# 4R Nitrogen Management for Sustainable Rice Production

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**Research conducted on N management in rice** at the ICAR-Indian Institute of Rice Research was aimed to increase the productivity while improving N use efficiency.

**Bringing the current N management in rice** under the concept of 4R Nutrient Stewardship can further help in achieving better economic, social, and environmental performance of N.

Rice is the most important staple food crop for more than half of the global population. In India, rice production has increased five-fold from about 20 million tonnes (Mt) in 1950-51 to more than 106 Mt in 2013-14. This increase in production is attributed to the development of fertilizer-responsive, high-yielding varieties. Fertilizer consumption, which contributes to nearly 50% of rice varietal yield potential, showed a phenomenal increase during this period [i.e., 69,800 t in 1950-51 to 25.6 Mt by 2014-15 (FAI, 2015)]. However, declining factor productivity in many intensive rice systems is a concern and this may be due to imbalanced fertilizer application by farmers.

Nitrogen is the key nutrient element required in large quantities by rice. In modern agro-ecosystems, it was estimated that the removal of as much as 300 kg N/ha/yr in the above-ground portions of the harvested produce requires substantial inputs of N either through fertilizers, manure, or N-fixation to maintain the productivity (Cassman et al., 2002). Indian soils are inherently low in soil organic matter, N is the major limiting plant nutrient, and N availability is routinely supplemented through the application of fertilizers. Though the yield increase due to N fertilization in rice has been substantial (47%), the average agronomic efficiency of N is only 11.4 kg grain/kg N (Prasad, 2011). It was earlier estimated, a 1% increase in the efficiency of N use for cereal production worldwide would lead to N fertilizer savings of 0.49 Mt, which accounts for US$0.24 billion savings in N fertilizer costs (Raun and Johnson, 1999).

Proper management of N is essential for achieving higher productivity, maximizing nutrient use efficiency (NUE), and improving environmental safety by ensuring minimal losses of applied N. In this context, promoting the 4R Nutrient Stewardship concept of applying the right fertilizer source, at the right rate, at the right time, and in the right place can help farmers maximize the economic, social, and environmental performance of N use. The research work conducted so far at the ICAR–Indian Institute of Rice Research (IIRR) and elsewhere in India, though aimed at achieving higher rice productivity while improving NUE, has not exactly followed the principles of the 4R approach. Considering the importance of bringing nutrient management for rice under the 4R perspective, an attempt was made to review the existing information to define 4R principles for N management in rice.

## Right N Source

The choice of selecting the right source of N fertilizer depends on soil properties, nutrient content and cost of the fertilizer, and water management. However, efficiency of applied N fertilizer primarily depends on the form of N applied and the ecosystem in which they are used. Several studies have reported the superiority of amide and ammonical sources of N (urea and ammonium sulphate) for rice over nitrate forms (Prasad et al., 1980; Surekha et al., 1999). These sources have more stable ammonia-N held by the soil cation exchange complex, which helps in the gradual release of N throughout the active growth stages of rice. This contributes to a higher grain yield under flooded conditions when it is compared to nitrate-N, which is highly mobile and subjected to losses through leaching and denitrification. Urea has been challenged as a N source for rice due to leaching losses in coarse-textured soils and surface runoff, which could be offset with the use of slow-release neem-coated urea (NCU). The co-ordinated studies conducted by the IIRR showed an increase in N response (33.1 kg grain/kg N) with NCU at Ghaghraghat (Uttar Pradesh), while the lowest N response (4.3 kg grain/kg N) was recorded with prilled urea (PU) at Chinsurah in West Bengal

**Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; Zn = zinc.**

**Dr. Surekha (on right) determining right timing of N** application in the rice field using leaf colour chart.

**Table 1.** Effect of right source of N on grain yield response of rice (DRR, 1988-89).

| | ---- Response, kg grain/kg N ---- | | | |
|---|---|---|---|---|
| Location | MRPU | NCU | GCU | PU |
| Bhubaneswar, Odisha | 20.0 | 25.5 | 26.4 | 18.4 |
| Chinsurah, West Bengal | 10.4 | 8.8 | 9.2 | 4.3 |
| Faizabad, Uttar Pradesh | 20.0 | 18.9 | 21.3 | 14.2 |
| Ghaghraghat, Uttar Pradesh | 22.9 | 33.1 | 27.9 | 17.8 |
| Mean (All locations) | 19.1 | 21.1 | 22.0 | 17.5 |

MRPU = Mussorie rock phosphate coated urea; NCU = Neem-coated urea; GCU= Gypsum-coated urea; PU = Prilled urea.

(**Table 1**). The recent urea policy by the government of India, introduced in January 2015, made it mandatory for all domestic urea manufactures to be neem coated. Use of NCU helps in the sustained slow release of N, by about 10 to 15%, and results in increased rice yields. Suganya et al. (2007) assessed the influence of NCU on yield and N use efficiency in rice and reported a 20% higher grain yield and the highest apparent N recovery with NCU over prilled urea in the Noyyal and Madukkur soil series of Tamil Nadu. NCU helped in reducing leaching and volatilization losses by inhibiting the nitrification process and accelerated the N availability while saving the N use by 20 kg/ha, indicating that NCU could be a right source of N fertilizer for sustaining rice production.

Chemical fertilizers that are high-grade in their N supply and are easily soluble in nature, release N at a rapid rate when applied to rice. On the other hand, organic manures with a low concentration of nutrients paired with other challenges such as a slow-releasing nature, have high transport costs and limited availability that may not be beneficial for rice when applied as the sole N source. However, a judicious combination of these two sources improves the use efficiency for applied N if compared to the sole use of either organic manure or N fertilizer. Many long-term fertilizer experiments reported the beneficial role of farmyard manure (FYM), indicating a positive yield growth of about 100 kg/ha/yr across different locations with a supplementary dose of 5 t FYM, or poultry manure, along with recommended rates of fertilizers (DRR, 1994, 2004, 2014). Thus, the supply of both manures and fertilizers in optimum combination would help in improving NUE while achieving higher productivity.

## Right Rate of N

On average, rice needs about 15 to 20 kg of N to produce 1 t of grain yield (IRRI, 2016). This indicates an uptake requirement of approximately 100 kg N both from soil and fertilizer sources to produce 5 t/ha of grain yield. Thus, a soil with indigenous N supporting 2.5 t/ha rice yield would need an external N supply of 50 kg/ha. However, considering (i) an agronomic efficiency for N fertilizer of 25 to 40%, (ii) N off-take with grain and straw, and (iii) the need to compensate for low N fertility status of Indian soils, 100 to 125 kg N/ha is recommended to achieve a target yield of 5 t/ha.

The site-specific decision on right application rate for N requires knowledge of the expected crop yield response to applied N, the function of N removal by the crop, the supply of N from indigenous sources, and the dynamics of the applied N fertilizer in the soil. Satyanarayana et al. (2012) considered yield response, agronomic efficiency ($AE_N$), and return on investment of N fertilizer ($ROI_N$) while determining the right rate of N to rice across the Indo-Gangetic plain. The right N rate can prevent the current imbalanced use of N fertilizers in India and can minimize its adverse effects on soil, climate, and the crop (Ray et al., 2000).

Application of right N rate in rice is also governed by crop duration, the nature of the variety, and the growing season. Studies conducted through the All India Coordinated Research Project on Rice (AICRP) showed that 90 to 120 kg N/ha increased grain yield in short and medium duration varieties, while N applied at 80 to 100 kg/ha proved to be optimum for long duration varieties (DRR, 1981-85). The high N requirement tested in the short and medium duration varieties was due to a high N response, which was 13 to 44 kg grain/kg N in short duration and 10 to 29 kg grain/kg N in medium duration varieties. The long duration varieties in the study showed a relatively low response of 8 to 22 kg grain/kg N, which resulted in application of low N rates in the long duration varieties. It was also observed that the long duration varieties were subjected to lodging with the higher rates of N application. Evaluation of N rates at AICRP centres revealed significant N response up to 120 kg/ha high-yielding varieties (HYVs). Few hybrids responded up to 150 kg/ha at most of the locations, while other hybrids responded up to 225 kg/ha indicating a variable N requirement to varying rice genotypes (IIRR, 2014). The higher N requirement of rice hybrids over HYVs is due to higher biomass of hybrids, higher number of panicles, larger panicle size, and more spikelets per panicle over HYVs.

Nitrogen requirement varies from field-to-field due to high variability in soil fertility across farmer fields and in cases the conventional blanket fertilizer recommendations may not be adequate enough to meet the N requirement of recently introduced HYVs and hybrids. Site-specific nutrient management (SSNM), an improved approach for determining right application rates, aims to apply nutrients at optimal rates and times to achieve high yield and high efficiency of nutrient use by rice. This leads to high economic return per unit of fertilizer invested. SSNM has shown the potential to close existing yield gaps in the intensive rice cropping systems of Asia (Dobermann et al., 2002), but widespread adoption of SSNM in smallholder farmer fields is challenged with limited acceptance due to the complex and knowledge-intensive nature of the approach. Agronomists and extension agents lacked confidence in using the approach that called for a scientifically robust, user friendly, and simple to use decision support tool for widespread adoption of SSNM. In response, the International Plant Nutrition Institute (IPNI), in collaboration with IIRR and other national partners, developed the *Nutrient Expert®* (NE) fertilizer decision support tool. NE is a 4R compliant tool that provides field-specific fertilizer recommendations to smallholder farmers.

IIRR and IPNI compared NE-based fertilizer recommendations with that of the generally recommended dose of fertilizer (RDF), farmer fertilizer practice (FFP), and an absolute control. The summarized results of four rice cropping seasons, spread over three years, in 18 locations indicated that SSNM based on NE yielded highest (5.5 t/ha). Yield under NE was 7%, 18%,

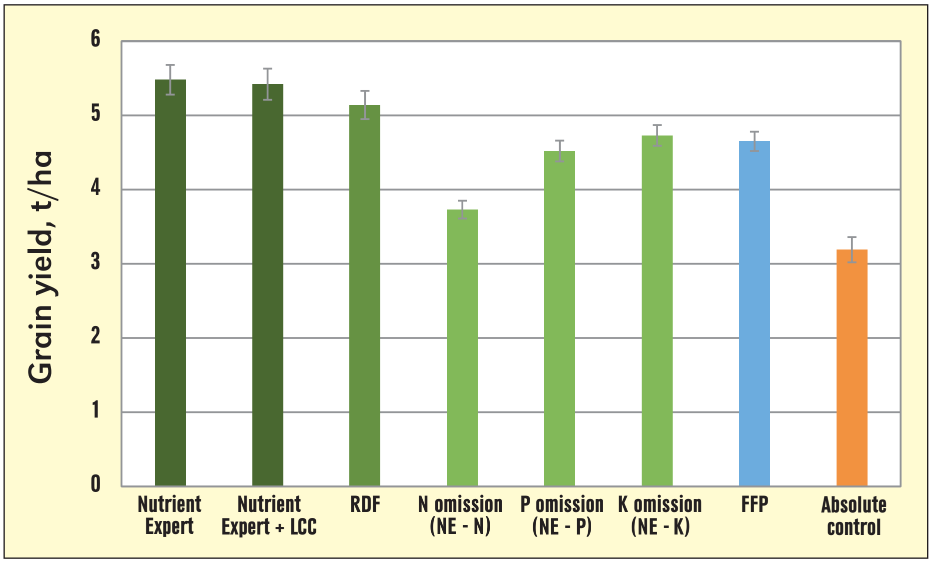


**Figure 1.** Comparative performance of SSNM-based Nutrient Expert® on grain yield of rice (summarized results of four cropping seasons, spread over three years, in 18 locations). Source: IIRR and IPNI joint collaborative research (2013-16).

**Notes on Figure 1**

NE = Nutrient Expert® based recommendation, which used an average N rate of 123 kg/ha.
NE+LCC (leaf colour chart) used same N rate as NE, but 50% was applied basally and remainder was guided through the use of LCC.
RDF = Recommended Dose of Fertilizer used an average N rate of 104 kg/ha.
-N; -P, and -K are omission plots derived from the NE treatment.
FFP = Farmer Fertilizer Practice used an average N rate of 140 kg/ha.
Absolute control = zero N, P, and K.

and 72% higher than RDF, FFP, and control, respectively (**Figure 1**). The comparison of N fertilizer use between RDF and NE revealed that N use in RDF varied from 80 to 120 kg/ha, with an average of 104 kg/ha. The corresponding N use, based on NE recommendation, varied from 90 to 150 kg/ha with an average of 123 kg/ha (data not shown). The NE-based individual field-specific fertilizer recommendation increased the average N fertilizer rate by 19 kg/ha, an increase of 18% over RDF. Similar studies were also conducted by Mandal et al. (2016) across 323 locations in West Bengal and reported an additional rice yield of 1.2 t/ha and additional gross benefit over fertilizer cost (US$235/ha) with the use of NE-based fertilizer recommendations over FFP.

## Right Time of N Application

Rice requires N at different growth stages and N fertilizers should be applied at these physiological stages (right time). This may help in the availability and absorption of N during the critical growth stages of rice leading to better utilization of the nutrient. Application of N, when not matched with the demands of rice, may result in considerable loss of applied N causing yield and economic loss. Several multi-location experiments conducted for determining the right timing of N suggested that the application occur in three splits, one-third at transplanting, one-third at tillering, and the final third at panicle initiation for achieving high grain yield (particularly for medium and long duration varieties) (**Table 2**). Patnaik and Mohanty (1985) instead suggested to apply 75 to 80% of the total N during the vegetative stage followed by the remaining being top-dressed during internode elongation and emergence of boot leaf. Nitrogen absorbed by the plant in the vegetative stage is used for formation of the 'source' and the N supply at tillering and the reproductive or panicle initiation stage improves the formation and filling up of the 'sink.'

In view of the existing interactions among the timing of N application, soil conditions, duration of the rice crop, and method of rice culture, the review by Rao (1985) suggests N application in two splits for tall ***indica*** varieties, three splits for dwarf *indicas*, a heavy basal application for Ponlei varieties (tropical *japonicas*), and low N dose (one-third) at seeding followed by heavy application (two-thirds) at tillering for direct seeded rice. For hybrid rice with higher sink capacity, an additional fourth N split was reported for the flowering stage. Surekha et al. (1999) observed an increase in the yield of rice hybrids (about 8%), when N was applied in four splits coinciding the last split with flowering, compared to the usually recommended three splits. The higher yield due to N application in four splits was ascribed to combine the favorable effects of improved leaf N concentration, rubisco content, photosynthetic rate of flag leaves, and increased grain filling percentage by delayed leaf senescence.

Recently, the chlorophyll meter (SPAD-502) has been used to diagnose the N status of a standing rice crop as a means of deciding the timing for N top dressing. Being a quick, simple and non-destructive method, it is preferred for predicting the N status of rice leaves with the ultimate goal of estimating the need for the side-dressing of fertilizer N as a part of precision N management. John Kutty and Palaniappan (1996) found a high linear regression ($y = 0.466 + 0.111x$; $r = 0.79$) between SPAD values and grain yield of rice. A positive correlation

**Table 2.** Effect of right timing of N application on grain yield of rice (Meelu and Morris, 1987).

| ------- Timing of N[1] application ------- | | | --------- Grain yield, t/ha --------- | | |
|---|---|---|---|---|---|
| Transplanting | Tillering | Panicle initiation | Ludhiana | Rajendranagar | Pantnagar |
| - | 100% | - | 4.73 | - | - |
| 100% | - | - | - | 6.59 | 4.71 |
| 50% | 50% | - | 5.24 | - | - |
| 75% | 25% | - | - | 6.66 | - |
| 75% | - | 25% | - | - | 4.76 |
| 33% | 33% | 33% | 5.50 | 7.27 | |
| 50% | 25% | 25% | - | - | 6.00 |

[1]A uniform N rate of 120 kg/ha was applied at all the three locations.

**Table 3.** Integrated effect of right source and method of N application on grain yield of rice (De Datta, 1987).

| N source | Method of application | Water depth, cm, at basal fertilizer application | - - - Grain yield, t/ha - - - Dry season | Wet season |
|---|---|---|---|---|
| Prilled Urea | Researcher's split | 0 | 6.4 a | 4.4 a |
| Prilled Urea | Researcher's split | 5 | 5.5 b | 3.9 b |
| Prilled Urea | Farmer's split | 0 | 5.4 b | 5.4 b |
| Prilled Urea | Farmer's split | 5 | 5.2 b | 5.2 b |
| Urea super granules | Basal, placement | 5 | 6.6 a | 4.5 a |

between the SPAD values and rice yields, and between SPAD values and the leaf colour chart (LCC) (DRR, 1997-98), indicated that farmers can appropriately adjust the timing of N application to rice by using the inexpensive LCC.

## Right Place of N Application

Rice-growing farmers in India generally broadcast urea directly into the floodwater after transplanting. However, Craswell et al. (1981) reported that broadcasting urea into floodwater resulted in low recovery of fertilizer N (only up to 30%) by rice, both in the dry and wet seasons. They also suggested to apply two-thirds of the required N by broadcasting and incorporating before transplanting and the remainder at panicle initiation (called best split), which increased N recovery to 40%. In the studies conducted at IRRI, fertilizer N application through incorporation in the mud, without standing water, resulted in only 13% of the applied N being detected in the subsequent floodwater. This was compared to the normal farmers' practice where 59% of the N was recorded in the floodwater. Similarly, yields from plots where N was applied to the soil without standing water were significantly higher (0.9 and 0.5 t/ha in the dry and wet season, respectively) than yields recorded after application of the fertilizer into standing water (**Table 3**).

As N recovery by rice is inversely related to the ammonical-N concentration in the floodwater immediately after fertilizer application (De Datta, 1987), deep placement of urea super granules (USG) through manual and/or by mechanical means recorded very low floodwater ammonical-N concentrations and increased yields of rice grain, indicating a better N recovery (**Table 3**). Fertilizer N application through deep placement method releases ammonical-N in the reduced layer, which remains stable and contributes to increased yield on account of its high recovery in comparison to broadcast-N on the surface, which is unstable due to losses associated with denitrification and/or ammonia volatilization. Among the right methods of N fertilizer application, deep placement of USG proved to be more effective followed by application of N through mud balls and as efficient as USG. This is because it results in partial placement effect caused by sinking in the soft puddled soil due to its high weight and partially due to the slow dissolution through less exposed specific surface area.

## Conclusion

Nitrogen management in rice within the framework of 4R Nutrient Stewardship proved to be helpful in the sustainable management of rice production. The use of the right source of N, applied at right rate, in the right time, and at the right place demonstrated significant yield improvement of rice while improving N use efficiency. The reduction in leaching and volatilization losses as a result of practicing 4R principles of N management could contribute to improving the environmental performance of N use. However, in the majority of rice growing regions of India, N, P, K, and Zn are considered as the major limiting nutrients. Even though, this paper discusses only the 4R guidelines of N management in rice, the concept of bringing nutrient management under the 4R perspective may not be confined to N application alone, rather a cumulative 4R approach for all the essential nutrients of rice may be followed in ensuring sustainable rice production for the country. BC-SA

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## References

Cassman, K.G., A. Dobermann, and D. Walters. 2002. Ambio. 31:132-140.
Craswell, E.T., S.K. De Datta, M. Hartantyo, and W.N. Obcemea. 1981. Fert. Res. 2:247-259.
De Datta, S.K. 1987. *In* Proceedings of the Meeting of the International Network on Soil Fertility and Fertilizer Evaluation for Rice. Griffith, New South Wales, Australia, 10-16 April 1985. pp 27-42.
Dobermann, A., C. Witt, D. Dawe, G.C. Gines, R. Nagarajan, S. Satawathananont, T.T. Son, P.S. Tan, G.H. Wang, N.V. Chien, V.T.K. Thoa, C.V. Phung, P. Stalin, P. Muthukrishnan, V. Ravi, M. Babu, S. Chatuporn, M. Kongchum, Q. Sun, R. Fu, G.C. Simbahan, and M.A.A. Adviento. 2002. Field Crops Res. 74:37-66.
DRR. 2014. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 2004. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1997-1998. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1994. Annual Report, Directorate of Rice Research, Hyderabad.
DRR. 1988-1989. Annual Report, Directorate of Rice Research. Hyderabad
DRR. 1981-1985. Quinquennial Report, Directorate of Rice Research. Hyderabad.
FAI. 2015. Fertiliser Statistics, 2014-15, Fertiliser Association of India, New Delhi.
IIRR. 2014. Progress Report. ICAR-Indian Institute of Rice Research, Hyderabad.
IRRI, 2016. http://www.knowledgebank.irri.org/ericeproduction/IV.3_Nutrient_calculator.htm. Last verified Nov. 14, 2016.
John Kutty, I. and S.P. Palaniappan. 1996. Fert. Res. 45:21-24.
Mandal, M.K., S. Dutta, and K. Majumdar. 2016. SATSA Mukhapatra–Annual Technical Issue 20, 113-119.
Meelu, O.P. and R.A. Morris. 1987. *In* Proceedings of the Meeting of the International Network on Soil Fertility and Fertilizer Evaluation for Rice. Griffith, New South Wales, Australia, 10-16 April 1985. pp. 185-194.
Patnaik, S. and S.K. Mohanty. 1985. *In* P.L. Jaiswal (ed.), Rice Research in India, ICAR, New Delhi. pp. 257-279.
Prasad, R. 2011. Indian J. Fert. 7(12):66-76.
Prasad, R., I.C. Mahapatra, and H.C. Jain. 1980. Fertilizer News 25(9):13-18.
Rao, M.V. 1985. *In* P.L. Jaiswal (ed.), Use of Fertilisers. Rice Research in India, ICAR, New Delhi, pp. 417-434.
Raun, W. R. and G.V. Johnson. 1999. Agron. J. 91(3):357-363.
Ray, P.K., A.K. Jana, D.N. Maitra, M.N. Saha, J. Chaudhury, S. Saha, and A.R. Saha. 2000. J. Indian Soc. Soil Sci. 48:79-84.
Satyanarayana, T., K. Majumdar, V. Shahi, A. Kumar, M. Pampolino, M.L. Jat, V.K. Singh, N. Gupta, V. Singh, B.S Dwivedi, D. Kumar, R.K. Malik, V. Singh, H.S Sidhu, and A. Johnston. 2012. Indian J. Fert. 8(8):62-71.
Suganya, S., K. Appavu, and A. Vadivel. 2007. Asian J. Soil Sci. 2(2):29-34.
Surekha, K., M. Narayana Reddy, R. M. Kumar, and C.H.M. Vijayakumar. 1999. Indian J. Agric. Sci. 69(7):477-481.