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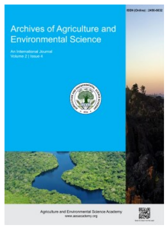

REVIEW ARTICLE

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Precision nitrogen management on crop production: A review

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ABSTRACT

Nitrogen (N) is the most essential nutrient for plants because of its value as a growth and yield determinant nutrient. Significant, and rapid increase in N application rates have occurred, but often at the expense of poor usage performance. The study enlights the causes of nitrogen loss in the environment, the need for its management and ways for precision management. Researches reveal only 50% of the applied fertilizer is uptake by the plants and the remaining is lost in the form of different pathways like denitrification, leaching, and volatilization that is very harmful for the biodiversity. Nitrogen management necessitates extra caution in its application in order to avoid major losses and optimize performance. Precision nitrogen management has been found especially useful to achieve the goals of improved productivity and higher nitrogen use efficiency (NUE). Leaf color charts, sensor based green seeker and chlorophyll meter like decisions tools in precision nitrogen management help in assisting the prediction of the need for N in the crops leading to higher nitrogen use efficiency without any reduction of yield. On the other hand, the use of urea briquettes deep placement supplements the nitrogen management techniques for higher NUE and crop productivity as well as sustain agriculture by avoiding the leakage of nitrogen to the environment thereby reducing the pollution. Hence, the synchronization between crop demand and nitrogen supply using the tools helps to minimize nitrogen losses, maximize nitrogen use efficiency and increase productivity.

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INTRODUCTION

Nitrogen is among the nutrients that limits the growth and development of plants. Biosynthesis and inter-conversions of amino acids, proteins, enzymes, nucleic acids, pigments, and many metabolites involve nitrogen. Plants need nitrogen in relatively larger amounts than other soil-borne elements and the endogenous application of nitrogen can often lead to improvement in yield (Van Cleemput *et al*., 2008). Most of the species in the agricultural system obtain nitrogen from the soil through mineralization of organic matter and from external supply, both organic and inorganic. There must be a synchrony between the supplied nitrogen and crop demand for higher nitrogen uptake and optimal yield matching its pattern and total amount (Van Cleemput *et al*., 2008). The nitrogen deficient soils are found all over the world in varying degrees but it is also the nutrient that is applied in the greatest quantity from outside sources. Since naturally fixed nitrogen is rarely sufficient for high-production systems, modern agricultural systems depend extensively on large inputs of N fertilizer to maintain productivity (Evenson and Gollin, 2003). Nitrogen fertilizers account for only 33% of total annual Nr creation or 63 percent of all anthropogenic sources of reactive nitrogen (Nr) globally (Dobermann, 2005). Reactive nitrogen is defined as biologically, photo-chemically, and radiatively active form of nitrogen; it includes diversified pool of nitrogenous compound that contains mineral forms like NO_3^-, NH_4^+ and chemically active gaseous form in the troposphere like NO_x, NH_3, N_2O which help in causing air pollution and greenhouse effect (Galloway *et al*., 1995). Harvested crops and their residues absorb just around half of all anthropogenic N inputs to cropland, with the remainder contributing significantly to Nr enrichment of the atmosphere, ground, and surface waters. The Nr enrichment in the environment causes damage to biodiversity.

One of the key goals of crop production for agronomists and breeders is to improve nitrogen use efficiency (NUE) that efficiently absorbs, assimilates, and remobilizes all available nitrogen (N) resources (Cho *et al*., 2007). High NUE not only boosts grain yield but also lowers environmental pollution and facilitates low-input, sustainable cultivation (Lee, 2021). When applied at the right time and in the right dosage, N fertilizer can increase yields while lowering farmer input costs. NUE is characterized by agronomists as seed yield divided by the amount of nitrogen available in the soil, including N fertilizer (Perchlik and Tegeder, 2017). Previous research studies have concentrated on the use of slow- and controlled-release fertilizers, coated (polymer, sulfur) fertilizers, nitrification inhibitors, and improved positioning methods to increase NUE (Gaihre *et al*., 2018). Different decision support tools that have been proposed for precision nitrogen management for higher NUE and grain yield like GreenSeeker (GS) optical sensor, soil plant analysis development (SPAD) meter, leaf color chart (LCC), urea briquette deep placement (UDP) (Baral *et al*., 2021). Precision nitrogen management (PNM) is a key component of advanced nutrient management and precision agriculture for addressing issues related to food and environmental protection in order to achieve long-term agricultural and social development. The use of these technologies decreases residual N in the soil by 30–50 percent and saves N fertilizers by 10 percent to about 80 percent without reducing yields or affecting grain quality. The objective of this study is to open up with the causes of nitrogen losses in the field, the need for precision nitrogen management and study different decision support tools used in the precision nitrogen management.

METHODOLOGY

The study was carried out using the secondary sources of data. Rigorous desk study was conducted for the literature collection on Precision nutrient management. Relevant journal articles, reports and books were consulted and studied thoroughly for the compilation of this study.

NITROGEN LOSS FROM FIELD

About 70% of the applied nitrogen can be lost due to excess amounts, low plant population, inadequate application methods and many other factors (Anas *et al*., 2020). The loss of nitrogen from the soil occurs through three principal pathways; Denitrification, Volatilization and Leaching.

Denitrification

Denitrification is a major biological process that returns available soil nitrogen to the non-available atmospheric nitrogen as various N oxides (NO, N_2O) and dinitrogen (N_2) (Martens, 2005). When the level of oxygen drops in the soil then the microorganisms take away oxygen from the nitrate ion and produce nitrogen (N_2) or nitrogen oxide (N_2O) that volatizes from the soil. Once the correct environmental conditions; low to no O_2 concentrations, and high soluble C content, are imposed with microbial reduction of N oxides, the denitrification pathway is prevalent (Martens, 2005). Hence, for denitrification to occur, all three conditions must be present: a carbon source, a low oxygen level, and enough NO_3. The loss through denitrification was about 20-40% in India whereas 30-50% of loss was reported in Japan in case of rice.

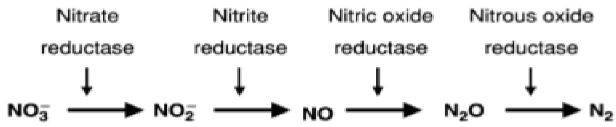

Figure 1. Pathway and enzymes involved in denitrification (Source: Martens, 2005).

Volatilization

The process by which ammonium form of nitrogen is converted into ammonia and released in the atmosphere is called volatilization. The loss of nitrogen through volatilization occurs when ammonium forms of N like ammonium nitrate, diammonium phosphate, ammonium polyphosphate, etc. are applied at the soil surface having pH higher than 7.5 i.e., in calcareous soils. Manures and urea fertilizers that are surface applied and not incorporated into the soil are subjected to high volatilization losses. Ammonia volatilization losses are higher for insoluble ammonium fertilizers (AS, DAP, MAP, and APP) than for AN, which forms a soluble reaction product (Vitosh *et al*., 1995).

Leaching and runoff

When soil becomes highly saturated from rain, it reaches a point where it can no longer retain any more water. The gravitational water flows down the soil profile due to the action of gravity and along with the water nitrogen moves with it, which is called leaching (Killpack and Buchholz, 2017). The nitrate (NO_3-) form of nitrogen is much more vulnerable towards leaching and runoff than Ammonium ions. Clay particles in the soil being negatively charged like nitrate ions do not retain the ion due to which there is an easy flow of nitrate with water in the soil. But NH_4^+ forms of nitrogen having positive charge are retained by negatively charged clay hence very little leaching occurs (Johnson *et al*., 2005). Similar is the case of runoff, it carries nitrogen forms from the surface of the soil when the rainfall is high and soil cannot absorb further water.

Need for precision nitrogen management

From the plant nutrition point of view, Nitrogen is the most important nutrient that often limits crop production. Blanket fertilizer recommendations, particularly for nitrogen, can result in fertilizer overuse, contamination, and increased cultivation costs (Arregui and Quemada, 2008). Crops have very poor nitrogen use efficiencies; about 50% of applied nitrogen is not assimilated (Dobermann and Cassman, 2005). Excessive accumulation of nitrogen causes major societal costs through direct and indirect negative effects on environmental quality, ecosystem services, and biodiversity. Therefore, the need for nitrogen management can be stated as;

- The need for nitrogen can vary from field to field, season to season and within different varieties of the same crop species.
- To adjust nitrogen input to nitrogen crop demand as a key factor in nitrogen application quality.
- To increase the nitrogen uptake by the plant thereby increasing the nitrogen use efficiency without any yield penalty.
- To help farmers practice more sustainable agriculture by having a sufficient rate of nitrogen when the crops need it and at a particular time, reducing the risk of losing the harvest

Precision nitrogen management tools and techniques

SPAD

One of the most widely used diagnostic methods for determining crop nitrogen status is the Soil Plant Analysis Development (SPAD) chlorophyll meter. The hand-held absorbance-based dual-wavelength chlorophyll meter was developed by Minolta in the 1980s (SPAD models 501 and, later, 502; Minolta corporation, Ltd., Osaka, Japan). The SPAD chlorophyll meter allows users to measure chlorophyll content in the field in a fast and non-destructive manner (Yuan *et al.*, 2016). It is quick and reliably assesses N status of a crop based on leaf area. The SPAD meter generates a three-digit SPAD value by calculating the difference between transmittance of red (650 nm) and infrared (940 nm) light through the leaf which corresponds the amount of chlorophyll present in the leaf sample (Uddling *et al.*, 2007). In cereals, measurements are taken at one or more points on either the uppermost completely extended leaf or the lower leaves, depending on the study goals. Some experiments have attempted to classify SPAD values at different points on the leaf blade, such as 1/3, 1/2, 2/3, and 3/4 of the distance from the leaf base to the tip (Lin *et al.*, 2010). When compared to farmers' fertilizer activities, SPAD meter-based N management substantially increases NUE by 45–110% (Singh *et al.*, 2015). The expensiveness of chlorophyll-meter keeps it out of reach of many Asian farmers.

LCC

Leaf color chart is a simple and low-cost diagnostic instrument for tracking the relative greenness of a rice leaf as an indicator of the plant's nitrogen status (Alam *et al.*, 2005). The LCC is a ruler-shaped plastic strip with four or more panels ranging in hue from yellowish green to dark green that are based on the wavelength characteristics of leaves. Nitrogen status of leaves is linked to photosynthetic rate and biomass production, and it is a sensitive indicator of changes in crop N demand over the course of a growing season. LCC quickly analyzes the leaf N status and helps to maintain optimal N content in the leaf. Cultivars and crop establishment methods can influence the critical threshold value of LCC. Cultivars with naturally yellowish leaves should have more yellowish green thresholds than cultivars with naturally dark green leaves (USAID, 2013). When compared to the recommended fixed-time split N application, LCC could save 20–42 kg N ha^{-1}, increasing the NUE by 59–68% in case of rice under irrigated conditions (Maiti *et al.*, 2004). In addition, LCC is inexpensive and easy to use for the farmers. It's an excellent tool for optimizing N utilization, regardless of whether the N comes from organic, bio fertilizers, or chemical fertilizers (Balasubramanian *et al.*, 1999). Increased farmer adoption of the LCC will reduce rice over fertilization, boost profitability, and reduce fertilizer-related pollution.

Green seeker

The use of remotely sensed crop spectral characteristics to assess crop N status in terms of plant/leaf N concentration, estimate plant N uptake, and guide N fertilization has been proved successful (Nguyen and Lee, 2006). Active sensors like green sensors are widely used for N management improvement. The GreenSeeker handheld sensor is a simple optical sensor that monitors plant health and vigor in NDVI values in real time. The sensor sends out short bursts of red and infrared light, then counts how much of each type of light is reflected back by the plant (Costa, 2019). Because healthy green plants absorb most of the red light and reflect the infrared light, NDVI is linked to vegetation (Abit and Arnall, 2017). NDVI can be called as a vegetation index derived from empirical data that is related to the leaf area index and forecasts biomass and yield (Raun *et al.*, 2002). Precise N fertilization timing can be determined with a response index calculated with the help of NDVI (Baral *et al.*, 2021). The response index can be calculated by dividing NDVI measurement of the non-N-limited plots by the GS-guided plot (Raun *et al.*, 2002).

Urea briquettes

A simple physical alteration of conventional urea fertilizer results in UB fertilizer. It is made up of big, distinct urea particles condensed with some conditions for slow hydrolysis that contain 46% nitrogen. The simple urea briquettes can also be prepared with some modification that 25 % of it are replaced with other essentials like organics, DAP, Potash, etc. The weight of the particles can vary significantly, but the average range that has been studied is 1-3 g per particle. A village-level briquetting machine may create UB through granulation and compression procedures. Briquetting looks to be the most practical method for producing UB due to its simplicity and cost effectiveness. The manufacturing process determines the shape of the granules of UB. The UB produced by any of the melt-type granulation methods is nearly spherical, though size and weight may vary. Briquettes are pillow-shaped, oblong, or oblate in shape, with broken edges from webbing, and are quite homogeneous in size and weight (Manikyam *et al.*, 2020). Use of urea briquette along with deep placement with the help of application was found to record the lowest nitrous emission, highest yield, as well as low level of volatilization (Chatterjee *et al.*, 2018).

Urea deep placement

The International Rice Research Institute (IRRI) and the International Fertilizer Development Center (IFDC) created the Urea Deep Placement (UDP) methodology, which is a good example of a climate-smart solution for rice systems. Fertilizer deep placement is a technique for improving nutrient delivery efficiency to crops by applying granular fertilizer directly in the root zone. Deep insertion maximizes nutrient uptake by crops while using less fertilizer than surface broadcasting. A broadcast application is the most common method for applying urea, rice's major nitrogen fertilizer. It is a wasteful method leading to GHG emissions and water pollution because 60 to 70 percent of the nitrogen applied is wasted. After the paddy is transplanted, urea is formed into "briquettes" of 1 to 3 grams and deposited at a depth of 7 to 10 cm in the soil. This approach reduces nitrogen losses by 40%, while increasing urea efficiency by 50% (Climate Smart Agriculture, 2018). Deep urea placement preserves nitrogen in the soil in the form of ammonium, which is less mobile than nitrates and makes nitrogen available to rice for a longer period, allowing it to grow more vigorously. As a result, deep placement minimizes the likelihood of applied nitrogen being leached, volatilized, nitrified, or denitrified, hence increasing its availability and absorption by crops.

Conclusion

The successful nitrogen management is still a major challenge in the developing world. The current fertilizer application, particularly of developing nations, is dependent on blanket recommendation and is set for the entire country irrespective of its regional variability within the nation. Hence, there is a need for precision nitrogen management to overcome the situation. The decision support tools help to predict the pattern and time of application of nitrogen with respect to the crop demand. The synchronization obtained between the N supply and crop N demand with the help of these tools help in increasing the nitrogen use efficiency of the plants as well as increases the productivity of crops.

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