Chapter 9
Techniques for Improving Nitrogen Use Efficiency in Rice

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Abstract Nitrogen (N) is an essential macroelement for rice growth and development in paddy fields. Nitrogen use efficiency (NUE) is an indicator of nitrogen utilization in rice plants. Increasing NUE reduces nitrogen fertilizer consumption, prevents N fertilizer loss and rice productivity. In the present study, fertilizer types, water irrigation management, and rice cultivars are the factors for improving nitrogen use efficiency in rice. The organic compound application with controlled-release N fertilizers in the soil is one of the effective techniques for NUE improvement. In this chapter, we have paid to N increase necessity, its loss of environmental consequences and increase plant yield.

Keywords Rice · Nitrogen fertilizer · Productivity

9.1 Introduction

Nitrogen is an essential element for the growth of rice plants (Spiertz 2010). To crop output increase, a lot of nitrogenous fertilizer is applied (Iqbal et al. 2020). Cereal plants have nitrogen use efficiency by nearly 33%. The rest of nitrogen fertilizer use efficiency is more than 65%, which causes a lot of financial loss annually (Fig. 9.1) (Raun and Johnson 1999), rise in the price of the crop, and to anthropological and ecological difficulties (Iqbal et al. 2020). However, it is possible to increase NUE in some ways (Fig. 9.2). The suitable methods are in the following (Iqbal et al. 2020):

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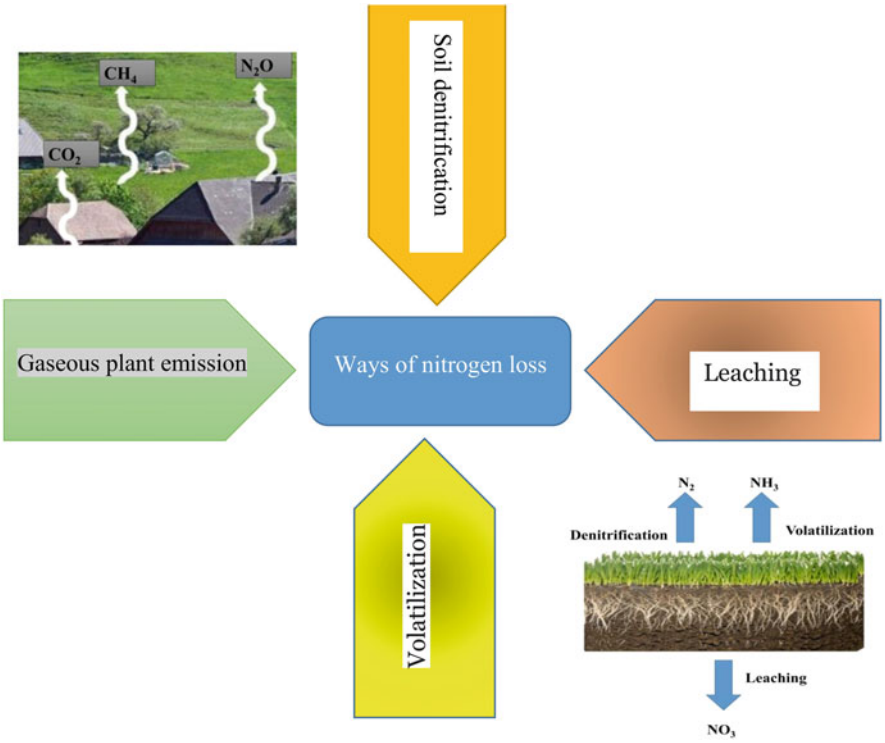

Fig. 9.1 The most important ways to fertilizer nitrogen loss

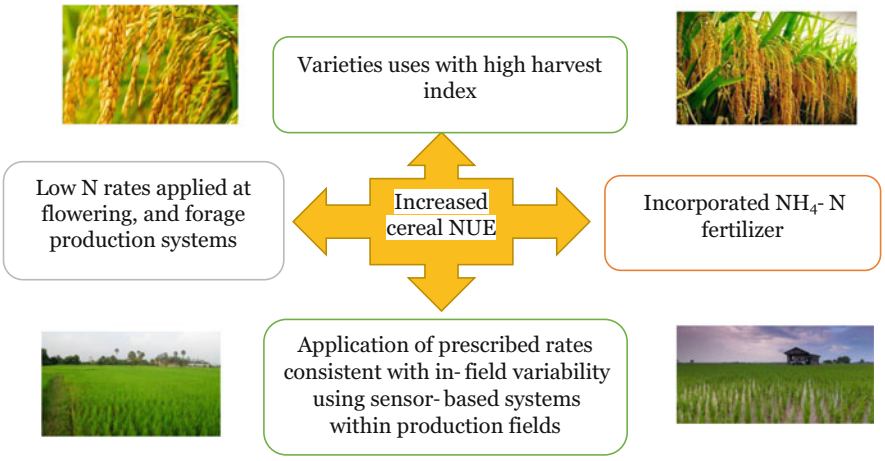

Fig. 9.2 The most important ways to increased cereal NUE

- Organization agronomic.
- Biotechnological.
- Breeding approaches.

Many studies about NUE are associated with irrigation, effective use of fertilizer, uptake of nitrogen fertilizer from the soil, and application of nitrogen fertilizer for plant yield (Cassman et al. 1993; Ye et al. 2013; Cabangon et al. 2011). Evaluation of each factor and its management has an effective role in determining it.

9.2 What Factors Does NUE Depend on?

If we want to summarize the effective detail factors on NUE in plant, we have to refer to Fig. 9.3. However, the following general factors can be described: These factors are two squares.

9.2.1 Application Fertilizer Types

Nitrogen recovery in rice is low, while it is significantly higher in the soil N pool (nearly 2 times) (Zistl-Schlingmann et al. 2020). Fertilizer nitrogen sources are used to play an important role in NUE changes, for example, controlled-release urea vs conventional urea (Guo et al. 2016) or organic and inorganic fertilizer (Behera et al. 2009) and N fertilizers with the new nitrification inhibitor (NI) 3,4-dimethyl pyrazole phosphate (Pasda et al. 2001).

9.2.2 Water Irrigation Management

Wetland rice systems maintained N uptake rice plants and increased N efficiency by improved management (Cassman et al. 1998). Other studies presented that

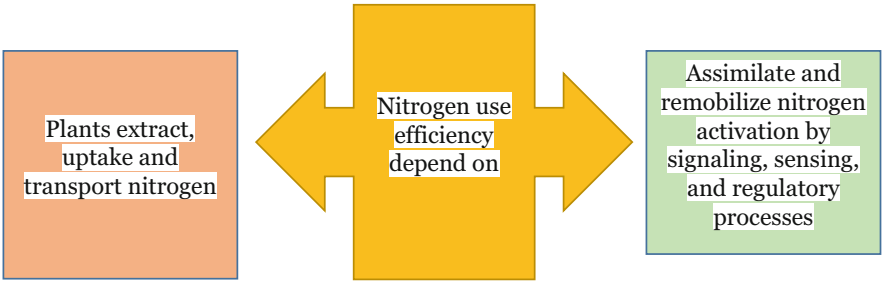

Fig. 9.3 The most important effective factors on NUE in plant

alternation irrigation and N application provide better rice growth, yield, and N utilization. Its reason is that increased glutamine synthetase and glutamate synthase activity in root rice (Sun et al. 2012). Alternate wetting and drying (AWD) are better than continuous flooding on plant NUE, while N fertilization as controlled-release nitrogen fertilizer application considerably increased NUE (Ye et al. 2013). Moderate AWD is an important practice in progressive integrative crop management to the increase in NUE rice (Zhang 2018).

In some studies, only AWD (without amendment) decreased water input and nitrogen fertilizer controlling without a negative impact on NUE rice. It can be stated that the alternative irrigation regime is convenient for low water areas (Cabangon et al. 2004).

9.2.3 Rice Cultivars

The choice of enhanced (NUE) genotypes is important to decrease N input. These plants can absorb, use, and the remobilization of N from in soils and help sustainable agriculture (Mauceri et al. 2020). Duan et al. (2007) stated that Nanguang is a high-NUE cultivar and Elio is a Low-NUE rice cultivar in chins. Change in ratio $N\text{-}NH_4$/$N\text{-}NO_3$ until to 3 increased N accumulation in the high-NUE cultivar more than the Low-NUE rice cultivar. Yang Dao had significantly greater NUE than Nong Ken for rice production. Application of a variety of nitrogenous compounds increased yield. Nitroxin and nano potassium consumption are used in two Iranian rice cultivars. Tarom Hashemi has a higher yield than Tarom Mahalli (Lemraski et al. 2017). Among to Hashemi, Ali-Kazemi, and Khazar as Iranian rice cultivars, Cultivar Khazar is the highest N physiological efficiency (Moosavi and Mohamadi 2014). Wuyunjing 23 (W23), Zhendao 11 (Z11), Wuyujing 3 (W3), and Aoyusi 386 (A386) are four cultivars of rice. W23 and Z11 are two high-NUE cultivars (Chen et al. 2020). *Japonica* and *indica-japonica* rice cultivar were grown in Progressive integrative crop management caused to improve NUE, grain yield agronomic, and physiological achievements (Zhang 2018).

Wuyunjing 7, Nanguang, and 4007 are high NUE and Elio is a low-NUE rice cultivar. Elio had fewer reproductive tillers due to a reduced amount of demand for N during rice middle growth (Zhang et al. 2009).

9.3 Some Methods to Increase Nitrogen Use Efficiency in Rice

The increase of NUE in the non-N2 fixing crops (for example rice) is done according to the growing population need of the world (via improved NUE cultivars and managing) (Raun and Johnson 1999). For this purpose, there is a need to recognize newer methods (Table 9.1).

Table 9.1 Some researches about nitrogen efficiency improvement

Methods and strategies	Results	reference
(Nitrogen–water management) distribution management (MNWD)	Grain yield maintenance Improved of N use efficiency (NUE) Improved of water-use efficiency (WUE) Reduction of input resources (20%)	Yang et al. (2020)
Controlled-release nitrogen fertilizer (CRNF)	Increased yield, N uptake, and N use efficiency compared with urea	Geng et al. (2015)
Progressive integrative crop management (ICM)	Increase grain yield, NUE, and irrigation water productivity in rice	Zhang (2018)
Omics technologies	The remobilization of N from leaves (a strategy to enhance N-utilization component)	Mauceri et al. (2020)
Use of urease inhibitor and nitrification inhibitor	Increase fertilizer use efficiency and to minimize its negative impact on the environment	Xiang et al. (2008)
Struvite	Nitrogen conservation	Kataki et al. (2016)
Swine production	Economic and environmental benefits	Monteiro et al. (2017)

Nitrogen and water irrigation management is a widespread technique to meet of rice production. Nitrogen–water management reduces N application and water irrigation by 20% and increases N uptake in rice plants (Yang et al. 2020).

Zeolite application (as soil amendment) with urea (as N fertilizer) improved NUE in rice (Kavoosi 2007).

Controlled-release urea applications could reduce N losses, yield increase, and N quantity in straw and grain (Guo et al. 2016).

9.4 Nitrogen Forms as a Particular Index

A nitrate is a nitrogen form for N uptake in rice plants. It is an indicator molecule for physiological developments in plant growth. Change of nitrate transporter and assimilation genes (Iqbal et al. 2020) may increase NUE in rice.

Bentonite hydro-char composites (BTHC) reduced archaeal amoA genes (AOA) that probably reserved nitrification and improved soil NH_4^+ maintenance (Chu et al. 2020). NUE and NH_3 volatilization relations have not been confirmed in paddy soils, but nitrogen losses are decreased by high-NUE rice cultivars farming (Chen et al. 2020). High-affinity transporter systems in high-NUE genotypes have an important role in the N efficiency of rice. Nitrate reductase and nitrite reductase activity are increased in low-NUE cultivars along with an increase in nitrogen fertilizer application (Hakeem et al. 2011).

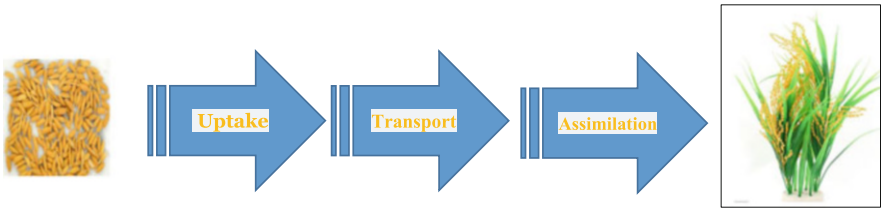

Fig. 9.4 N consumption process (three steps)

High-NUE rice meaningfully improved NH4 + cycle and tissue accumulation in the rhizosphere (Chen et al. 2013).

Li et al. (2017) stated N utilization includes three procedures (Fig. 9.4). Transport and assimilation management determine NUE in rice plants (enzymes, nitrate, and ammonium transporters).

9.5 Compounds Application and Their Effects

Many compounds are applied for increasing rice yield and growth (Fig. 9.5). These compounds cause more nitrogen uptake and increase NUE in different ways without environmental damage.

- In terms of N accumulation, conventional urea performed poorly than controlled-release urea in rice straws and grains (Guo et al. 2016).
- Ammonia volatilization is reduced by Bentonite hydro-char composites in flood-water and it subsequently leads to an increase of rice yield and NUE (by nearly 40%) (Chu et al. 2020) in paddy fields.
- Motesharezadeh et al. (2015) stated that zeolite and nitrifying bacteria application decreased ammonia loss and increased plant biomass.
- The application of organic amendments (rice straw and azolla compost) increased the concentration of total nitrogen in paddy fields (Novair et al. 2020).

9.6 Agricultural Managements

Agricultural management will change NUE in according to different points in agriculture and climate conditions. Some studies investigated that intensive and extensive management with slurry applications. The nitrogen harvest of intensive management is more than extensive management (Zistl-Schlingmann et al. 2020).

Another issue is soil tillage condition in paddy fields (tillage and no-till conditions and with and without cover). Continuous no-till and covering showed to increase NUE and WUE (Habbib et al. 2020).

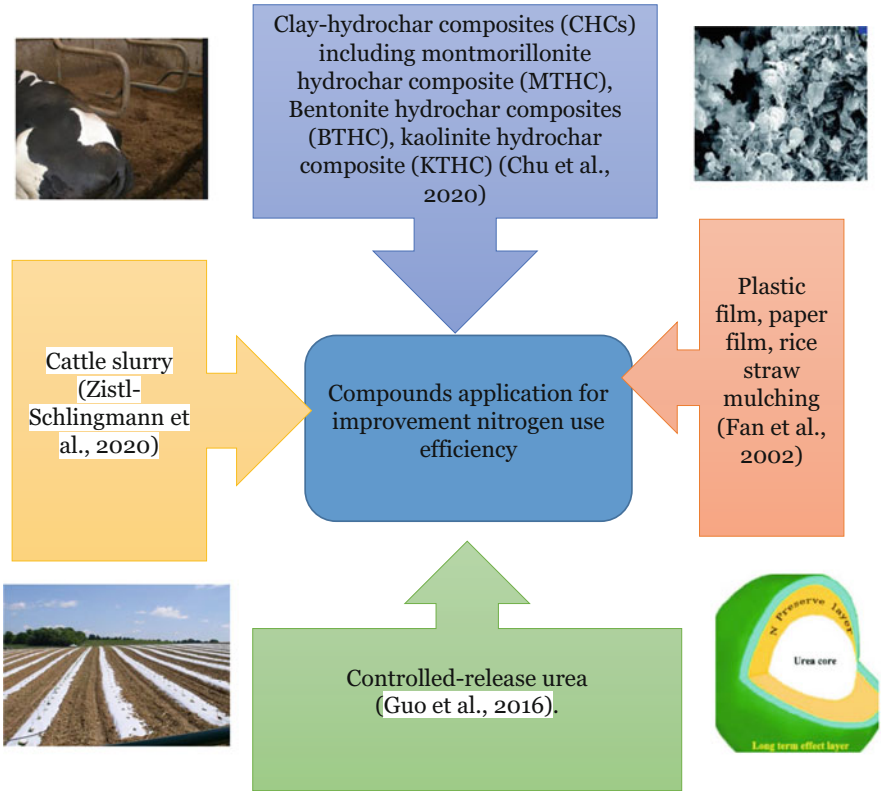

Fig. 9.5 Usual compounds application for increasing NUE

One of the most effective ways to reduce nitrogen loss, urea must be applied with a nitrification inhibitor (3,4-dimethyl pyrazole phosphate, DMPP) and urease inhibitor (n-butyl thiophosphoric triamide, NBPT). These applications increased recovery of N and reduced N loss in the soil (Wallace et al. 2020).

Integrative crop management along with moderate alternative drying-rewetting are techniques in higher NUE and productivity (Zhang 2018).

9.7 Laboratory Analysis Types

Indicators related to the measurement of NUE rice are photosynthesis parameters and water-use recovery. Leaf area, and chlorophyll are factors related to photosynthesis parameters. Transpiration rate and stomatal conductance are factors related to water-use recovery (Habbib et al., 2020).

Agronomic and physiological factors are evaluated leaf epidermal cell cytosolic nitrate activities and nitrate reductase activity (Fan et al. 2007).

15 N mass balance was evaluated to the determination of nitrogen fertilizer fate (Wallace et al., 2020).

Comparison of root morphology, NH4+ concentration, root oxygen consumption, and transmembrane NH4+ fluxes in the root meristem was done among two rice cultivars (high NUE and low NUE) (Chen et al. 2013).

Zhang (2018) estimated the number of other indicators with NUE:

- Spikelet.
- Tillers.
- Leaf characters.
- Rice growth.
- Carbohydrate accumulation and remobilization.
- Photosynthetic characters.
- Morphological characteristics.
- Redox properties of root.
- Growth regulating chemical compounds in roots and leaves.

9.8 Environmental Issues and Problems

One of the most important problems in the application of nitrogen fertilizers is their loss to the environment. The low rice NUE causes to N losses, ecological problems and degradation, floodwater pollution, and economic cost.

In summary, the main effects of increasing fertilizer nitrogen concentration on the environment can be described as follows (Fig. 9.6) (Kant et al. 2011; Bashir et al. 2013):

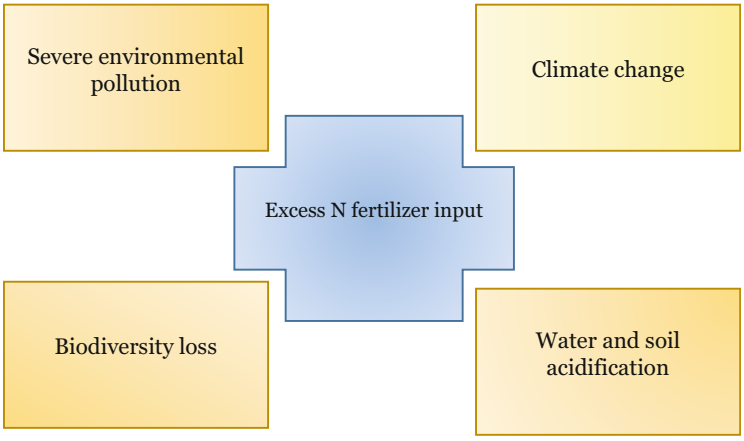

Fig. 9.6 Impact of excess N fertilizer input

However, different results were observed in this regard. Chen et al. (2020) observed that higher-NUE genotypes do not decrease ammonia volatilization. It can be done in other loss ways because low NUE causes excess N concentration in the soil condition (Johnson and Raun 2003).

Including different losses of nitrogen in ecological (−) and best N management (+):

(−) Zhu and Chen (2002) showed that increase the concentration of nitrogen in surface and subsurface waters, algal growth and greenhouse gas emissions.

(−) High concentration nitrogen fertilizer (NH4+) reserved the total root expansion (Chen et al. 2013).

(−) Leached ammonium is transferred to underground water and transformed to NH3 and it accelerated nitrification reactions rapidly in the soil pore spaces. Then, nitrates changed to gaseous (denitrification) upon drainage (nitrification-denitrification in paddy soil) (Aulakh 1996).

(+) The soil manure controlling system returns 50% of lost nitrogen to the plant nutrient cycle (Oenema et al. 2007).

(+) Organic matter addition to soil caused to aggregate stability and nitrogen sequestrated in macroaggregate (Guo et al. 2007).

9.9 Conclusion

It is important to improve the NUE today to reduce the negative environmental effects, increase crop yield, and decrease N fertilizer use in the twenty-first century. Increasing NUE plays an important role in improving rice growth and reducing the loss of different forms of nitrogen. It is possible with the application of N fertilizer compounds, field management, type rice cultivar (high NUE), and irrigation regime. According to the listed content, the organic application is the best way to increase nitrogen maintenance in the soil.

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