Oryza Vol. 56 (Special Issue) 2019 (125-135)
DOI https://doi.org/10.35709/ory.2019.56.spl.5

Nitrogen management in rice

D Panda*, AK Nayak and S Mohanty

ICAR-National Rice Research Institute, Cuttack, Odisha, India

****Corresponding author e-mail:***

Received : 15 May 2019 Accepted: 27 May 2019 Published : 29 May 2019

ABSTRACT

Nitrogen is the one of most limiting nutrient for rice production, and in India rice cultivation alone accounts approximately 37% of the total fertilizer-N consumption in the year 1917-18. However, 60-70% of applied N is lost from the rice ecosystem system in the form of reactive N species such as ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO), nitrogen dioxide (NO_2) and nitrate (NO_3) through various processes. Hence enhancing N use efficiency through improved N management is of greater importance for ensuring food security and environmental sustainability. The decisions on optimum level, time, form and method of N application are crucial to an efficient N management strategy. Earlier studies suggested blanket fertilizer recommendations for different rice ecosystems and soil test based fertilizer applications. Subsequently, innovative methods of N application including deep placement of urea super granule in reduced zone, subsurface incorporation of urea through farmer friendly methods were also recommended Recently several advancements have been made in N management practices for rice crop such as site specific N management, real time N management using leaf colour chart (LCC) and customised LCC, enhanced efficiency N fertilizers (EENF) using N transformation regulators and GIS and remote sensing (RS) - based N application technologies. The objective of this paper is to comprehensively discuss about the established and emerging N management options for improving yield, N use efficiency and environmental sustainability of rice.

Key words: *Rice, Nitrogen fertilizer, Nitrogen use efficiency, Nitrogen Management, Urea*

INTRODUCTION

Rice is the staple food for about half of the global population and for more than two thirds of the people of India. Rice production in the world was more than 740 million tonnes (Mt) in 2014, 90% of which was produced in Asia (FAOSTAT, 2016). In 2017-18 Rice production in India was 112Mt from the gross rice cropped area of 43 million hectares (Mha). Since the demand for food in the world is projected to double by 2050, there remains a greater challenge to achieve still higher rice production, that too, ensuring the environmental sustainability. Efficient management of fertilizers is one of the major options to meet this challenge. Nitrogen is the single most important essential nutrient element that has profound effect on growth and yield of rice. It is a component of amino acids, nucleic acids, nucleotides, chlorophyll, enzymes and hormones. It promotes plant growth and grain yield, grain quality through high tillering, leaf area development and photosynthesis, grain formation, grain filling and protein synthesis.

Nitrogen is highly mobile within the rice plant and soil. Of the total fertilizer-N consumption of 17.4 Mt in India in the year, 2017-18, the share of rice crop was 37% (FAI, 2018). With the average response of 10kg paddy grain per kg of applied N and head rice recovery of 66.7%, the contribution of fertilizer-N to the total rice production in India works out to 43 Mt ($17.4\times0.37\times10\times0.667\cong43$), which is about 38% of the total rice production of the country in2017-18. This contribution of the fertilizer-N was of course, possible with the existing package of practices/factors such as irrigation, larger coverage of area under high yielding varieties, management of land, soil and water and above all, the protection of the rice crop from pests and diseases. This estimation also implies that had we deleted fertilizer N usage from the package of practices of rice cultivation in the country as a whole, there would been a large decline in the total rice production to the tune of about 43 Mt out of 112 Mt achieved in 2017-18. It clearly depicts the importance of N management in rice. Efficient and scientific N management practices in rice cultivation can be developed with a comprehensive understanding of site and soil characteristics, chemistry of submerged rice soils, nitrogen cycle in the environment, chemistry of transformation processes of native and applied nitrogen in rice soil, and N demand pattern of rice crop.

Available N status of Indian soils

A soil test summary based on analysis of 9.2 million soil samples collected from all over the country revealed that out of 365 districts, only 18 districts of north-eastern and north-western hill regions have high available soil N and the rest have either medium or low available N status (Ghosh and Hasan, 1980). Hence, rice crop invariably responds to application of fertilizer-N in almost all the Indian soil.

Chemistry of submerged rice soils

The typical rice soils are located on imperfectly drained land, they are naturally wet and have water table almost close to land surface. The rice cultivation practices include : (a) Rainfed lowland direct sown rice, (b) Rainfed lowland transplanted rice (c) Irrigated transplanted rice or puddled land (d) Puddled lands direct sown with sprouted rice seeds and rainfed upland direct dry sown rice. While all these practices are adopted in most of the Asian countries, in other countries of the world such as the United States, Australia, parts of Europe and in some of the Asian countries, rice land is prepared dry, rice is direct sown on dry soil and land is irrigated afterwards. Except the upland direct (dry) sown rice, in all the other rice cultivation practices the land is either naturally submerged with rainfall or artificially submerged by irrigation. In India, upland rice accounts for only about 15% of the gross rice area. In the rest 85% of the gross rice area wetland rice is cultivated, wherein the soils exhibit special features of soil submergence.

The chemistry of submerged soil has been studied and reviewed in greater detail by many researchers (Ponnamperuma, 1965, 1972; Patnaik and Mandal, 1982; Panda, 2005). When a dry soil is submerged, the soil gets depleted of molecular oxygen due to mechanical displacement by water, decomposition of organic matter and respiration of microorganisms. The replenishment of oxygen in submerged soil is negligible because diffusion of oxygen in interstitial water of soil is 10000 times slower than that in gas filled pores. As a result, soil reduction sets in and soil profile in wetland rice field is differentiated into a surface aerobic layer, a few mm in thickness, overlying a reduced subsurface layer that constitutes major part of the root feeding zone of rice plant (Pearsall, 1950; Mitsui, 1955). The aerobic surface soil layer is characterized by its brown color. It contains oxidized ions of soil components such as Fe^{2+}, Mn^{4+}, NO^{3-}, SO_4^{2-} etc. The underlying reduced soil layer is bluish grey or dark grey in color with low redox potential and contains reduced ions such as NH_4^+, Fe^{2+}, Mn^{2+}, S^{2-} and products of anaerobic decomposition of organic matter. The reduction reaction in submerged soil follows a thermodynamic sequence. The soil components, *viz*., O_2, NO_3-, Mn^{4+}, Fe^{3+}, SO_4^{2-}, Co_2 and H^+ are reduced to H_2O, N_2O or N_2, Mn^{2+}, Fe^{2+}, S^{2-}, CH_4 and H_2 gas, respectively almost in a sequence with the decreasing redox potential in a submerge soil. Molecular oxygen is the 1st component to be completely reduced within a day. The next substance in the sequence is nitrate which is reduced at a redox potential (Eh) less than 0.2V. Presence of native or applied nitrate stabilizes Eh at 0.2 to 0.4V and prevents reduction of Mn^{4+}.

In submerged rice fields the bulk of the soil mass is reduced but there are three sites within the system where soil is oxidized or partly oxidized. These three aerobic sites of submerged rice soil are: (a) the top oxidized soil layer in contact with flood water, (b) the rhizosphere due to transport of oxygen from rice plant through its roots to soil (Savant and De Datta, 1982).

Nitrogen cycle in rice environment

Atmosphere is the single most important source of nitrogen which contains about 78% N_2 on volume basis. Atomspheric N_2 is added to soil due to formation of its oxides durring thunder storm, lightening and rainfall (natural N_2 fixation), fertilizers (industrial N_2, fixation) and biological N_2 fixation by autotrophs (blue green algae), heterotrophs (Azotobacter and Azospirillum) and associative/symbiotic N_2, fixers (Azolla and legumes). Besides, application of organics such as farmyard manure, compost, green manures, crop residues, irrigation water and direct absorption of ammonia from atmosphere also add significant amount of N to rice soil. On the other hand, N is removed from the rice soil system through crop uptake, microbial immobilization , run-off, soil erosion, leaching, ammonia volatilization, denitrification and weed removal. While the first two processes of N removal are desirable from crop production point of view, the rest other processes cause loss of N from soil system and hence are undesirable and detrimental for environment and economy. Since ammonia volatization and nitrification-denitrification process occur in wetland rice soil, nitrogen in the form of NH_3, N_2O and N_2 gas escape back to atmosphere in the nitrogen cycle. An appropriate N management practice therefore ensures adequate addition of N to soil, maximum N utilization by rice plant and minimum losses of N preventing its adverse impacts on the environment.

Chemistry of nitrogen transformation in rice soil

Urea is the prime source of fertilizer-N accounting for more than 80% of total N usage in Injdian agriculture. When urea is applied to a soil, it hydrolyses to ammonium carbonate by the enzyme, urease principally produced by soil microbes (Gould et al., 1986). Ammonium carbonate further decomposes to ammonia gas depending upon the alkalinity and pH buffering capacity of soil, which escapes to the atmosphere resulting in volatilization loss of ammonia. The ammonium ion produced from urea hydrolysis also undergoes the process of nitrification i.e. biochemical oxidation of ammonium ion to nitrate ion, which takes place in aerobic soil as well as at three sites in submerged rice soil system, *viz*., (i) top oxidized soil layer of few mm in thickness, (ii) rice rhizosphere, and (iii) flood water present above the ground. The nitrate thus formed in aerobic dry seeded rice soil in rainfed lowland ecology is reduced to nitrous oxide and molecular di-nitrogen through denitrification process due to subsequent flooding following onset of monsoon. The nitrate formed in the three aerobic sites of the submerged rice soil diffuses into the underlying anaerobic zone and also undergoes denitrification (Patrick and Reddy, 1976). Besides, the N from rice field is also lost from soil through leaching, runoff, weed removal, soil erosion etc.

More than 95% of the total N present in soil is organic, which is mostly found in the form of proteins derived from plant and animal residues and microbial biomass. Besides applied N, the native soil-N also undergoes transformation by microbial action. The organic forms of N are converted into ammonium and then to nitrate through mineralization process in aerobic soil, while in anaerobic soils of wet land rice, the mineralization stops at ammonium formation stage causing accumulation of NH_4^+/NH_3. Rate of N mineralization is slow in anaerobic soil (Mohanty et al., 2013) but the accumulation of ammonia is greater and faster in anaerobic soil because of less immobilization.

Hydrolysis of urea

Urea hydrolysis is a two step process which involves initial cleavage of urea molecule into ammonia and carbamic acid by the enzyme urease and the subsequent chemical hydrolysis of carbamic acid into ammonia and carbon dioxide. The rate of urea hydrolysis is faster in soils with high organic C and also in soils with applied organic manure , pH around 8.0, moisture status at field capacity and temperature around 35°C. Presence of adequate amount of urease enzyme was detected in seeds of legumes, *viz*., pigeon pea, horsegram and soyabean (Panda and Pathak, 1985; Nayak, 1996). Complete hydrolysis of urea in rice field takes place within 2-3 days of its broadcasting onto flooded soil, within 5-7 days of deep placement of USG in flooded soil and within 7-14 days of its basal application in dry soil (Nayak and Panda, 2002) hydroquinone at a concentration of $1 mgl^{-1}$, thiourea, phenyl phosphorodiamidate (PPD), N-(n-butyl) thiophosphoric triamide (NBPT) are some of the widely evaluated urease inhibitors that can slow down the process of urea hydrolysis and reduce subsequent losses of N (Byrnes et al., 1983; Panda and Patnaik, 1985; Buresh et al. 1988; Kabat, 2001; Panda, 2005).

Ammonia volatilization

Ammonia volatilization is a major pathway of N loss that involves transformation of ammonium ion added to soil from ammonical or amide fertilizers, and decomposition of added or native organic matter to ammonia gas which escapes to the atmosphere. A study indicated that ammonia volatilization from hydrolyzed urea followed the first order reaction kinetics with rate constants of 0.173-0.231 d^{-1} and half lives of 3-4 days (Panda, 1986; Nayak, 1996). Ammonia volatilization loss has been reported to range from 48 to 56% at N level of 53-80 kg ha^{-1} when urea was broadcast-applied onto flood water 10 days after transplanting at a lowland site (De Datta et al., 1989)

Several techniques such as deep placement of urea supergranules (USG), urea mudlumps, coated urea fertilizers, soil incorporation of urea with suitable water management and use of several urease inhibitors, have been suggested to minimize N loss due to ammonia volatilization in low land rice soil. Application of urea to dry soil surface at seeding followed by flooding after two days could reduce significant amount of ammonia loss (Humphreys et al., 1988). Relative ammonia loss from surface broadcast urea in tropical low land rice soils of eastern India was estimated to be 6%, however it was reduced to 0.4% with deep placement of USG (Panda et al., 1989). Application of N fertilizer to dry soil before irrigating the field and incorporation of N fertilizer into soil are some of the fertilizer application methods that have reportedly reduced ammonia volitaizaion loss from soil (Singh et al., 1995). Slow release fertilizers such as neem coated and shellac coated urea when used for basal dressing also reduced ammonia loss (Mishra et al., 1990).

Nitrification - denitrification

Nitrification is the process of conversion of ammonia to nitrate in aerobic condition through two sequential steps *i.e.*, ammonium to nitrite and then from nitrite to nitrate by. Nitrosomonas and Nitrobacter, respectively. The nitrate formed in this process further undergoes process of denitrification upon submergence of soil by rainfall or irrigation. Besides this, the nitrate ions formed through nitrification in aerobic sites (top oxidized soil layer, rhizosphere, and flood water) of submerged rice soil diffuses to underlyinf reduced layer and where it is subjected to denitrification process which is mediated by anaerobic heterotrophs *e.g.*, *Pseudomonas*, *Micrococcus, Alcaligenes* and *Bacillus* which use organic carbon compounds as electron donors for energy and synthesis of cellular constituents. Isotopic analysis using 15N indicated denitrification loss accounts for 5-10% of applied urea-15N (Mohanty and Mosier, 1990).

Optimum soil pH (7.0-8.5), adequate oxygen supply in soil (Eh value more than 200 mV), soil moisture content equivalent to 60% of the water holding capacity and soil temperature ranging from 25 to 35°C favour nitrification process. Whereas pH range of 6-8, Eh less than 200 mV, water-filled pore space beyond 80%, high organic carbon content and temperature range of 25-35 °C, are optimum conditions for denitrification process. Rice fields subjected to alternate wetting and drying create favourable conditions for increased denitrification loss.

Coating or blending of urea or other N fertilizers with several natural and synthetic inhibitors like neem (*Azadirachta indica*) cake, karanj (*Pongamia glabra*) cake, neem oil, nimin, dicyandiamide (DCD), N-serve, thiourea, hydroquinone etc. have been reported to inhibit nitrification and thereby reduce the loss of N through denitrification (Panda, 1986; Mishra et al., 1990; Nayak and Panda, 1999; Kabat, 2001). Among nitrification inhibitors, hydroquinone was more effective in alluvial and laterite soils and alcoholic extract of neem cake was better in black soil than dicyandiarnide (DCD) (Nayak and Panda, 1999). Experiments conducted in India and other countries of the world showed that deep placement of USG or urea mud balls in the reduced zone of submerged rice soil, subsurface placement of urea through thorough incorporation of applied urea into wet soil by puddling in absence of any standing water decreased N losses and improved N use efficiency in rice (Savant et al., 1982; Panda, 1986; Panda and Patnaik, 1989; Humphreys et al., 1992; Nayak, 1996; Kabat, 2001)..

Leaching loss of N

Leaching of N from urea takes place mostly as NO_3^- ion which is a product of urea transformation processes in soil and to some extent as unhydrolysed urea molecules. However, leaching of unhydrolysed urea is comparatively less because of the rapid rate of hydrolysis to NH_4^+ ion and weak adsorption property (Nayak and Panda, 2000). Leaching loss to the extent of 45-60% of applied N has been reported from upland rice soils having coarse texture, low cation exchange capacity and higher rate of water percolation (Pandey and Adak, 1971). However, in case of flooded rice fields of eastern India which are characterized by low percolation rate and high ground water table, the leaching loss of N was measured to be less than 1 percent (Panda et al., 1989) . In some poorly drained, puddled rice field with sandy clay loam texture, movement of N from broadcast applied urea was restricted to top 0-5 cm of soil layer, while movement of N from deep placed USG was limited to a vertical distance of 5-10 cm (Panda et al., 1988b). The intermittent irrigation practices in aerobic direct seeded rice resulted in leaching of 3.2-10.6% of applied N below 45 cm. Application of neem coated urea (NCU), because of its nitrification inhibition and slow release property, could reduce NO_3^--N leaching by 18.6% as compared to prilled urea (Mohanty et al., 2018). Blending of urea with nitrification inhibitors such as N-serve, coating with neem cake or use of slow release N fertilizer and split application of N are some of the measures suggested for minimizing leaching loss of N (Rao and Prasad, 1980; Gehl et al., 2005)

Run-off loss of N

Being highly mobile in nature NO_3^--N ion is also susceptible to runoff loss particularly in unbunded slopy land or land with impervious layer that hinders downward movement of water. Depending upon the form, rate and method of N application and water management, runoff loss of N varied from 6 to 70% of applied N (Pamaja and Koshy, 1978; Panda, 1986; Nayak, 1996). Runoff loss of N as high as 78% of applied N has been reported in rainfed lowland rice field with 25 cm ponding water in case of surface broadcasting of PU. However, it was reduced to only 6-8 % in USG deep placement method (Nayak and Panda, 2002). Practices like deep placement of USG, soil incorporation, use of slow release N fertilizer etc that minimize N concentration in flood water can reduce its loss through runoff. Efficient water management practices and provision of dykes around the field are some of the measures suggested for reducing runoff loss of N.

Efficient management of fertilizer-N in rice

Efficient N management strategy should follow 4 'R' principles *i.e.*, right level, right time, right form and right method of N application.

Earlier studies on N recommendation was based the yield-N response, which indicated linear increase in grain yield up to 120 kg N ha^{-1} in dwarf *indica* and *japonica* rice and up to 30 kg N ha^{-1} in tall *indica* (Tanaka, 1965). Semi-dwarf rice responded upto 40-80 kg N ha^{-1} in wet season (Patnaik and Rao, 1979).The optimum N levels for rainfed lowland direct sown rice varieties, Savitri and 1agannath were in the range of 56-57 and 60-62 kg N ha^{-1}, respectively (Samantaray et al., 1991). In hybrid rice 100 kg N ha^{-1} is recommended in *kharif* and 120-135 kg N ha^{-1} in rabi season (Mohanty, 2005).

Decision on number and timing of split application of N should take into consideration the N uptake pattern of crop. Short duration varieties (80-100 days) generally show a continous N absorption pattern from transplanting to flowering whereas in case of medium and late duration varieties (120-140 days) the rate of N accumulation are faster from transplanting to maximum tillering stage after which it slows down during the vegetative lag phase and again becomes faster between panicle initiation and flowering stage. Accordingly, scheduling of N application as basal and top dressing in splits has been worked out for short duration and medium and late duration varieties (Patnaik et al., 1967; Samantaray et al., 1990). For hybrid rice, four equal splits of 25% N each at transplanting , MT, PI and flowering stages have been recommended (Mohanty, 2005).

The texture of soil is also an important criteria that should be taken into account while deciding the number of splits. In soils of relatively finer texture, recommendation has been given for 50% of N as basal dressing followed by two splits of 25% each at maximum tillering (MT) and panicle initiation (PI) stages. However for light texture soils splitting of N in 25:50:25 or 30:30:30 proportion is considered the best . In rainfed lowland rice, prone to waterlogging, however, application of entire dose of 60 kg N ha^{-1} along with 30 kg P_2O_5 and 30 kg K_2O ha^{-1} in seed furrows at the time of dry sowing has been suggested (Nayak and Panda, 2002; Kabat et al., 2005).

Though ammonical fertilizers such as ammonium sulphate and ammonium chloride are considered effective for rice they are not popular among farmers due to low N content and high cost involved. Diammonium phosphate (DAP) that contains N in ammonical form along with P is now widely being used by the rice framers of eastern India for basal dressing.

Studies conducted in India indicated superior performance of urea and ammonium sulphate over nitrate fertilizers (Patnaik and Rao, 1979). In India urea is the most widely used N fertilizer in rice, because of its high N content and good physical properties. But the major disadvantage still associated with urea is that it is prone to loss to the extent of 30-40% particularly in submerged rice soils. Extensive research has been conducted to enhance efficiency of urea by providing coatings of sulphur, gypsum, lac, polymer, neem cake etc and modifying the size of urea granules to urea briquettes and urea super granules to slow down the process of urea release and its subsequent transformation and loss. Different grades of controlled release N fertilizers (CRF) differ in their N release patterns, hence combined application of two or more CRFs provides better options of synchronizing N supply patterns with the demand patterns of crop. Application of polyurathane-coated controlled release N fertilizer along with PU at 3: 1 ratio as basal dressing in seed furrows showed better promise in the unfavorable rainfed lowland rice system of eastern India (Kabat and Panda, 2009)

Right method of N application is also a crucial component of efficient N mangemnet strategy. Basal furrow placement and incorporation of split N into soil are more efficient than broadcasting in drought-prone and rainfed upland direct sown rice. One of the three methods, *viz*., (1) basal seed furrow placement of entire dose of 60 kg N ha^{-1} as prilled urea, (2) deep placement of urea super granules and (3) deep placement of urea mud lumps in a single dose of 60 kg N ha^{-1} in submerged soil at early tillering stage has been identified as effective N application option in rainfed lowland rice ecosystem where the crop is dry direct seeded before onset of monsoon and subsequently, there occures continuous waterlogging due to intense monsoon rain leaving little scope of split N application (Panda and Patnaik, 1989; Nayak and Panda, 2002). Seed furrow placement of N fertilizers may slightly affect germination of seed and seedling emergence which can be taken care of by increasing the normal seed rate by 20%. Field experiments conducted at CRRI, Cuttack showed that N application practice that involves thorough basal incorporation of prilled urea into completely drained saturated soil by cross-puddling two days before transplanting is superior to the conventional method of surface broadcasting of prilled urea in rabi season (Unpublished data of D. Panda and S.C. Nayak, CRRI, Cuttack). Application of urea to saturated soil after removal of flood water followed by its incorporation by harrowing significantly reduced the total N loss compared to surface broadcasting of PU (De Datta et al., 1989). Application of urea to dry soil before puddling has been reported to enhance yield and reduce N loss as compared to conventional application to wet soil (Wilson et al., 1989; Zia, 1987), because irrigating field after fertilization enabled urea to move down into soil deapth of about 15cm with the wetting front, prevented its entry into flood water and thereby reduced the N loss (Humphreys et al., 1987).

Integrated nitrogen management in rice

Integrated nitrogen management (INM) in rice production plays an important role in the pursuit of food security and soil health improvement. It is achieved through combined use of different source of N such as chemical fertilizers, organic manures, green manures, crop residues and biofertilizers depending upon their availability, suitability and feasibility in a specific agroecological situation (Hegde and Dwivedi, 1993; Panda and Singh, 1998; Panda, 2005). In a holistic approach, the INM practices improve quality and quantity of crop produce, decrease nutrient losses, increase N use efficiency, economises on fertilizer use and minimise energy consumption in agriculture. In long-term fertilizer experiments conducted at several locations of India, combined application of NPK fertilizers at optimum level and farmyard manure @ 5-10 t/ha/year increased rice grain yield by 0.4-0.7 t/ha over NPK fertilizers. It also resulted in favourable balance of nutrients in soil and sustained rice yield at higher levels. Experiments conducted for 6 years at CRRI, reaveled that green manuering with dhaincha (*Sasbenia aculeata*) registered avarage contribution of 60kg N /ha in 45 days and it was as good as or even better than application of prilled urea @ 57 kg N/ha in increasing grain yield N nutrition of transplanted rice. Green manuring with dhainch supplemented with topdressing of urea @ 15kgN ha^{-1} at three weeks after rice transplanting and @ 15 kg N ha^{-1} at panicle initition was superior to many other INM practices including the use of *Azospirilum*, BGA and Azolla along with urea under favourable rainfed lowland conditions

(Panda, 2005).

Recent advances in N management in rice

Site specific N management

Most of the earlier methods of N recommendation were based on yield N response that did not consider the site specific variations with respect to available N status. Hence there was either excess or deficit application resulting in poor N use efficiency. Recent approach of site specific nutrient management (SSNM) emphasizes on determining the exact amount of N required by the crop after considering climatic yield potential, yield target and availability of N from all possible indigenous sources which generally vary from site to site. Field experiments conducted in several parts of south Asia indicated 30-40% increase in N-use efficiency of irrigated rice following SSNM based N application (Doberman et al., 2002). On the basis of principles of site specific nutrient recommendation, a web based nutrient management tool, rice crop manager (RCM) has been developed jointly by International Rice Research Institute and ICAR-NRRI for rice growers of Odisha which gives region specific NPK recommendation on the basis of cropping history. Field evaluation showed RCM recommendation provided rice grain yield advantage of 9.8 to 39.6 % with an average of 22.6% over farmer's practice (FFP).

Real time N management

Considering the fact that nitrogenous fertilizers are quickly lost from the soil system through various mechanisms, for enhanced crop N uptake, N supply should be in synchrony with the N demand. Sensor based technologies such as chlorophyll meter, green seeker etc have been developed to assess the crop N status nondestructively on the basis of greenness of crop and ensure real time N management. Leaf colour chart (LCC) is a recently developed easy to use, cheap and farmer's friendly diagnostic tool of real time N application. It is a plastic, ruler-shaped strip containing several panels of color ranging from yellowish green to dark green matching the color range of rice leaves which is used for monitoring the relative greenness of a rice leaf as an indicator of the leaf N status. Field research in several parts of Asia indicated that up to 25 % saving of N in rice production could be achieved by using LCC. On station and farmers' field evaluation of a five-panel customized leaf colour chart (CLCC) developed by ICAR-NRRI indicated that at same level of N application yield advantages of 0.5-0.7 t ha^{-1} and 0.5-1.0 t ha^{-1} could be achieved following CLCC recommendation over RDF application and farmer's practice, respectively (Nayak et al., 2017)

Enhanced Efficiency N Fertilizer (EENF)

The EENFs are fertilizer materials that contain coatings of less permeable material and inhibitors (either nitrification or urease inhibitors or both) within the formulation or in the coating to regulate either nitrification or urea hydrolysis or both *e.g.* neem coated urea, sulphur coated urea etc.

One of the recent approaches of minimizing N losses is blending of urea with other fertilizer materials/ agrochemicals and compaction into super granules of urea by dry granulation. The fertilizers to be compacted with urea should produce acid microsites or generate cations that favour ammonium adsorption on clay complex to decrease ammonia volatilization (Fenn et al., 1982). Compaction of urea individually with muriate of potash, zinc sulphate, DAP or ammonium chloride is one of the innovative approaches in fertilizer research (Katyal, 2001). These dry granulated fertilizers decreased NH_3, volatilization loss up to 44% relative to urea. Attempts have been made to produce agglomerated urea briquettes by mixing prilled urea with suitable amendments *viz*., phosphogypsum, fly ash, silica powder, neem cake and rice husk through mechanical compaction. Use of amendments and binders improved the crushing strength of briquettes and reduced the concentration of urea in pellet thereby ensured its uniform distribution in the field.

Meta-analysis of effects of EENFs indicated NBPT [N-(n-butyl) phosphoric triamide] and neem proved effective in increasing yield (Linquist et al., 2 013). Combining EENFs with real time N application could be an effective strategy for reducing N loss and enhance N use efficiency. Field studies indicated application of neem coated urea (NCU) because of its nitrification inhibition and slow release property could reduce NO^3-N leaching and N_2O emission by 18.6% and 21.4%, respectively as compared to prilled urea (PU). However, when applied on the basis of leaf color chart (LCC) reading NCU further reduced NO_3-N leaching by 39.8% as compared to PU applied in conventional method. As compared to PU, NCU increased yield by 6% when applied conventionally and it was increased by 21% when NCU was applied on the basis of LCC reading (Mohanty et al., 2018).

Sub surface N application

Application of N below reduced zone has been identified as an effective strategy to slow down the process of conversion of NH_4 to NO_3 and its further losses through denitrification and leaching. Extensive studies in Bangladesh and other parts of South Asia on deep placement of urea super granules (USG) have proved superior performance of this technology over broadcasting of PU in terms of N use efficiency and yield. Saving of urea fertilizer to the extent of 65% by deep-placement of USG has been reported (Savant and Strangel, 1990). However inherent problem of drudgery associated with manual deep placement often hinders its wide spread adoption by farmers. Hence effort has been made to develop and fine tune easy to use urea briquette/USG applicators. Field experiments show deep placement of urea briquettes manually or mechanical applicator resulted in the higher yield, N uptake and N use efficiency than broadcasting of urea granules. Moreover deep placement of urea briquettes using CLCC reading resulted in the highest yield (Nayak et al., 2017).

Application of GIS and RS technology for N management

The GIS and RS based techniques have great potential for up scaling site specific recommendations to regional level thereby reducing fertilizer use and environmental risks. Ground-based remote sensors, and digital, aerial, and satellite imageries can be used to overcome tedious soil and tissue testing required for regional scale quantitative recommendations. Effort has been initiated to delineate homogeneous management zones for precise N recommendations for rice growing areas of Odisha by classifying an area into several subsets based on homogeneous soil and plant attributes using fuzzy clustering approach. A site-specific N recommendation map was developed for Ersama block, Odisha by using NUE and N uptake data obtained from trials involving omission plot techniques. Site specific recommendations enhanced yield by 8-12% and NUE by 7-9% as compared to recommended dose of fertilizer (Tripathi et al., 2015). Techniques of geostatistical analysis and kriging were used to develop the soil test-based N recommendation map for five blocks of Balasore and two blocks of Bhadrak districts by which a minimum of 72 kg N ha^{-1} and maximum of 94 kg N ha^{-1} were recommended. Nitrogen recommendation map ranging from minimum requirement of 60 kg N ha^{-1} and maximum of 120 kg N ha^{-1} was developed using the moderate-resolution imaging spectroradiometer (MODIS), leaf area index (LAI) and normalized difference vegetation index (NDVI) satellite data (Tripathi et al., 2017).

CONCLUSION

Demand for food in the world is projected to double by 2050. Rice is the staple food for majority of Indian population and about half of the global population. Nitrogen is the formost essential nutrient element that plays a very crucial role in enhancing rice production. Hence N management in rice assumes greater importance in ensuring food security and environmental sustainability. In an efficient N management strategy, N fertilizer, especially urea, needs to be applied to rice crop in such a manner that N supply synchronizes with the N demand pattern of the rice crop maximizing utilization of native and applied N and minimizing N lossesfrom rice soil system such as ammonia volatization, nitrification-denitrification, run-off, leaching and removal of N by weeds.

Improved N manamegent agenda include decisions on optimum level, time, form and method of N application. Earlier studies suggested blanket fertilizer recommendations for different rice ecosystems and soil test based fertilizer applications. Subsequently, innovative methodsof N application were suggested. These include deep placement of fertilizer N, mostly in the form of urea in reduced zone of submerged rice soil through larger granules and urea super granules. Subsurface incorporation of urea through farmer friendly methods were also recommended. Currently controlled release N fertilizers such as polymer coated urea fertilizers are at various stages of testing and recommendations.

Recently, several advancements have been made in N management practices for rice crop such as site specific N management, real time N management using leaf colour chart (LCC) and customised LCC, enhanced efficiency N fertilizers (EENF) using N transformation regulators and GIS and remote sensing (RS) - based N application technologies.

REFERENCES

Buresh RJ, De Datta SK, Padilla JL and Samson M (1988). Effect of two urease inhibitors on floodwater ammonia following urea application to lowland rice. Soil Science Society of America Journal 52: 856-861

Byrnes BH, Savant NK and Craswell ET (1983). Effect of urease inhibitor phenyl phosphorodiamidateon efficiency of urea applied to rice. Soil Science Society of America Journal 47: 270-274

De Datta SK,Trevitt ACF,Freney JR, Obcemea WN, Real JG and Simpson JR (1989). Measuring nitrogen losses from lowland rice using bulkaerodynamic and nitrogen-IS balance methods. SoilScience Society of America Journal 53: 1275-1281

Dobermann A, Witt C and Dawe D (2002). Nutrient management in intensive rice cropping systems of Asia. Better Crops International 16 (1): 25-30

Faostat F (2016). Agriculture Organization of the United Nations Statistics Division. Economic and Social Development Department, Rome, Italy. http:// faostat3. fao. org/home/E. Accessed pp. 12

Fenn LB, Matocha JE and Wu E (1982). Substitution of ammonium and potassium for added calcium in reduction of ammonia loss from surface applied urea. Soil Science Society of America Journal 46: 771-776

Gehl RJ, Schmidt JP, Maddux LD and Gordon WB (2005). Corn yield response to nitrogen rate and timing in sandy irrigated soils. Agronomy Journal 97(4): 1230-1238

Ghosh AB and Hasan R (1980). Nitrogen fertility status of soils of India. Fertiliser News 25: 19-24

Gould WD,Hagedorn C and McCready RGL (1986). Urea transformations and fertilizer efficiency in soil. Advances in Agronomy 46: 209-238

Humphreys E, Muirhead WA, Melhuish FM, White RJG, Chalk PM. and Douglas LA (1987). Effects of time of urea application on ~ombine-sown Calrose rice in south-east Australia. II. Mineral nitrogen transformation in the soil-water system. Australian Journal of Agricultural Research 38: 13-123

Humphreys E, Freney JR, Muirhead WA, DenmeadO.T, Simpson J.R,Lenning R, Trevitt ACF, Obcemea W.N, Wetselaar R and Cai GX (1988). Loss of ammonia after application of urea at different times to dry seeded, irrigated rice. Fertilizer Research 16: 47-57

Humphreys E, Chalk PM, Muirhead WA and White RJG (1992). Nitrogen fertilization of dry-seeded ricein south-east Australia. Fertilizer Research 31: 221-234

Kabat B and Panda D (2009). Nitrogen release characteristics of controlled release N fertilizers and their effect on yield and N nutrition of rice in Alluvial and Laterite soils. Journal of the Indian Society of Soil Science, 57(2): 154-160

Kabat B (2001). Studies on placement of urea-based fertilizers and their use in integration with biofertilizersin rainfed lowland rice (*Oryza sativa* L.). Ph.D. Thesis, Utkal University, Bhubaneswar, Odisha, India

Kabat B, Panda D, Jha KP, Sahoo N, Rao KS, Mishra P and Balasubramanian V (2005). On-farmdevelopment and evaluation of urea placement technologies in rainfed intermediate lowland directsown rice. Oryza 42: 31-36

Mishra B, Sharma D and Murthy JR (1990). Effect of neem cake and shellac coating of urea and green manure on ammonia volatilization and nitrogen use efficiency for rice. Journal of the Indian Society of Soil Science 38: 224 - 228

MitsuiS (1955). Inorganic nutrition, fertilization, and soil amelioration for lowland rice 79(3): 230

Mohanty BB (2005). 'We are like the living dead': Farmer suicides in Maharashtra, western India. Journal of Peasant Studies 32(2): 243-276

Mohanty SK and Mosier AR (1990). Nitrification-denitrification in flooded rice soils. In Transactions 14th International Congress of Soil Science, Kyoto, Japan 4: 326-331

Mohanty S, Nayak AK, Kumar A,Tripathi R, Shahid M, Bhattacharyya P, Raja R. and Panda BB (2013). Carbon and nitrogen mineralization kinetics in soil of rice-rice system under long term application of chemical fertilizers and farmyard manure. European Journal of Soil Biology 58: 113-121

Mohanty S, Swain CK, Tripathi R, Sethi SK, Bhattacharyya P, Kumar A, Raja R, ShahidM, Panda BB,Lal B, Gautam P, Munda S and Nayak A K (2018). Nitrate leaching, nitrous oxide emission and N use efficiency of aerobic rice under different N application strategy. Archives of Agronomy and Soil Science. https://doi.org/10.1080/

03650340.2017.1359414

Nayak SC (1996). Studies on urea transformation in waterlogged soil and efficient utilization of prilled urea by rainfed lowland rice (*Oryza sativa* L.). Ph.D.Thesis, Utkal University, Bhubaneswar, Odisha, India

Nayak SC and Panda D (1999). Kinetics of nitrification of applied urea in alluvial, laterite and black soils with and without nitrification regulators. Journal of the Indian Society of Soil Science 47: 544-546

Nayak SC and Panda D (2002). Transformation of applied urea and its efficient utilization in rainfed lowland rice (*Oryza sativa* L). Fertiliser News 47(2): 47-58

Nayak SC and Panda D (2000). Urea adsorption in alluvial soils. Journal of the Indian Society of Soil Science 48:179-181.

Nayak AK, Mohanty S, Chatterjee D, Guru PK, Lal B, Shahid M, Tripathi R, Gautam P, Kumar A, Bhattacharyya P, Panda BB and Kumar U (2017). Placement of Urea Briquettes in Lowland Rice: An Environment-friendlyTechnology for Enhancing Yield and Nitrogen Use Efficiency. NRRI Research Bulletin No.12ICAR-National Rice Research Institute, Cuttack, Odisha 753006, India. pp. 1-26

Padmaja P and Koshy MM (1978). A note on the runoff losses of nutrients in waterlogged rice soil. Journal of the Indian Society of Soil Science 26: 74-75

Panda D (1986). Management of fertilizer nitrogen for rice (Oryza sativa L.) under lowland waterlogged conditions. Ph. D. Thesis, Utkal University, Bhubaneswar.

Panda D (2005). Chemistry of nitrogen transformation in submerged soil and scientific management of urea fertilizer for higher rice productivity. Journal of the Indian Society of Soil Science 53(4): 500-513

Panda D and Patnaik S (1985). Determination of urea-N by steam distillation. Journal of the Indian Societyof Soil Science 33: 811-815

Panda D and Patnaik S (1989). Fate and efficiency of urea supergranules in different rice culture systems in a deltaic alluvial soil of eastern India. In soil fertility and fertilizer use, urea supergranules for increasing nitrogen use efficiency. IFFCO, New Delhi-I 9, Pi'. 3: 58-68

Panda D, Mahata KR, Sen HS and Patnaik S (1989). Transformation and loss of nitrogen due to leaching and ammonia volatilization in wetland rice (*Oryza sativa* L.).soil. Indian Journal of Agricultural Sciences 59: 91-96

Panda D, Sen H and Patnaik S (1988b). Spatial and temporal distribution of nitrogen in a puddled rice soil following application of urea based fertilizers by different methods. Biology and Fertility of Soils 6: 89-92

Pandey HK and Adak NK (1971). Leaching loss of nitrogen in submerged rice cultivation. Experimental Agriculture 7: 329 - 336

Patnaik S, Bhadrachalam A and John J (1967). Production efficiency of nitrogen absorbed during variousgrowth stages of high yielding Taiwan rice varieties under tropical conditions. Indian Journal of Agricultural Sciences 37: 282-289

Patnaik S and Mandal LN (1982). Chemistry of submerged rice soils. In Review of Soil Research in India. I2[th] International Congress of Soil Science, New Delhi pp. 181-189

Patnaik S and Rao MV (1979). Sources of nitrogen for rice production. In: Nitrogen and Rice, International Rice Research Institute, Los Banos, Philippines pp. 25-43

Patrick WH Jr. and Reddy KR (1976). Nitrification - denitrification reactions in flooded soils and waterbottoms: Dependence on oxygen supply and diffusion. Journal of Environmental Quality 5: 469-472

Pearsall WH (1950). The investigations of wet soils and its agricultural implications. Empire Journal of Experimental Agriculture 18: 289-298

Ponnamperuma FN (1965). Dynamic aspects of flooded soils and the nutrition of the rice plant. The mineral nutrition of the rice plant 295: 328

Ponnamperuma FN (1972). The chemistry of submerged soils. In Advances in Agronomy 24: 29-96

Rao EVSP and Prasad R (1980). Nitrogen leaching losses from conventional and new nitrogenous fertilizers in lowland rice culture. Plant and Soil 57: 382-394

Samantaray RN, Panda D and Patnaik S (1990). Contribution of soil nitrogen towards the growth and yieldof rice varieties of different durations. Journal of the Indian Society of Soil Science 38: 674-679

Samantaray RN, Panda D and Patnaik S (1991). Response of photosensitive elite rice varieties to nitrogen under direct sown rainfed lowland conditions. Oryza 28:

77-83

Savant NK and De Datta SK (1982). Nitrogen transformations in wetland rice soils. Advances in Agronomy 35: 241-302

Savant NK and Stangel PJ(1990). Deep placement of urea super granule in transplanted rice: Principles and practices. Fertilizer Research 25: 1-83

Savant NK,De Datta, SK and Craswell ET (1982). Distribution pattern of ammonium nitrogen and "15_N uptake by rice after deep placement of ureasupergranules in wetland soil. Soil Science Society of America Journal 46: 567-573

Singh JP, KumarV and Singh M (1995). Effect of different nitrogen carriers and methods of urea application on ammonia volatilization losses in soils.Journal of the Indian Society of Soil Science 43: 269-271

Tanaka A (1965). Plant characters related to nitrogen response in rice. pp 419 - 435. In 77,e Mineral Nutrition of the Rice Plant. The Johns Hopkins Press,USA

Tripathi R,Nayak AK,Shahid M, Raja R, Panda BB,Mohanty S, Kumar A,Lal, B,Gautam, P. and Sahoo R.N (2015). Characterizing spatial variability of soil properties in salt affected coastal India using geostatistics and kriging. Arabian Journal of Geosciences 8(12): 10693-10703

Tripathi R, Nayak AK, Raja R, Shahid Md, Mohanty S, Lal B, Gautam P, Panda BB, Kumar A and Sahoo RN (2017). Site-specific nitrogen management in rice using remote sensing and geostatistics. Communications in Soil Science and Plant Analysis, 48(10): 1154-1166

Wilson CEJr., Norman JR and Wells BR (1989). Seasonal uptake pattern of fertilizer nitrogen applied in split application to rice. Soil Science Society of America Journal 53: 1884-1887

Zia MS (1987). Nitrogen sources and placement for irrigated rice. International Rice Research Newsletter12(3): 51