Nitrogen loss from plants – an ignored aspect

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Fertilizer nitrogen (N) is universally used in crop production to attain high crop yields. However, the efficiency of fertilizer N is often reported to be in the range 30–50%. High N loss through ammonia volatilization, denitrification and surface run-off is reported as the main reason for low use efficiency. Another pathway for N loss is during the catabolism process when plants senesce. This has not been studied well and is often ignored in the calculation of the N balance sheet. Thus, considering N loss from plants will help in constructing an accurate balance sheet.

Among the fertilizer nutrients, nitrogen (N) is needed in large amounts and crops respond to N application due to severe deficiency[1]. Only legume crops have the ability to fix atmospheric N, while all the other crops by and large depend on external N supply through fertilizers. Synthesis of ammonia by Haber and Bosch was one of the significant breakthroughs that led to the award of the Nobel Prize to the duo[2]. This landmark achievement was responsible for the large-scale production of ammonia (NH_3)-based fertilizers, when most crop breeders were making an effort to develop high-yielding varieties and hybrids. Although the breeders did succeed in developing cultivars with high yield potential, this would not be realized without the use of fertilizer N. Thus these two factors brought about the green revolution in the well-endowed areas, i.e. irrigated regions[3]. With greater use of fertilizer, high yield potentials were attained. However, with time, the yield levels did not show any further improvements. As a result, more fertilizer was being applied[4]. Decontrol of phosphate and potash fertilizers led to further application of the cheap nitrogenous fertilizers such as urea. This imbalanced fertilizer use did contribute to yield decline as well as declining factor productivity. There was also a growing awareness of inefficient fertilizer use and most of the research was concentrated on improving the fertilizer N use efficiency[5]. Studies indicated that the efficiency was as low as 30% in crops such as rice, while it was about 50–60% in upland crops such as maize and wheat. The low efficiency was due to N loss through volatilization soon after it was applied. Most of the fertilizers are broadcast applied to the cereal crops. Thus, the fertilizer remains on the soil surface and is soon lost through volatilization as NH_3 loss[6]. The fertilizer N on hydrolysis is transformed into nitrate that is either taken up by the crops or is lost through leaching or surface run-off[7]. Thus, most of the research efforts were to identify strategies to improve the use efficiency of the crop plant or to reduce N loss. Among the first developments was the use of nitrification inhibitors with the most popular chemical being N-Serve[8]. Other chemicals that did become popular were dicyandiamide[9], 2-amino 4-chloro 6-methyl pyrimidine (AM) and 3,4-dimethylpyrazole phosphate (DMPP)[10]. Urease inhibitors[11], another class of chemicals such as *N*-(*n*-butyl)thiophosphoric triamide (NBPT), etc. were identified to improve efficiency of fertilizer urea. These chemicals are still being used in the developed nations because of the stringent legislative measures to curb pollution. However, the adverse effects of chemicals led to alternative solutions and strategies[12]. Furthermore, their high cost prevented commercial success in developing countries like India. Therefore, research in the Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi in the 1960s and 1970s led to the identification of neem cake as a nitrification inhibitor[13]. Substantial research was done subsequently across the country by the state agricultural universities, research institutions and private organizations. From the crude extraction and mixing procedures, a formulation ‘Pusa Neem Gold’ was developed and patented[14]. However, large-scale use became a possibility with the Government issuing directives to the fertilizer manufacturers that prilled urea would necessarily be coated with neem before it was sold to the farmers. This was done to avoid the misuse of fertilizer urea that is heavily subsidized by the Government.

It is well agreed that N loss can be reduced using amended fertilizer and its better management such as split application and applying fertilizers based on crop demand. However, all these have limitations because the principles of chemistry operate when a fertilizer is applied to the field. Thus, it is important to consider plant characteristics for improvement in use efficiency.

The bulk of N absorbed by the plants is used in protein synthesis and a small proportion is present in macromolecular forms such as nucleic acids. Lowland crops like rice absorb N in the ammoniacal form, while upland crops absorb N mostly as nitrates. The main form of storage is amino acids and proteins in the leaves[15]. Nitrogen in the plants is reduced to NH_3 and is later transformed to amino acids such as glutamine or asparagine because these molecules are involved in the long-distance transport in plants to meet the N requirement.

Most of the N absorption by the plant roots takes place during the vegetative phase with the peak uptake coinciding with the highest N requirement of a plant, such as anthesis in cereals (rice, wheat, etc.), silking or tasselling in maize, or boll development in cotton. However, at this point of time, except for the crops that are irrigated, N uptake ceases. During this period, the proteins and amino acids are broken down by the process of catabolism and remobilized/translocated from the leaves to fruit/seed. The degradation could take place by three possible pathways: (i) chloroplast degradation, (ii) vacuolar pathway and (iii) ubiquitin 26S proteasome pathway[16]. It is in the process of catabolism that NH_3 is produced in the leaves and some of it escapes to the atmosphere through the stomata which open for the absorption of carbon dioxide during photosynthesis. Ammonia is produced during decarboxylation of glycine in the mitochondria[17], amino acid deamination in the cytosol[18] and also in lignin biosynthesis[19].

Nitrogen loss from the plant canopy has not received much attention, although some researchers did suggest substantial loss of plant N[20]. Substantial post-anthesis N losses for wheat have been reported to range from 5.9 to 80 kg N ha^{-1}. Nitrogen loss was attributed to its volatilization from the aboveground biomass resulting from inefficient N translocation and re-assimilation within the plant during senescence[21]. Similarly, total N uptake declined at maturity, suggesting N loss from plants occurred in field crops such as barley[22], sunflower[23], mustard[24] and Acala cotton[25]. Nitrogen loss varied among species and crops[22,25], as well as between seasons[25–27].

For an understanding of N loss, it is important to obtain data on N uptake when it is at the peak, such as at anthesis in case of cereals such as wheat[21], rice[26], silking or tasseling in maize[27] and boll development in cotton[25]. In India, majority of the studies have focused on plant recovery and soil N loss mechanisms[28]. Most of the plant N analysis was done on samples collected at harvest with an aim to estimate the recovery efficiency. Few studies have reported N uptake at various growth stages. The difference in N uptake at the stage when it is maximum and that at the time of physiological maturity will indicate whether the plant is losing N or there is an efficient remobilization.

Despite substantial research on N fertilizer use[5], transformations and dynamics[28], there are still many unanswered questions such as the unaccounted N loss in the balance sheets. Therefore, research is needed to understand the fate of N in the plants and identify cultivars that are efficient users with a high harvest index. Research efforts will enable more accurate nutrient balance sheets that are presently done without considering the plant N loss. Taking into account N loss from the plant canopy will also help (i) gain a better understanding of the N loss pathways, (ii) the quantum of loss, (iii) develop cropping systems with higher efficiency and (iv) reduce environmental impacts.

1. Prasad, R., *Curr. Sci.*, 1998, **75**, 677–683.
2. Appl, M., In *Ullmann's Encylopedia of Industrial Chemistry*, Wiley-VCH, Weiheim, Germany, 2006.
3. Swaminathan, M. S., *50 years of Green Revolution: An Anthology of Research Papers*, M.S. Swaminathan Research Foundation (MSSRF), Chennai, India, 2017, p. 484; doi:10.1142/10279.
4. NAAS, Policy Paper No. 35, National Academy of Agricultural Sciences, New Delhi, 2006, p. 8.
5. Ladha, J. K., Pathak, H., Krupnik, T. J., Six, J. and van Kessel, C., *Adv. Agron.*, 2005, **87**, 85–156.
6. Blaise, D., Tyagi, P. C., Khola, O. P. S. and Ahlawat, S. P., *Nutr. Cycl. Agroecosyst.*, 1996, **46**, 97–101.
7. Prakasa Rao, E. V. S. and Prasad, R., *Plant Soil*, 1980, **57**, 382–392.
8. Bremner, J. M., Breitenbeck, G. A. and Blackmer, A. M., *Geophys. Res. Lett.*, 1981, **8**, 353–356.
9. Amberger, A., *Commun. Soil Sci. Plant Anal.*, 1989, **20**, 1933–1955.
10. Zerulla, W. *et al.*, *Biol. Fertil. Soils*, 2001, **34**, 79–84.
11. Byrne, M. P. *et al.*, *Sustainability*, 2020, **12**, 6018.
12. Subbarao, G. *et al.*, *Crit. Rev. Plant Sci.*, 2006, **25**, 303–335.
13. Prasad, R., Rajale, G. B. and Lakhdive, B. A., *Adv. Agron.*, 1971, **23**, 337–383.
14. Prasad, R., Saxena, V. S. and Devakumar, C., *Curr. Sci.*, 1998, **75**, 15.
15. Nordin, A. and Nasholm, T., *Oecologia*, 1997, **110**, 487–492.
16. Zhang, X. and Jiang, L., *Front. Plant Sci.*, 2019, **10**, 359.
17. Keys, A. J., Bird, I. F., Cornelius, M. J., Lea, P. J., Wallsgrove, R. M. and Miflin, B. I., *Nature*, 1978, **2275**, 741–743.
18. Nakashima, J., Awanmo, K., Fujita, M. and Saikai, H., *Plant Cell Physiol*., 1997, **38**, 113–123.
19. Olea, F. *et al.*, *Plant Cell Physiol.*, 2004, **45**, 770–780.
20. Wetselaar, R. and Farquhar, G. D., *Adv. Agron.*, 1980, **33**, 269–302.
21. Harper, L. A., Sharpe, R. R., Langdale, G. W. and Giddens, J. E., *Agron. J.*, 1987, **79**, 965–973.
22. Rogers, C. W., Dari, B., Hu, G. and Mikkelsen, R., *J. Plant Nutr. Soil Sci*., 2019, **182**, 367–373.
23. Scheiner, J. D., Gutiérrez-Boem, F. H. and Lavado, R. S., *Eur. J. Agron*., 2002, **17**, 73–79.
24. Karamanos, R. E., *Prairie Soils Crops J.*, 2013, **6**, 52–63.
25. Fritschi, F. B., Roberts, B. A., Travis, R. L., Rains, D. W. and Hutmacher, R. B., *Crop Sci*., 2004, **44**, 516–527.
26. Fageria, N. K., *Commun. Soil Sci. Plant Anal*., 2003, **34**, 259–270.
27. Francis, D. D., Schepers, J. S. and Vigil, M. F., *Agron. J*., 1993, **85**, 659–663.
28. Pathak, H., Li, R., Wasserman, R. and Ladha, J. K., *Soil Sci. Soc. Am. J*., 2006, **70**, 1612–1622.

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