers, the findings obtained show that the use of coated CAN fertilizers significantly boosts yield, improves N fertilization efficiency, and lowers N losses. According to this study, applying a 1:2 mixture of conventional and coated CAN during spring fertilization seems to be an appropriate technique. This ensures that there is an adequate supply of quickly releasing nitrogen during rapeseed regeneration and its slower release during subsequent developmental stages. Oil-based polymer coatings on might fertilizer might be



regarded as a suitable substitute for traditional polyurethane that has been partially changed in the fertilizer production process.

The prospect of increasing the NUE in coffee growing (*Coffea arabica* L.) was examined in the second paper on CRF fertilizers in this collection. In order to reduce  $\text{NH}_3\text{-N}$  losses in coffee production systems, (Freitas et al 2022). hypothesized that enhanced-efficiency N fertilizers and other fertilizers, such as ammonium nitrate and sulfate and prilled urea diluted in water, are better solutions than ordinary urea. The following fertilization treatments were tested in field experiments to validate the hypothesis: blended N fertilizer, urea + elastic resin, urea-formaldehyde, urea + polyurethane (all applied once), prilled urea, prilled urea dissolved in water, ammonium sulfate (AS), ammonium nitrate (AN), urea + Cu + B, urea + adhesive +  $\text{CaCO}_3$ , and urea + NBPT (all with three split applications).

In the Minas Gerais area of Brazil, coffee plants under field conditions for two crop seasons were used to test fertilizer treatments. The study's treatments were administered at a dosage of  $300 \text{ kg N ha}^{-1}$  annually. The authors demonstrated that different fertilization combinations had a considerable impact on urea losses. All N-fertilizer methods decreased  $\text{NH}_3\text{-N}$  losses in comparison to plucked urea, with the exception of urea + adhesive +  $\text{CaCO}_3$  (27.9% of  $\text{NH}_3\text{-N}$  losses). AS and AN saw the lowest losses, at 0.6% and 0.5%, respectively. However, the authors note that the costs of fertilizer application must be taken into account while selecting the best fertilization approach (treatment choice).

One of the more recent fertilizers available on the market is biochar. Biochar are typically solid, carbon-rich solids that are produced by the thermochemical breakdown of organic biomasses (Verma et al., 2014). They can be used as a component in the manufacturing of CRF fertilizers or as mineral fertilizers. The application of biochars to the soil improves soil carbon sequestration and lowers greenhouse gas emissions. Applying biochar also increases agricultural production and soil fertility. However, there's not enough data in the literature about how biochars affect tomato yield physiology. The article by (Murtaza et al 2024). closes this gap.

The authors hypothesized that plant development, a few physiological indices, and tomato output would all benefit from the enhanced agro-chemical qualities of the soil created with biochar and vermicompost. The authors conducted an experiment to test this theory, examining the effects of vermicompost (VA3, 3%, VA5, 5%; by mass of soil) and biochar (CK0%; BA3, 3%, BA5, 5%; by mass of soil) on tomato production, photosynthesis, and chlorophyll fluorescence in a greenhouse setting. Several characteristics unique to tomato plant photosynthesis and chlorophyll fluorescence were examined. The treatment with the highest vermicompost rate (VA5) had the best parameter values. Whereas the values from the BA treatments were lower than those from the CK treatments, they were nonetheless greater. In conclusion, the authors point out that applying 3% vermicompost for a single tomato production season is thought to be practical in terms of boosting photosynthesis, raising the WUE, and raising tomato output.



## USE EFFICIENCY OF PHOSPHORUS AND POTASSIUM UNDER DIFFERENT CROPPING SYSTEMS

Unbalanced and careless use of plant nutrients is thought to be one of the main causes of poor nutrient use efficiency (NUE) and the establishment and spread of widespread multi-nutrient deficiencies in soils in intensive agriculture. Due to a larger nutrient turnover in the soil-plant system than in the relatively low yielding systems, the issues of soil fertility degradation and poor NUE are evidently more severe and noticeable in high yielding systems. According to recent diagnostic surveys conducted in the Garhwal zone of Uttarakhand and the rice-wheat growing regions of the Trans- and Upper-Gangetic Plains (TGP and UGP), all farmers applied nitrogen to both crops; however, only 89, 86, and 69% of the fields in these zones received P for rice, and 99, 100, and 40% for wheat. In these zones, 18, 23, and 10% of all farmers applied K to rice crops, whereas 14, 1, and 3% applied K to wheat crops. The majority of farmers, according to the surveys, applied N at rates higher than those advised locally and P nearly at the suggested rate, while ignoring or applying K, S, and micronutrients in levels below those advised.

In agriculture, phosphorus (P), potassium (K), and nitrogen (N) are the three most often used and needed nutrients (Dhillon et al., 2019). The importance of food security has increased in tandem with the world's population growth. Furthermore, it is anticipated that the frequency and duration of heat stress and drought would rise, which would have a negative impact on food security and important crops. Alternative technologies that boost yield per unit of land will be needed to produce food for a growing global population. Commercial

fertilizers will be needed more when production per unit area increases. As a result, boosting food production to fulfill rising global food demands requires a steady supply of N, P, and K (Fixen et al., 2002).

For mineral soils, the range of soil K concentrations is 0.04 to 3.0%. Sedimentary rocks including clayey shales (30 g K kg<sup>-1</sup>), igneous rocks like granites and syenites (46–54 g K kg<sup>-1</sup>), basalts (7 g K kg<sup>-1</sup>), and peridotites (2 g K kg<sup>-1</sup>), as well as limestone, have an average of just 6 g K kg<sup>-1</sup>. Although resource estimates are approximately 250 billion tons, it is believed that 3.7 billion tons of K as a K<sub>2</sub>O equivalent are still in reserves globally. With 35% of global output, Canada is the biggest producer. Canada, Belarus, and Russia have reserves of 1, 0.75, and 0.6 billion tons, respectively, according to the USGS assessment.

Four pools of K may be distinguished: soil solution K, exchangeable K, non-exchangeable K, and structural K. The majority of the K in soil is not accessible to plants. K is absorbed by growing plants from the soil solution (Rengel et al., 2002). While releasing K from the other two forms takes longer and is less accessible, exchangeable K may be swiftly liberated from soil particles and enter the soil solution. Soil-unavailable K is 96 to 99%, exchangeable K is 1 to 2%, non-exchangeable K is 1 to 2% (fixed in 2:1 clays), and the proportion of plant-available K in soil solution is 0.1 to 0.2% of total soil K. show the specific K cycles in soils. Use Efficiency of Phosphorus and Potassium under Different Cropping Systems tabulated in Table 1.





**Table 1: Use Efficiency of Phosphorus and Potassium under Different Cropping**

**Systems**

Cropping System	Phosphorus Use Efficiency (%)	Potassium Use Efficiency (%)	Remarks
<b>Monocropping</b> (e.g., <b>Maize</b> )	15–25	30–40	Often lower efficiency due to nutrient depletion and limited root diversity
<b>Cereal–Legume Intercropping</b>	30–45	40–55	Legumes improve P availability via root exudates and enhance nutrient cycling
<b>Crop Rotation</b> (e.g., <b>Rice–Wheat</b> )	25–40	35–50	Breaks pest/disease cycles and enhances soil structure, improving uptake
<b>Agroforestry</b>	35–50	45–60	Deep-rooted trees improve nutrient retention and recycling
<b>Organic Farming Systems</b>	20–35	25–40	Nutrient release is slower, depends on organic matter mineralization
<b>Integrated Nutrient Management</b>	40–60	50–70	Combines practices for improved nutrient use efficiency

The physical (the kind and quantity of clay and organic matter), chemical, and biological characteristics of the soil have the most effects on the K availability, which varies depending on the kind of soil. Additionally, the kind of parent material, weathering, fertilizer and manure addition, leaching, erosion, and crop removal all affect the amount of K in soils. Soils around the globe are often found to be K deficient. One-fourth of arable soils and three-fourths of paddy soils are deficient in K in China. Similar trends were noted for wheat production in southwestern Australia, where K deficiencies have also increased. It has been noted that 72% of agricultural soils in India require immediate K fertilization for improved crop production (Dhillon et al., 2019). The soils where K deficiency predominantly occurs are acid sandy soils, waterlogged soils, and saline soils.

The removal of biomass from the soil in the form of grain, straw, or hay is one of the primary causes of K deficiency. Decreased soil is also a result of K leaching and erosion. K content concluded that the usage of K fertilizer has decreased recently, resulting in

inadequate soils because the K that is withdrawn is not sufficiently restored. It has been shown that only 35% of the K lost is restored by using K fertilizers. Furthermore, Manning noted that the counterbalancing inputs, which usually amount to less than 10% of K removal, are greatly outweighed by K mining from soil

### IMPROVING FERTILIZER USE EFFICIENCY BY OPTIMIZING NITROGEN UPTAKE AND APPLICATION RATE

Optimizing nitrogen (N) uptake and fertilizer application rates is essential to improving fertilizer use efficiency (FUE) in agriculture. Nitrogen is a vital nutrient for plant growth, but inefficient use can lead to nutrient loss, environmental pollution, and economic inefficiencies. Optimizing N uptake by plants and adjusting fertilizer rates to match crop needs can significantly reduce nitrogen losses and improve the sustainability of farming practices.



## • **UNDERSTANDING NITROGEN UPTAKE MECHANISMS**

Nitrogen is absorbed by plants primarily as ammonium ( $\text{NH}_4^+$ ) or nitrate ( $\text{NO}_3^-$ ) through their roots. The efficiency of N uptake is influenced by various factors, including soil type, root architecture, soil microbial communities, and the plant's growth stage. One of the main challenges in improving N uptake is ensuring that the nitrogen applied as fertilizer is available to the plant when needed. Nitrogen can be lost from the soil due to processes like leaching, volatilization, and denitrification before the plant can absorb it. To optimize N uptake, it is essential to synchronize the timing of fertilizer application with plant nutrient demand. This means applying fertilizers when crops are in their active growth stages and require the highest levels of nitrogen. Additionally, soil properties such as texture, pH, and moisture content should be considered, as they affect the availability of nitrogen to plants.

## • **PRECISION FERTILIZATION TECHNIQUES**

Precision agriculture techniques can help optimize nitrogen fertilizer use by ensuring that the right amount of fertilizer is applied to the right location at the right time. These techniques use technology such as sensors, GPS, and variable rate application (VRA) systems to adjust the amount of nitrogen applied based on real-time data from the field. For example, soil sensors can measure nitrogen levels and help farmers apply fertilizer precisely where it is needed, reducing over-application and minimizing environmental losses. Variable Rate Application (VRA): VRA allows for the tailored application of nitrogen across different parts of a field, based on soil

nutrient levels, crop requirements, and environmental factors. This reduces nitrogen excess in areas where the soil already has sufficient nutrients and ensures that crops in nutrient-deficient areas receive adequate nitrogen.

## • **SLOW-RELEASE AND STABILIZED NITROGEN FERTILIZERS**

One of the most effective ways to improve nitrogen fertilizer use efficiency is by using slow-release or stabilized fertilizers. Slow-release fertilizers release nitrogen gradually over time, which reduces the risk of nutrient loss due to leaching and volatilization. These fertilizers are designed to provide a steady supply of nitrogen to plants, matching their uptake rate and reducing the need for frequent applications. In addition to slow-release fertilizers, stabilized nitrogen fertilizers include inhibitors that slow down nitrogen loss processes like nitrification and denitrification. For example, nitrification inhibitors slow the conversion of ammonium to nitrate, reducing the risk of nitrogen leaching. Similarly, urease inhibitors reduce ammonia volatilization by slowing the breakdown of urea in the soil. Using these types of fertilizers ensures that nitrogen remains available to crops over a longer period, which improves nitrogen uptake and minimizes environmental losses.

## • **Improving Soil Health and Nitrogen Retention**

Soil health plays a crucial role in improving nitrogen uptake efficiency. Healthy soils with adequate organic matter content support a diverse range of microorganisms that aid in nitrogen fixation, ammonification, and nitrification, making nitrogen more accessible to plants. Practices that



enhance soil health, such as crop rotation, reduced tillage, and the use of organic amendments like compost or manure, can improve soil structure and nutrient retention. (Singh et al., 2024). Adding organic matter to the soil helps retain nitrogen by increasing cation exchange capacity (CEC) and promoting microbial activity. Organic amendments can also provide a source of slow-release nitrogen, reducing the need for synthetic fertilizers and improving overall nitrogen use efficiency.

### **OPTIMIZING FERTILIZER APPLICATION TIMING**

Timing is one of the most critical factors in optimizing nitrogen fertilizer use. Applying fertilizers too early or too late in the growing season can lead to inefficiencies (Balasubramanian et al., 2004). Fertilizing when plants are not actively growing can lead to nitrogen loss through leaching, while late applications can reduce uptake efficiency and may not result in a significant yield improvement. One strategy to optimize fertilizer timing is split application, where nitrogen is applied in multiple smaller doses throughout the growing season. This allows nitrogen to be available to the plant during its most critical growth stages and reduces the risk of nutrient losses due to excess nitrogen in the soil (Chen et al., 2014).

### **USE OF CROP-SPECIFIC FERTILIZER RECOMMENDATIONS**

Different crops have varying nitrogen needs depending on their growth stages, variety, and environmental conditions. Therefore, it is essential to tailor nitrogen fertilizer recommendations to specific crops. By using crop-specific recommendations, farmers can optimize nitrogen application rates, avoiding both over-fertilization and under-fertilization. Crop Models and Tools: Models that predict

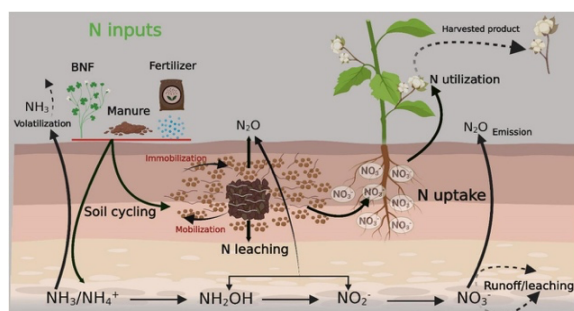
the nitrogen requirements of crops based on soil type, climate, and growth stage are increasingly being used to provide farmers with accurate recommendations for fertilizer application. These tools can help optimize the amount and timing of nitrogen applications to match the specific needs of the crop, improving both crop yields and fertilizer use efficiency.

#### **• Enhanced Efficiency with Microbial Inoculants**

Microbial inoculants, which are beneficial microorganisms that promote plant growth and nutrient uptake, can enhance the efficiency of nitrogen use. Certain soil bacteria, such as nitrogen-fixing species, help in converting atmospheric nitrogen into forms that plants can use. These inoculants can be particularly beneficial in low-nitrogen soils, reducing the need for synthetic nitrogen fertilizers. The use of legume crops in rotation with nitrogen-fixing bacteria (e.g., *Rhizobium*) can enhance soil nitrogen levels naturally. This reduces the reliance on synthetic nitrogen fertilizers and improves nitrogen cycling in the soil.

Nitrogen plays a crucial role in plant growth and productivity, but its efficient management in agricultural systems remains a challenge due to various transformation and loss pathways. As illustrated in **Fig. 1**, nitrogen enters the soil system primarily through biological nitrogen fixation (BNF), fertilizers, and organic manure. Once in the soil, nitrogen undergoes several transformations, including ammonification, nitrification, and immobilization, forming intermediate compounds such as  $\text{NH}_4^+$ ,  $\text{NH}_2\text{OH}$ ,  $\text{NO}_2^-$ , and  $\text{NO}_3^-$ . While plants uptake nitrogen mainly in the nitrate ( $\text{NO}_3^-$ ) form, significant nitrogen losses can occur via volatilization (as  $\text{NH}_3$ ), leaching, and gaseous emissions (e.g.,  $\text{N}_2\text{O}$ ), especially under conditions of excessive input

or poor management. Soil cycling processes, including microbial immobilization and mobilization, further regulate nitrogen availability. Ultimately, efficient nitrogen utilization is vital not only for crop yield and quality (as in the harvested product shown) but also for reducing environmental impacts like greenhouse gas emissions and water pollution through runoff or leaching.



**Fig. 1.** Nitrogen (N) cycle in soil–plant systems depicting N inputs, transformations, losses, and plant uptake.

### • Monitoring and Data-Driven Decision Making

Continued advancements in digital agriculture allow farmers to monitor soil nutrient levels and crop health in real-time, enabling data-driven decisions regarding nitrogen fertilizer application. The integration of soil sensors, drones, and satellite imagery allows farmers to track nitrogen levels and adjust their application strategies accordingly. This technology makes it easier to apply the correct amount of nitrogen at the optimal time, improving fertilizer use efficiency and reducing waste. Remote sensing technologies, including satellite imaging and drones, can help identify nutrient deficiencies in crops and assess the effectiveness of fertilizer applications. By providing real-time feedback, these tools help farmers make timely adjustments to improve fertilizer efficiency and crop productivity.

## CONCLUSION

Given the rising demand for food and the mounting environmental strain, one of the most crucial objectives of contemporary agriculture is to improve the use of nutrients from fertilizers (the FUE). Several options and tactics to enhance the FUE are presented in this Special Issue. The majority of study, according to the articles that are being presented, focuses on the potential for balanced fertilization to enhance plants' usage of nitrogen. It is only feasible to fully use a cultivated plant's yield potential when the plant's supply of nitrogen and other nutrients are balanced across the growth season. Therefore, the secret to sustaining agricultural output is balanced plant fertilization. The application of innovative fertilizers with a controlled release rate of nutrients and/or nitrification inhibitors, foliar fertilization, or the creation of the ideal conditions for nutrient uptake such as the efficient use of P and K from fertilizers—should be used in conjunction with balanced fertilization to improve the FUE. In addition, advancements in plant breeding that make greater use of both natural and man-made sources of nutrients should coincide with the creation of new technologies and fertilization techniques.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.





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