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Nitrogen use efficiency in crops with new and available technologies

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ABSTRACT

Among fertilizers, nitrogen (N) is the one that is used in the largest amounts mainly due to immediate response to the fertilizer-N application. However, the N use efficiency (NUE) is very low leading to high production costs and also a threat to the environment. Therefore, improving NUE is imperative. The 4 R's (right quantity, right time, right method and right source) should be considered as the first step for enhancing NUE. Best management practices (BMP's) of production and protection need to be adopted in order to achieve high NUE. Integration of novel N sources and nanofertilizers and better N fertilization products would lead to high NUE. Furthermore, novel techniques such as Precision Nutrient Management and Variable Rate Application to time nutrient application with crop need, and remote sensing are upcoming technologies that will bring about considerable savings in fertilizer-N. Further we should also account for plant physiological processes, including the diversity of mineral nutrient uptake mechanisms, their translocation and metabolism in order to breed and develop crop cultivars that are efficient N users.

Key words: Agronomic efficiency, Nanofertilizers, Precision Agriculture, SPAD meter

INTRODUCTION

Crop yield increases were possible due to two major agronomic factors, namely, water and fertilizer. High yielding varieties developed were responsive to fertilizer nutrients without which yield potential would not be achieved. Among the fertilizers, the greatest response was reported to the application of nitrogenous (N) fertilizers (Prasad, 2013). It is the single major reason for the highest consumption of urea. Fertilizer-N on application is subjected to several loss mechanisms such as ammonia volatilization, denitrification, surface runoff and leaching (Blaise and Prasad, 1995; Prasad and Power, 1995: Pathak *et al.*, 2006; Prakasa Rao and Puttana, 2006). Pathak (2016) simulated N loss through ammonia volatilization from rice–wheat cropping systems of the Indo-Gangetic plains (IGP) and found that the loss was 16–62 kg N/ha with an average loss of 30 kg N/ha from a field having average fertilizer application of 98 kg N/ha. Consequently, crop N use efficiency (NUE) values reported are low (Prasad, 2013).

Various efficiency terms are used to quantify the nitrogen use such as the recovery efficiency, physiological efficiency and agronomic efficiency. Recovery efficiency is defined as an increase in the above-ground N uptake per unit of N applied (Eq. 1). It is also referred to as the Apparent Recovery. Physiological efficiency (PE) is defined as the yield (biological production) per unit of N absorbed (Eq. 2). It provides information on the yield gain due to N recovered and is also referred to as Efficiency ratio. Agronomic efficiency (AE) is the yield increase due to the applied fertilizer-N and provides an answer to the direct question about yield gain due to the applied fertilizer-N. It integrates information of the uptake and N utilization in the plant. Therefore, AE is a product of the RE and PE.

RE (%)=(N uptake in N_f - N uptake in N_0)¦(N_f))*100
PE (kg grain/kg N uptake) = (Yield in N_f – Yield in N_0)/ (N upt in N_f – N upt in N_0)
AE (kg grain/kg N applied) = (Yield in N_f – Yield in N_0)/ (N_f)

Crops differ in their NUE with recovery of applied N ranging from18.9 to 41.8% in rice (Katyal *et al.*, 1985; Goswami *et al.*, 1988), 37.2% in maize (Arora *et al.*, 1980) and 36% in a cowpea–rice cropping system (John *et al.* 1989). In the last two decades there was a decline in NUE (Omara *et al.*, 2019). Such decline in the use efficiency has three implications; firstly, more fertilizer N is needed to meet the crop needs, secondly, an increase in cost of cultivation, and, thirdly, loss to the environment leads to pollution. Furthermore, gaseous N loss contributes to greenhouse gas emission contributing to global warming. Keeping in mind the 17 Sustainable Development Goals (SDG's) defined by the United Nations to be met by 2030; it becomes imperative to check N loss and enhance the NUE. Reducing N loss and improving NUE addresses three of the 17 SDGs, Zero Hunger, Climate Action and Life on Land.

Several strategies, agro-techniques and proven technologies are available that can improve NUE. The first step of the best management practices (BMP's) is the basic 4 R strategy. The 4R's are: right quantity, right time, right method, and right source, which are simple to follow and adopt and the easiest way to increase NUE.

Right quantity

Crop yields can be achieved only with application of fertilizer-N. However, the quantum of fertilizer-N used, in general, has increased due to a decline in partial factor productivity. Application of the right quantity is possible by taking into account the soil test and plant N requirement. Soil test crop response based N-fertilizer recommendations is not new concept and was proposed by Ramaoorthy to make fertilizer prescriptions based on the yield target and soil type (Ramamoorthy *et al.*, 1967). Fertilizer recommendation based on soil test has been reported to improve fertilizer use efficiency as well as bring about considerable savings in fertilizer-N (Rao and Srivastava, 2000). Although good correlation has been observed with the soil test based fertilizer-application and crop yields, this basis of recommendation is not very successful because it is largely ignorant of the N released from crop residues, organic manures and irrigation water (Bijay-Singh, 2008). A recent study, showed a decline in the NUE in India compared to the World average, while the fertilizer-N use increased significantly (Omara *et al.*, 2019). Generally, high N inputs leads to a decline in NUE and therefore, one needs to use the fertilizer-N inputs judiciously. Application of N at lower than the recommended or the need based N fertilizer would lead to mining of the soil reserves at the detriment of the food security. Studies in China showed that a decrease in fertilizer rate by half resulted in a decrease in groundwater N pollution by 17% (Gu *et al.*, 2011). Such studies are needed for our cropping systems wherein fertilizer use is high.

Right time

Synchronizing N availability with crop N demand can be a major pathway to improve NUE. Therefore, timing the N application to match the maximum uptake by the crop is fundamental to maximizing uptake by the crop and minimizing N losses. A precise synchronization of N application is especially important in environments prone to N leaching such as sandy soils. In the sandy soils, nitrate leaching would depend on the nitrate concentration in the soil solution which in turn would depend on the fertilizer-N rate and the nitrification potential of the soil (Cameron *et al.*, 2013). Obviously in the well aerated soils, nitrification rate would be high. In such situations, split application would result in a lower potential for N loss through leaching. Many studies have documented the benefits of split application instead of the one-time application of the fertilizer-N (Avasthe, 2009; Sarkar *et al.*, 2007). In the northern sandy soil types, Thind *et al.* (2010) demonstrated the benefits of split application by way of reduced NH_3 loss (Katyal *et al.*, 1985), improved efficiency (Table 1).

Table 1: Effect of split application of urea and neem coated urea on the use efficiency of wheat at Ludhiana, Punjab

Treatment	Agronomic efficiency (kg grain/kg N applied)	Recovery efficiency (%)
Urea (120 kg/ha)	19.2	53.3
Urea (20 kg/ha in 3 splits; 48-48-24)	23.9	66.7
Neem coated urea (120 kg/ha)	20.0	60.0
Neem coated urea (3 splits)	24.2	75.8

Source: Adapted from Thind et al. (2010)

Right method

Fertilizer N is most often applied as broadcast, especially to the close growing cereal crops. When such method is followed, especially on the alkaline soils having high soil pH, N in the fertilizer is lost through volatilization. In the lowland paddies, denitrification is the major loss mechanism (Freney *et al.*, 1990). In such situations, incorporating urea into the soil may bring about a reduction in NH_3 loss, but it favours denitification loss. Therefore, some application methods may be more suitable than others or not suitable at all, depending on the crop, climate and soil conditions. Proper application technique, straw incorporation, availability of soil moisture, and avoiding application at high wind speed are some of the techniques used to reduce the rate of volatilization of the applied fertilizer N (Cao *et al.*, 2018). Thind *et al.* (2010) reported that the right method of application would reduce the losses of N, especially ammonia (NH_3) loss that is the most predominant loss when fertilizer-N is applied in the form of urea. Drilling of the urea especially in the sandy soils reduces the NH_3 loss as compared to the surface application. Losses of fertilizer-N as N_2O through denitrification or NH_3 volatilization are lower when N is split applied. An *et al.* (2021) demonstrated that well-timed split application to wheat at GS4 stage compared to late-fall application minimized N_2O emissions.

Right source

Among the sources of available nitrogenous fertilizers, urea has the highest N content (46%). Coated urea products have slightly lower N content ranging from 38 to 41% N. Other commonly used N fertilizers are ammonium sulphate (21% N), ammonium nitrate (34%), potassium nitrate (13%), diammonium phosphate and NPK complex fertilizers. Ammonium based-N fertilizers are the best sources for the lowland rice systems. While the upland crops prefer nitrate-N for absorption and the nitrate containing fertilizers are ideal N source for application.

Controlled release fertilizers: Coated/ Controlled release fertilizers are fertilizer products that contain the fertilizer-N in a form which releases the N slowly and gradually. Several coated nitrogenous fertilizers were developed and used commercially such as sulphur coated urea (Prasad *et al.*, 1971), polymer coated urea, gypsum coated urea (Blaise and Prasad, 1996; Gil-Ortiz *et al.*, 2020), resin coated urea (Kundu *et al.*, 2013), and neem coated urea (Bains *et al.*, 1971; Prasad *et al.*, 1999). These controlled release fertilizers were found to improve yields because they reduced N loss through leaching and volatilization (Mao *et al.*, 2005). Other novel coating materials such biochar (Shi *et al.*, 2020), zeolite coated urea (Dubey and Maliapalli, 2019) and adducts to slow down the dissolution rate are being developed and evaluated. Because of the slow diffusion of the N, it is perceived as the best option to mitigate N loss and improve use efficiency.

Nitrification inhibitors and urease inhibitors: Another approach to increase the efficiency of fertilizer N has been the use of nitrification-inhibitors (NI) (Prasad *et al.*, 1971; Prasad and Power, 1995; Prasad, 2005) and urease inhibitors (Byrnes and Freney, 1995). NI's are used to retard the nitrification of the ammonium and urea fertilizers in order to reduce leaching and denitrification. Furthermore, these NI's were found to substantially improve the NUE (Prasad and Power, 1995). Among the NI's, nitrapyrin, dicyandiamide and DMPP (3,4-dimethylpyrazole phosphate) are used commercially. However, they are not marketed in India. Neem was first shown to have nitrificidal activity (Bains *et al.*, 1971) with potential to enhance NUE (Prasad *et al.*, 2013). Neem oil micro-emulsion-coated urea was developed by Dr Rajendra Prasad and his team (Prasad *et al.*, 2001; Devakumar, 2016). Following results of the greater efficiency of the neem coated urea across locations on farmers fields (**Table 2**) and other crops, the Government made it mandatory that all the urea manufacturers produce neem coated urea for field use.

Table 2: Partial Factor Productivity (PFP) of N with neem coated urea (NCU) and urea for rice

Location	Grain (Mg/ha)		PFP (kg grain/kg N)	
	Urea	NCU	Urea	NCU
Delhi	4.5	4.9	37.5	40.8
Punjab	4.9	5.2	40.8	43.8
Haryana	4.3	4.9	35.8	40.8

Source: Prasad (2007)

Urease inhibitors (UI) have been developed for lowland crops to retard urea hydrolysis (Byrnes and Freney, 1995; Cantarella *et al.*, 2018). A number of UI's namely, PPD (phenyl phosphorodiamide), NBTPT (N-n-butyl thiophosphoric triamide), ATS (ammonium thioslphate) and several other compounds have been reported to be effective in retarding urea hydrolysis (Kiss and Simihain, 2002). Treating urea with NBTPT resulted in a substantial increase in productivity and farmers profitability (Wade, 2009). These chemicals, except for the indigenous neem, have not been used on a commercial scale due to their high costs as well as inconsistent results as compared to those reported in the temperate countries. Moreover some NI's may interrupt the activity of some soil bacteria for a certain period as well as killing of soil bacteria. This could be an undesirable interference in the natural agroecosystem (Sturm *et al.*, 1994). Nevertheless, the 4 R strategies invariably leads to a reduction in N loss will make more N available to the crop resulting in high NUE.

New N sources

Nanofertilizers: Nanosized fertilizers are the new frontier of nanotechnology (Carmona *et al.*, 2021). Nanofertilizers (1–100 nm), due to their small size are highly reactive and have a large surface area, compared to the traditional fertilizer sources that have small surface area and are less reactive. It is hypothesized that the highly water soluble N nanofertilizers once applied would be transformed into highly dynamic forms. This makes nanofertilizers effective at lower doses and correct severe N deficiencies rapidly (Subramanian *et al.*, 2015). However, research on their use is still in infancy. Many patents have been acquired and some research results do suggest potential benefits of the nanofertilizers over the conventional fertilizer sources (Gogos *et al.*, 2012). Intensive research on nanofertilizers in our country led to the development of nanofertilizer products. Kottegoda *et al.* (2019) developed urea-hydroxyapatite nanohybrid. The slow release for up to a week was attributed to the moderately strong bond between the amine group of urea and carbonyl group of hydroxyapatites. It was also proven in field applications to be able to save up to 50% of urea consumption. Carmona *et al.* (2021) reported higher NUE (69%) with an efficient N-nanofertilizer obtained by post-synthetic modification of nitrate-doped amorphous calcium phosphate nanoparticles with urea than the conventional fertilizer (49%). However, as with most new technologies, nanotechnology has potential risks such as, undesirable effects on non-target organisms (plants, soil microbes and humans). Therefore, bio-safety studies should be done when developing and evaluating nanofertilizers.

Microorganisms for N Nutrition

Microorganisms are used in agriculture, with potential for large-scale use and most suitable for low-input systems. Field studies across agro-ecosystems pointed out that *Azospirillum* sp. inoculation increased yield of cereals (Pereg *et al.*, 2016). These yield increases were due to effective N_2 fixation, increased root development and increased rates of water and mineral uptake. Integration of microbial inoculants into fertilization programs could reduce fertilizer-N inputs (Bindraban *et al.*, 2015). Khaitov *et al.* (2019) reported the benefits of bio-inoculant (*Azotobacter chroococcum*) on the saline soils of the Uzbekistan. Seedcotton yield as well as the NUE was higher with the bio-inoculant than the control treatments without any bio-inoculant. However, doubts about their effectiveness exist. Furthermore, concerns about the stability of the inoculants over time and under varying climatic conditions are yet to be resolved.

Precision Agriculture and N Diagnosis

Low NUE occurs when N is applied in excess of the crop demand. Precision Agriculture (PA) is based on innovative system approaches that use a combination of various technologies for timely in-season and between season crop management (Liaghat and Balasundaram, 2010) and allows maximizing NUE. The technologies forming a component of PA are Geographic Information System, Global Navigation Satellite System, computer modelling, Remote Sensing, Variable Rate Technology, Mapping and Advanced Information Processing. Crop response to applied N is not linear and depends on several factors. For instance, in a controlled environment, the efficiency of different types of N fertilizers in cereals is nearly identical. However, we observe differences in the field due to interactions between N sources and environmental conditions (e.g., precipitation and temperature). Further, soil properties dictate crop response to N such as soil pH, limiting nutrient, soil nutrient status etc. (Olfs *et al.*, 2005). Similarly, crop rotation can change the dynamics of N, modifying the expected response to the N fertilizer; for example, cover crops were shown to increase the availability of N for the subsequent crop (Delgado *et al.*, 2000). In legumes, there is an additional source of N resulting from the symbiotic association with species of the genus *Bradyrhizobium* (Boon-Long *et al.*, 1983). Furthermore, the type, timing, intensity, and depth of tillage were reported to affect the response to N fertilization (Zimmer *et al.*, 2016). The crop choice also influences N fertilization and losses (Delogu *et al.*, 1998). Thus, N diagnosis should integrate several sources of information and consider in-season dynamics to deliver correct N recommendations.

Satellite Image Analysis

Satellite images currently offer the possibility to cover large areas at affordable prices or for free. Initial attempts to use satellite data were limited due to drawbacks such as: (a) high cost of images; (b) interference by weather conditions (e.g., clouds); (c) slow and time-consuming image pre-processing; (d) delays between image capture and the availability of usable data (Wu *et al.*, 2008) and (e) overly spaced coverage. The high cost of images is not a limitation anymore since there have been significant reductions in their price or have become available for free. In addition, the replacement of older satellites by a new generation of satellites that can obtain images at higher resolutions is taking place. These satellites are also enlarging the constellation of satellites that screen fields, making possible to overcome other initial limitations such as overly spaced coverage. Similarly, more accurate N deficiency detection could be achieved in the near future by advances in the development of light and portable hyperspectral sensors (Munoz-Huerta *et al.*, 2013).

With unmanned aerial vehicles becoming more affordable, research efforts are being allocated to developing sensors for drones. Indices for assessing maize N status based on airborne measurements were found to be as reliable as measurements taken on the ground; field level readings with a chlorophyll meter (SPAD), red edge optical reflectance (R_{750}/R_{710}), and solar-induced fluorescence retrieval had the lowest error rates when distinguishing N-sufficient from N-deficient treatments (Quemada *et al.*, 2014). Several indices based on waveband combinations of canopy reflectance have also been used: the normalized vegetation index (NDVI), the ratio vegetation index (RVI), and other indices (Rodriguez *et al.*, 2006). As hyperspectral sensors become more affordable (Gonzalez *et al.*, 2015) spectral indices based on differences (NDVI, green NDVI, red NDVI, green vegetation index (GVI), red and green vegetation index (RGVI) or ratios (RVI, GVI, RGVI) are calculated from averaged crop canopy reflectance readings at green (520–600 nm), red (630–690 nm), and near infrared reflectance (NIR; 760–900 nm) bandwidths (Li *et al.*, 2008). Commercial reflectance sensors applied to estimate crop N status can be classified as passive or active, depending whether the energy source is the sun or an artificial source. Passive crop canopy reflectance sensors measure crop canopy reflectance generated by sunlight. A positive linear relationship between RVI and N uptake in winter wheat was demonstrated, as well as independence from growth stages and crop varieties. As a result, a major advantage of the RVI is that can also determine the N status in fields with high levels of N availability (Li *et al.*, 2008).

Decision Support Systems

Robust decision support tools were developed to help determine N fertilizer recommendations (Setiyono *et al.*, 2011). Crop simulation models have proven to be useful also to decide N applications that match crop needs (Holzworth *et al.*, 2014). Decision support systems are therefore fundamental in developing scenarios that predict potential consequences of N management practices.

Green Seeker (GS) as a Tool: The spectral properties of leaves are used in leaf colour charts and chlorophyll or SPAD (Soil Plant Analysis Development) meters to measure light transmittance through leaves in order to guide real-time N topdressings. Thus SPAD meter offers an alternative to N fertilization in a non-destructive way. In real-time N management, N-fertilizer is applied at a certain rate only when leaf N content is below a doorstep limit (Singh *et al.*, 2010). The GS resulted in significant higher agronomic NUE, partial factor productivity of N, RE, PE compared to RP. These results suggest that application of N fertilizer guided by the GS decision support tool can save significant amount of N fertilizer compared to the current RP without compromising grain yield. Alam *et al.* (2013) reported increased rice grain yield with Best Management Practices (BMP) and two N management options compared with the farmers' practice (FP). The higher yield response (24.6% in Aman and 8.6% in Boro season) occurred with BMP in combination with leaf colour chart aided N management than BMP with Urea Super Granule as N source. These N savings may be traded in future water and air quality markets (Delgado *et al.*, 2010).

According to Gu *et al.* (2011), technological developments play a key role in atmospheric N pollution control while effective policies mainly contribute to groundwater N pollution control. Therefore, the development and implementation of regulations is critical to orientate N fertilization practices that minimize the environmental impact (Van Grinsven *et al.*, 2012). Varying N management policies have not been implemented so far in our country; though soil test based application of fertilizers is being followed to a limited extent. Blanket rate of fertilizer recommendation is still widely adopted for the singular reason that it is easy to follow. However, to improve use efficiency and reduce cost of cultivation, it is important that more research efforts be concentrated on these novel strategies not only for the major crops such as rice and wheat but also the other field and horticultural crops as well. We need to ascertain the degree of success with variable rate of application without compromising the food production levels required. Efforts are to be taken to assess the N footprint of different activities and protect the environment.

Agronomic Practices

In addition to proper nutrient management, other aspects of soil and crop management including timely sowing, use of high yielding varieties, nutrient efficient cultivars, pest and disease management should be followed to supplement the above mentioned approaches in order to improve the overall NUE. Kumar *et al.* (1998) reported that NUE was greater in optimum and timely sown crop as compared with late sown crop. Interdependence of irrigation and nutrient use efficiency was demonstrated in increasing wheat yields at Bhopal, Madhya Pradesh (**Table 3**) due to improvement in the root growth and better soil moisture extraction. With drip irrigation system, not only water is conserved but it also results in higher nutrient use efficiency than the conventional flood irrigation methods (Sankarnarayanan *et al.*, 2011).

Table 3: Influence of irrigation and nutrient management on fertilizer-N use efficiency (kg grain/Kg N applied)

Irrigation	Nutrient management	
	NPK	NPK + FYM
No irrigation	6.8	12.8
Two irrigations	14.5	21.0
Three irrigations	117.0	24.1

Source: Adapted from Mandal et al. (2005)

Organic materials have an important role in maintaining buffering capacity of soil apart from its role in maintaining the soils physical and biological properties. Thus, the use of farmyard manure (FYM) was observed to stabilize yields and improve the NUE (Tables 3 and 4).

Table 4: Mean yield response of cotton (kg/ha), yield stability and PFP as affected by fertilizer application on the rainfed Vertisols

Treatment	Mean yield response	Slope	PFP
N	634.7	0.63* (<1)	10.6
NP	920.5	0.92	15.3
NPK	950.2	1.09	15.8
NPK + FYM	1100.8	1.47* (>1)	18.4

Source: Blaise et al. (2006)

Among the good agronomic practices, balanced fertilizer approach is an approach to improve crop productivity. Efficient use of N depends on the balanced supply of all the other essential nutrients. Blaise *et al.* (2006) observed in a long-term study that yield stability was achieved only in systems receiving balanced nutrition supply (Table 4). Furthermore, the PFP in the balanced fertilizer plots were better compared to the plots wherein one or more of the fertilizer nutrients were omitted.

Breeding strategies

Efficient genotypes have specific physiological mechanisms that enable plants either to access sufficient N quantities and/or to more effectively utilize their N uptake (utilization efficiency) (Sattelmacher *et al.*, 1994). Genotypes with superior N uptake, storage, and translocation capabilities will allow for further gains in NUE and yield (Berry *et al.*, 2010). Further, the efficient nutrient acquisition cultivars or genotypes tend to perform better than the inefficient ones under nutrient stress conditions. Venugopalan and Pundarikakshudu (1999) observed that the desi cotton (*Gossypium arboreum*) varieties had higher N utilization efficiency than the American cotton (*G. hirsutum*) varieties. The *desi* cotton had NUE of 18.7kg seedcotton/kg N uptake as compared to 14.9 kg seedcotton/Kg N uptake with the American cotton varieties. Similarly, Bt cotton hybrids differed in their response and use efficiency (Table 5). Taking up cultivars or hybrids that are recommended for the region is important, else it would result in low NUE and a wastage of nutrients. However, breeding strategies have mostly focussed on developing cultivars or hybrids having the highest yield potential and at times for a superior quality for instance high oil content in oilseed crops, better fibre quality in cotton etc. Breeding strategies should be focused on cultivars/hybrids with high NUE and adaptability to low nutrient conditions. Development of cultivars/hybrids with efficient N uptake from the available N pools and utilizing it for the economic part of the crop plant (Good *et al.*, 2004). Improving NUE is possible through the genetic modification of target genes, pathways or metabolic processes involved in N assimilation process. Identification of N-efficient crop cultivars will result in fitting it into existing infertile soils. This will not only make the infertile soils productive but also lead to a reduction in the N fertilizer inputs. Another approach gaining in popularity for discovering genes underpinning variation in complex traits such as NUE or responses to available N is via transcriptome analysis. Such studies are needed for making our cropping systems more robust and sustainable. Some plant species produce exudates which are nitrification inhibitors and the transfer of this trait is now being explored as a means of improving NUE (Subbarao *et al.*, 2013).

Table 5: PFP of applied fertilizer to Bt cotton hybrids

Bt hybrids	Seedcotton yield (kg/ha)	PFP
MECH-184	1718	11.8
MECH-162	1717	11.8
MECH-12	1143	7.8

Source: Singh et al. (2003)

Improving nitrogen use efficiency (NUE) is imperative in order to curtail N loss and production costs. The 4 R’s (right quantity, right time, right method and right source) should be considered as the first step for enhancing NUE. Several other best management practices (BMP’s) of production and protection need to be adopted to achieve high NUE. Newer technologies are becoming available such as novel N sources, use of microbes, nanofertilizers, and recycled nutrients The fundamental aspect is to develop better N fertilization products and management strategies to synchronize soil N availability with crop N demand, and thus maximize NUE. We also need to take into account plant physiological processes, including the diversity of mineral nutrient uptake mechanisms, their translocation and metabolism for the breeding of crop cultivars that are eventually more N efficient.

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