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Review/Overview Article

Deep placement and foliar fertilization of nitrogen for increased use efficiency – An overview

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ABSTRACT

Fertilizer nitrogen is the most important plant nutrient in agriculture all over the world. It accounts for about 68% of the total plant nutrients (NPK) consumed in India. About an 80% N is consumed as urea in India. Since the efficiency of fertilizer N is 50% or less, efforts are needed to increase it, because unutilized N is lost to atmosphere and groundwater creating pollution problems. Deep placement and foliar application of urea can significantly increase nitrogen-use efficiency, but adequate data on these aspects are not available and need to be created without further delay.

Key words: Deep placement, Environmental pollution, Foliar application, Nitrogen-use efficiency, Urea

Among the 3 major areas of agronomic research, namely nutrient, water and weed management, about two-thirds of the research papers appearing in the Indian Journal of Agronomy are on nutrient management, and out of these about 80% are directly or indirectly related to nitrogen management. Nitrogen is thus the key plant nutrient in field crop production and out of the total N, P and K consumption of 24.5 million tonnes in 2013–14 in India, N alone was 16.7 million tonnes (68% of total NPK). Further, about 80% of fertilizer N is supplied by urea in India (Prasad, 1998). However, the nitrogen-use efficiency in field crops is generally below 50% and is about 33% or even lower in rice (*Oryza sativa* L.) (Prasad, 2013).

Nitrogen uptake and assimilation in crop plants

Nitrogen is applied to field crops to enhance the growth and development of plants to increase the production of the targeted product from the crop, which could be: sugar in sugarcane (*Saccharum* sp.) and sugarbeet (Beta *vulgaris* sub sp. V*ulgaris*); starch in cereals, potato (*Solanum tuberosum* L.), sweet potato and cassava (*Manihot esculenta* crantz]; protein in pulses and cereals; oil in rapeseed-mustard, safflower (*Carthamus tinctorius* L.) and sunflower (*Helianthus annuus* L.); and protein and oil in soybean [*Glycine max* (L.) Merr.] and groundnut (*Arachis hypogaea* L.). By conducting field experiments with graded levels of nitrogen, the agronomists determine the yield and economic optimum levels of nitrogen application to different crops and cropping systems in different ecological conditions. Recently attention has been drawn to determine eco-friendly optimum nitrogen levels for different crops and cropping systems in view of environmental problems associated with high levels of nitrogen application (Prasad *et al.*, 2016).

Nitrogen is taken up by plants through roots, mostly as nitrates in upland crops (Xu *et al.*, 2012), although some ammonium may also be taken up (Nadelhoffer *et al*., 1984). Under lowland field conditions, such as in rice paddies, ammonium is the dominant species (Yu, 1985; Prasad *et al.*, 2000) and most of the nitrogen is taken up as ammonium (Ishii *et al*., 2011) and rice has been referred to as an ammoniphilic plant (Prasad *et al.*, 1983). Ammonium could also be the dominant species in nitrogen uptake by plants in grasslands (Jackson *et al*., 1989).

Nitrate is absorbed by plant roots through several nitrate transporters that use the proton gradient as the power to transport it (Tischner, 2000; Sorgonà *et al*., 2011). Similarly ammonium ions are also absorbed through ammonium transporters (Loque' and von Wiren, 2004; Bao-zhen *et al*., 2009). Nitrogen is transported to shoot via xylem. Nitrate absorbed is reduced to ammonium mostly but not always (Stewart *et al*., 1986; Scheurwater *et al.*, 2002) in the roots. Nitrate reduction is a two-step process. Nitrate is first reduced to nitrite (NO_2^-) in the cytosol by the enzyme nitrate reductase (NR) using NADP or NADPH

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(Tischner, 2000), which is then reduced to ammonium in the chloroplasts by a ferrodoxin-dependent nitrate reduction (Hanke *et al.*, 2004). Once ammonium is produced in the chloroplast, it is incorporated as amide group in the amino acid glutamine. Other amino acids are later produced from glutamine. Proteins are synthesized through genetically-controlled processes by DNA and ribosomes. The DNA produces messenger-RNA by transcription and sequence of m-RNA translates specific sequence of amino acids to produce peptide chains, which undergo post-synthetic processing to produce different proteins, such as structural, regulatory, transport and cell signaling proteins, immunoglobins and enzymes (Mathews *et al*., 2000; Kent, 2009).

Plants can also absorb nitrogen as urea, when applied to foliage and even by roots (Gooding and Davies, 1992). However, in soils, urea gets hydrolysed rapidly (Reddy and Prasad, 1975) and is not available for absorption as such. Kuykendall and Wallace (1953) reported that foliar application of urea on citrus (*Citrus* sp.) leaves increased their N content from 2 to 6% in 24 hours; however, most of the N in leaf at that time was not present as urea, indicating its rapid hydrolysis in the leaf. Smith *et al.* (1991) using ^{15}N-labelled urea found that when applied to foliage at the full emergence of inflorescence in the main stem of wheat (*Triticum aestivum* L.), 69% of applied N was in the above-ground portion of the plant. Thus, absorption of foliar-applied urea is fairly rapid and N so applied avoids its loss through various N loss mechanisms associated with soil-applied fertilizer N discussed later in this paper. Efficiency of foliar applied urea is reported to be higher than when it is soil-applied (De, 1971; Balasubramanian *et al.*, 2004). Bhuyan *et al.* (2012) from Bangladesh reported that agronomic efficiency of foliar-applied urea in rice was 93.8 kg/N as compared to 43.7 kg/N for soil-applied urea. Saleem *et al*. (2013) from Pakistan reported that, soil application of 60 kg N/ha plus 2 foliar sprays of 2% urea solution at tillering and booting in wheat was as good as soil application of 120 kg N/ha as urea. Foliar application of urea is the best way to apply nitrogen to crop, when its deficiency is detected at later stages of crop growth, since soil-applied N takes more time for its absorption and translocation to the targeted plant part. Foliar application of urea is the only way to supply N to flooded rice fields. Urea is compatible with most insecticides and can be applied with them. The only drawback is that using large volume knap-sack sprayers available with small-holder farmers only about 10 kg N/ha can be applied in a single spray; 3% urea is the maximum concentration possible in such foliar sprays.

In addition to amino acids and proteins, chlorophyll is the most important nitrogen biomolecule, responsible for the synthesis of carbohydrates and all other foods for the animals including humans. Chlorophyll is made of 4 pyrrole rings held together by a single Mg ion. Nitrogen deficiency in plants is first shown by the shortage of chlorophyll and is expressed by pale yellow coloration of lower leaves, which may ultimately die and fall, because chlorophyll moves to the upper young leaves. When this happens, fertilizer nitrogen has to be applied. This is the basis of developing fertilizer nitrogen recommendations using leaf-colour charts and chlorophyll meters (Bijay-Singh *et al*., 2001).

Nitrogen dynamics in soils

This subject has been thoroughly investigated and excellent reviews are available (Prasad, 1998, 2013, 2013; Pathak, 2013, 2016; Prasad and Shivay, 2015; Prasad *et al.,* 1993). Only the most important points are brought out here. A large part of fertilizer nitrogen, mostly urea is broadcast applied at surface and is subject to runoff losses, especially on sloping lands in the hills, where rains are torrential and rice is the main crop. However, no data are available on such losses in India. This is one reason, why the farmers in upper regions of a hilly tract do not apply the required rates of N and the crops suffer and yields are low.

Once urea is applied, it hydrolyses fairly rapidly, most of it within 2 weeks of application (Reddy and Prasad, 1975) and ammonium formed is lost by ammonia volatilization. Ammonia volatilization losses from fields are estimated at 20 to 30 kg N/ha with an application of 120 kg N/ha in rice and wheat (Katyal *et al*., 1987; Aulakh and Bijai-Singh, 1997). 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; average loss was 30 kg N/ha, with an average fertilizer application of 98 kg N/ha. It is estimated that 4.1 million tonnes of N is lost by ammonia volatilization in India; the global loss of N due to ammonia volatilization is estimated at 37 million tonnes (Prasad *et al.*, 2014). Placement of urea in soil can greatly reduce N losses (Mohanty *et al.*, 1998), but agronomists have really not investigated this seriously and more field experiments are urgently needed.

Ammonium is later oxidized to nitrate, which being a negatively charged ion cannot be retained by the clay particles and is easily leached out or denitrified under submerged soil conditions (Prasad, 1998). Pathak *et al.* (2009) reported that about 10% of applied urea-N was lost in the rice–wheat cropping system belt and the total leaching loss of nitrogen is estimated at 3.1 million tonnes in India, while the global estimates are at 95 million tonnes (Prasad *et al.*, 2014). As regards losses of N due to denitrification, Pathak *et al.* (2004) reported a loss of 10–15 kg N/ha in rice and 5–10 kg N/ha in wheat with an application of 120 kg N/ha to each crop. Aulakh *et al.* (2001) reported a loss of 30 kg N/ha from flooded rice fields in north-western India. Denitrification losses are most under alternate flooding and drying conditions as obtained under irrigated rice cultivation (Prasad and Rajale, 1972; Prasad, 2011). The total loss of N due to denitrification is estimated at 3.1 million tonnes in India and 25 million tonnes in the world (Prasad *et al.*, 2014). Losses due to leaching and denitrification are difficult to prevent. The only way is to apply fertilizer N in split doses and enormous data are available in the country to show the advantage of split application of nitrogen (Tandon, 1989).

One approach to increase the efficiency of fertilizer N use globally has been the use of nitrification-inhibitors and slow-release N fertilizers (Prasad *et al.*, 1971; Prasad and Power, 1995; Shaviv, 2001; Prasad, 2005), and in India neem oil micro-emulsion-coated urea was developed by Dr Rajendra Prasad and his team (Prasad *et al.*, 1994, 2007; Devakumar, 2016). Recently, Government of India has decided that all urea produced in the country has to be coated with neem-oil emulsion. While this technology will be helpful in increasing the efficiency of fertilizer nitrogen, research on methods and timing of nitrogen application needs to be intensified.

Deep placement of nitrogen

There has been great emphasis on deep placement of phosphorus in the root zone of crop plants (Eggball and Sanders, 1989; Anonymous, 1999), but not on nitrogen. Nitrogen applied at sowing can be easily deep-placed at 3–5 cm depth with a fertilizer drill attached to a tractor or a *pora* (a metallic funnel used for seeding, when bullock power is used); however, a majority of farmers in India broadcast nitrogen after seeding. Field experimental data need to be created on the relative efficiency of deep-placed *versus* broadcast fertilizer N in all crops. With a little effort, ammonia volatilization losses can be measured in these experiments using closed chamber technique (Prasad *et al.*, 2000). These data will help convince the farmers about the advantage of deep placement of nitrogen. Deep placement of N while top-dressing is difficult, but techniques need to be developed to do so.

Foliar application of nitrogen

Foliar application of N has not received the attention it deserves, despite the fact that it is well established that the efficiency of foliar-applied N is higher than its soil application (De, 1971; Balasubramanian *et al*., 2004; Bhuyan *et al.*, 2012; Saleem *et al.*, 2013). In most cereals, two spray applications of urea @ 10 kg N/ha (700 litres of 3% urea solution) are possible at appropriate growth stages. These 2 foliar sprays of urea are likely to be equal to 30–40 kg N/ha applied to soil; however, actual data on this need to be generated. At least 10 kg N/ha can be saved in each crop by resorting to part foliar application. Thus in rice–wheat cropping system belt itself, it can lead to a saving of 0.2 million tonnes N or 0.43 million tonnes of urea. Similarly, if 10 kg N/ha is saved on each hectare of 195 million ha of India's gross cropped area, a saving of 1.95 million tonnes of N or 4.2 million tonnes of urea is possible. This technology is thus worth trying. Foliar application of N can be combined with the foliar application of Zn, Fe and other micronutrients and with insecticides to reduce application cost. Again for iron only foliar application is recommended.

Thus, fertilizer N is a costly input and its use efficiency is 50% or less. Further its overuse is associated with environmental pollution. Increasing N use efficiency is therefore important. Deep placement and foliar application of N can go a long way in achieving increased nitrogen use efficiency.

REFERENCES

Anonymous. 1999. Phosphorus fertilizer placement. *Better Crops* **83**(1): 34–36 and 39.

Aulakh, M.S. and Bijay-Singh. 1997. Nitrogen losses and fertilizer N-use efficiency in irrigated porous soils. *Nutrient Cycling in Agro-ecosystems* **47:** 197–212.

Aulakh, M.S., Khera, T.S., Doran, J.W. and Bronson, K.F. 2001. Denitrification, N_2O and CO_2 fluxes in rice–wheat cropping system as affected by crop residues, fertilizer N and legume green manure. *Biology and Fertility of Soils* **34:** 375–389.

Balasubramanian, V., Alves, B., Aulakh, M.S., Bekunda, M., Cai, Z.C., Drinkwater, L., Mugendi, D., van Kassel, C. and Onenema, O. 2004. *Crop, environment and management factors affecting N use efficiency. (In) Agriculture and Nitorgen Cycle: Assessing the Impacts of Fertilizer Use on Food Production and the Environment* (Mosier, A.R., Seyers, J.K. and Freney, J.R., eds.), SCOPE, Paris 65: 19–33.

Bao-zhen, L., Merrick, M., Su-mei, L., Hong-ying, L., Shuwen, Z., Wei-ming, S. and Yen-hua, S. 2009. Molecular basis and regulation of ammonium transporters in rice. *Rice Science* **16:** 314–322.

Bhuyan, M.H.M., Ferdousi, M. and Iqbal, M.T. 2012. Foliar spray of nitrogen fertilizer on raised bed increases yield of transplanted aman rice over conventional method. *ISRN Agronomy* 2012 (2012), Article ID 184953.

Bijay-Singh., Ladha, J.K., Bronson, K.F., Singh, J. and Khind, C.S. 2001. Chlorophyll meter-and leaf color chart-based nitrogen management for rice and wheat in North-western India. *Agronomy Journal* **94:** 821–829.

De, R. 1971. A review of fertilization of crops in India. *Fertiliser News* **16**(12): 77–81.

Devakumar, C. 2016. Evolution of neem oil coated urea through frugal innovation. *Indian Journal of Fertilizers* **12**(4): 120–125.

Eggball, B. and Sanders, D.H. 1989. Distance and distribution of phosphorus fertilizer for corn. *Soil Science Society of America Journal* **53:** 282–287.

Gooding, M.J. and Davies, W.P. 1992. Foliar urea application of cereals: A review. *Fertilizer Research* **32:** 209–222.

Hanke, G.T., Kimata-Ariga, Y., Taniguchi, I. and Hase, T. 2004. A post genomic characterization of Arabidopsis ferredoxins. *Plant Physiology* **134**: 255–264.

Ishii, S., Ikeda, S., Minamisawa, K. and Senoo, K. 2011. Nitrogen cycling in rice paddy environments: Past achievements and future challenges. *Microbes and environments/ JSME 2*6(**4): 282–292.**

Jackson, L.E., Schimel, J.P. and Firestone, M.K. 1989. Short-term partitioning of ammonium and nitrate between plants and microbes in an annual grassland. *Soil Biology and Biochemistry* **21:** 409–415.

Katyal, J.C., Bijay-Singh, Vlek, P. and Buresh, R. 1987. Efficient nitrogen use as affected by urea application and irrigation sequence. *Soil Science Society of America Journal* **51**: 366–370.

Kent, S.B. 2009. Total chemical synthesis of proteins. *Chemical Reviews* **38:** 338–351.

Kuykendall, J.R. and Wallac, R. 1953. California Agriculturist, March 1953: 6.

Loque', D. and von Wiren, N. 2004. Regulatory levels for transport of ammonium in plant roots. *Journal of Experimental Botany* 55**:** 1,293–1,305.

Mathews, C.K., van Holde, K.E. and Ahern, K. 2000. Biochemistry, Edn 3, Benjamin/Cummings, San Fransisco, CA, USA.

Mohanty, S.K., Singh, U., Balasubramanian, V. and Jha, K. 1998. Nitrogen deep-placement technologies for productivity, profitability and environment quality of rainfed lowland rice systems. *Nutrient Cycling in Agroecosystems* **53:** 43–57.

Nadelhoffer, K.J., Aber, J.D. and Melillo, J.M. 1984. Seasonal patterns of ammonium and nitrate uptake in nine temperate forest ecosystems. *Plant and Soil* **80:** 321–335.

Pathak, H. 2013. Nitrogen and climate change: Interactions, impacts, mitigation and adaptation. *Journal of Indian Society of Soil Science* **60**: 109–119.

Pathak, H. 2016. Fertilizer use in Indian Agriculture: trend, budget and impacts on environment. *Society for Fertilizers and Environment News* **2**: 2–3.

Pathak, H., Mohanty, S. and Prasad, R. 2009. Fate of nitrogen in Indian agriculture; environmental impacts-quantification and uncertainties - A review. *Proceedings of the National Academy of Sciences, India,* Sect. B **79**: 322–335.

Pathak, H., Timsina, J., Humphreys, E. and Godwin, D. 2004. Simulation of rice crop performance and water and N dynamics, and methane emissions from rice in northwest India using CERES Rice model. *Technical Report, CSIRO Land and Water* **23**(4): 111.

Prasad, R. 1998. Fertilizer urea, food security, health and the environment. *Current Science* **75:** 677–683.

Prasad, R. 2005. Research on nitrification inhibitors and slow-release nitrogen fertilizers in India. *Proceedings of the National Academy of Sciences, India, Sect. B* 75: 149–157.

Prasad, R. 2011. Aerobic rice systems. *Advances in Agronomy* **111:** 207–247.

Prasad, R. 2013. Fertilizer nitrogen, food security, health and the environment. *Proceedings of Indian National Science Academy* **79 B** (4 Special): 997–1,010.

Prasad, R., Pathak, H., Patra, A.K. and Shivay. Y.S. 2014. Nitrogen management. (In) *Textbook of Plant Nutrient Management,* pp. 73–92. (Prasad, R., Kumar, D., Rana, D.S., Shivay, Y.S. and Tewatia, R.K., (Eds), Indian Society of Agronomy, New Delhi.

Prasad, R. and Power, J.F. 1995. Nitrification inhibitors for agriculture, health and the environment. *Advances in Agronomy* **54**: 233–287.

Prasad, R. and Rajale, G.B. 1972. The influence of nitrification inhibitors and slow-release nitrogen materials on transformations of fertilizer nitrogen in soils of fluctuating moisture content. *Soil Biology and Biochemistry* **4**: 451–457.

Prasad, R. and Shivay, Y.S. 2015. Fertilizer nitrogen for the life, agriculture and the environment. *Indian Journal of Fertilisers* **11**(8): 47–53.

Prasad, R., Devakumar, C. and Shivay, Y.S. 1993. Significance in increasing fertilizer nitrogen efficiency, pp. 97–109. (In) *Neem Research and Development* Randhawa, N.S. and Parmar, B.S., (Eds). Pesticide Society of India, New Delhi.

Prasad, R., Rajale, G.B. and Lakhdive, B.A. 1971. Nitrification retarders and slow-release nitrogen fertilizers. *Advances in Agronomy* **23**: 357–383.

Prasad, R., Shivay, Y.S., Kumar, D., Sharma, S.N. and Devakumar, C. 2007. Neem for sustainable agriculture and the environment – A review. *Proceedings of National Academy of Sciences, India, Sect. B 77: 313–330.*

Prasad, R., Singh, D.K. and Singh, R.K. 2000. Mineralization studies with new neem coated urea fertilisers. *Fertiliser News* **45**(11): 65–67.

Prasad, R., Singh, G., Shivay, Y.S. and Pathak, H. 2016. Need for determining ecofriendly optimum fertilizer nitrogen level for better environment and for alleviating hunger and malnutrition. *Indian Journal of Agronomy* **61**: 1–8.

Prasad, R., Singh, S., Saxena, V.S. and Devakumar, C. 1994. Coating prilled urea with neem (*Azadirachta indica* Juss.) oil for efficient nitrogen use in rice. *Naturwissenschaften* **86**: 538–539.

Prasad, R., Thomas, J., Gupta, V.S.S.R. and Singh, S. 1983. Ammoniphilic plants for reducing water pollution. *Environmental Conservation* **10**: 260–261.

Reddy, R.N.S. and Prasad, R. 1975. Studies on the mineralization of urea, coated urea and nitrification-inhibitor treated urea in soil. *Journal of Soil Science* **26**: 217–223.

Saleem, I., Javid, S., Sial, R.A., Ehsan, S. and Ahmed, Z.A. 2013. Substitution of soil application of urea with foliar application to minimize the wheat yield losses. *Soil Environment* **32**: 141–145.

Scheurwater, I., Koren, M., Lambers, H. and Atkin, O.K. 2002. The contribution of roots and shoots to whole plant nitrate reduction in fast- and slow-growing grass species. *Journal of Experimental Botany* **53**(374): 1,635–1,642.

Shaviv, A. 2001. Advances in controlled release fertilizers. *Advances in Agronomy* **71**: 1–49.

Smith, C.J., Freney, J.R., Sherlock, R.R. and Galbally, I.E. 1991. The role of urea nitrogen applied in a foliar spray to wheat at heading. *Fertilizer Research* **28**: 129–138.

Sorgonà, A., Lupini, A., Mercati, F., Di Dio, L., Sunseri, F. and Abenavoli, M.R. 2011. Nitrate uptake along the maize primary root: An integrated physiological and molecular approach. *Plant, Cell and Environment* **34**: 1,127–1,140.

Stewart, G.R., Popp, M., Holzapfel, I., Stewart, J.A. and Dickie-Eskew, A.N.N. 1986. Localization of nitrate reduction in ferns and its relationship to environment and physiological characteristics. *New Phytologist* **104**: 373–384.

Tandon, H.L.S. 1989. Nitrogen recommendations for higher fertiliser efficiency. *Fertiliser News* **34**(12): 63–77.

Tischner, R. 2000. Nitrate uptake and reduction in higher and lower plants. *Plant, Cell and Environment* **23**: 1005–1024.

Xu, G., Fan, X. and Miller, A.J. 2012. Plant nitrogen assimilation and use efficiency. *Annual Review of Plant Biology* **63**: 153–182.

Yu, T.R. 1985. Soils and plants. pp. 197–217. (In) *Physical Chemistry of Paddy Soils.* Science Press, Beijing, China.