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NUTRIENT USE EFFICIENCY CONCEPT AND INTERVENTIONS FOR IMPROVING NITROGEN USE EFFICIENCY

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Abstract

Nutrient use efficiency (NUE) is a very important concept in the evaluation of crop production systems. All the essential plant nutrients play a vital role in plant growth and development. Nitrogen (N) is the most critical externally added input for any crop production system. Most of the population depends on fertilizers for food supply. More than 90% of the fertilizers are consumed by the cereals mainly wheat, maize and rice. Less use of fertilizers leads to low yield and more use of fertilizers leads to soil, water and environment pollution. The main point of consideration is that the response of applied fertilizers and their use efficiency to get the maximum output .Nutrient use efficiency of applied fertilizers is very low due to many reasons like surface run off, leaching, volatilization, denitrification and fixation of micro nutrients in the soil due to very high pH. The highest nutrient use efficiency always occurs at the lower parts of the yield response curve, where fertilizer inputs are the lowest, but effectiveness of fertilizers in increasing crop yields and optimizing farmer profitability should not be sacrificed for the sake of efficiency alone. There must be a balance between optimal nutrient use efficiency and optimal crop productivity. Hence here is a need to understand the best soil and water management practices which helps in increasing nutrient use efficiency and yield by using less fertilizers so that the goal of sustainable agriculture can be achieved. Nutrient use efficiency can be optimized by fertilizer best management practices that apply nutrients at the right rate, time, and place and accompanied by the right agronomic practices. This paper is a review, in which an approach has been made to clear the concept of nutrient use efficiency and the interventions which can be used to increase the nutrient use efficiency.

***Key words**:* Nutrient use efficiency, Right rate, Right time, Right place, leaching, volatilization and denitrification.

Introduction

Out of all the essential plant nutrients for crop growth, N is the nutrient which commonly limits crop production (Mosier *et al.,* 2001). N plays a vital role in crop production system just because of its large requirement in all metabolic activities of plants and its heavy losses associated with soil-plant systems (Ladha *et al.,* 2003). To meet the demand of N to the crop growth, globally farmers using around 120 million metric tons of nitrogenous fertiliser each year (FAO, 2014). Due to heavy losses of N because of leaching, volatilisation and denitrification NUE is very low (30-50%), to meet the demand of N farmer needs to apply huge amount of nitrogen fertilizer in agricultural crops (Fageria, 2002). Almost all the agricultural soils and cropping systems of the world deficient with nitrogen so, it is necessary to use additional nitrogen sources for the production of crops to fulfil the demands of human populations (Mohan *et al.,* 2015).

Essential plant nutrients used by plants when they are present in usable form. Many leguminous plants and soil microorganisms have potential to convert N into plant usable forms. Significant amounts of N contributed by them to meet crop needs, but increasing human population demand can only be fulfilled by additional nitrogen which is supplied by fertilizers (Ladha *et al.,* 2003). Sustainable agriculture production requires balanced and judicious, efficient, eco-friendly and environmentally sound management practices.

The aim of sustainable agriculture to get more crop

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output from a particular area of a land can be achieved through accurate use of fertilizers (Kumar *et al.,* 2016). Efficient N fertilizer management can simply be defined as reduced various losses and maximize the amount of nutrient made available for crop (Ladha and Reddy, 2003). By 2050, nitrogen fertilization is expected to increase by 2.7 times and phosphorus by 2.4 times on a global scale (Tilman 2011). By continuously increasing the rate of fertilizer application to crops mainly cereals it shows adverse effect on the crops and followed the law of diminishing returns.

It is measured that only 30-50% of applied nitrogen fertilizers and 45% of phosphorous fertilizers are used by the crops remaining fertilizers are lost or remain unused (Ladha *et al.,* 2005). For example, only 20–60 % of nitrogen fertilizers applied in intensive wheat production is taken up by the crop, 20–60 % remains in the soil, and approximately 20 % is lost to the environment (Pilbeam 1996). The phosphorus-use efficiency can be as high as 90% for well managed agro-ecosystems (Syers *et al.,* 2008) or as low as 10–20 % in highly phosphorus-fixing soils (Bolland and Gilkes 1998). In recent time, there is an urgent need for improving N and P use efficiency and balance use of natural resources which is necessary for sustainable agricultural production (Kumar and Agarwal, 2013; Paul *et al.,* 2014).

The Concept and Importance of NUE

Meeting societal demand for food is a global challenge as recent estimates indicate that global crop demand will increase by 100 to 110% from 2005 to 2050 (Tilman *et al.,* 2011). Others have estimated that the world will need 60% more cereal production between 2000 and 2050 (FAO, 2009), while others predict food demand will double within 30 years (Glenn *et al.,* 2008), equivalent to maintaining a proportional rate of increase of more than 2.4% per year. Sustainably meeting such demand is a huge challenge, especially when compared to historical cereal yield trends which have been linear for nearly half a century with slopes equal to only 1.2 to 1.3% of 2007 yields (FAO, 2009). Improving NUE and improving water use efficiency (WUE) have been listed among today's most critical research issues (Thompson, 2012).

NUE is a critically important concept for evaluating crop production systems and can be greatly impacted by fertilizer management as well as soil- and plant-water relationships. NUE indicates the potential for nutrient losses to the environment from cropping systems as managers strive to meet the increasing societal demand for food, fibre and fuel. NUE measures are not measures of nutrient loss since nutrients can be retained in soil, and systems with relatively low NUE may not necessarily be harmful to the environment, while those with high NUE may not be harmless (Thompson, 2012).

Importance of N and P for plants

Functions of N and P: Being a major nutrient, N has special significance for healthy growth and development of plants. N is principle component of many organic compounds (protein, nucleic acids, alkaloids etc.). It inbuilt component of energy transfer compounds such as adenosine diphosphate (ADP) and adenosine triphosphate (ATP) which play a key role in energy use, transfer and release in various metabolic processes of plants (Riedell *et al.,* 1996). N is also component of nucleic acid (deoxyribonucleic acid and ribonucleic acid) which play a crucial role in genetic inheritance of plants. It is also constituent of chlorophyll which acts as factory of photosynthesis. Increase the vegetative growth of plants. Encourage the formation of good quality foliage. P stimulates root growth and formation which has special significance in absorption of water and nutrients (Fageria and Barbosa, 2001). It helps in cell division, hastens maturity and makes plant more tolerant to drought, insect-pest, increase calcium in plants and increase grain to straw ratio.

Deficiency symptoms: Nutrient deficiency symptoms result of imbalance in metabolic activities of plant system (Robson and Snowball, 1986). Deficiency symptoms on plants are typical for given nutrients; hence, it is possible to diagnose nutritional disorders by visual symptoms deficient plants show stunted growth, yellow leaves, reduced tillering in cereals, reduced pods in legumes, and consequently, yield reductions in both cereals and legumes. Overall reductions of plant biomass as well as premature senescence are important symptoms of its deficiency (McConnell *et al.,* 1995). N is placed in category of highly mobile nutrient in the soil as well in plants; hence its deficiency sign are unique and first visible on the lower leaves. Leaves become pale and yellowish green in the early stages of growth, and become more yellow and even orange or red in later stages (Kravchecko *et al.,* 2003) If N deficiency persists for long durations, older leaves may dry and fall off due to senescence, especially in legumes. Severe N deficiency for a short duration can reduce leaf area which leads to lower interception of solar radiation; lower the beneficial use of intercepted radiation and lower photosynthetic rates in crop plants (Fageria and Barbosa, 2001). Phosphorous deficiency reduces the leaf area, leaves become purple in color, delays maturity and growth is stunted (Barbieri *et al.,* 2000).

Fate of nitrogen in the field

When the fertilizer mainly urea is applied to the plants it is taken up by the plants and utilized by them for their growth and development, but along with this most of the applied fertilizers are lost in the soil-crop production system through various mechanisms *i.e.* soil erosion, surface runoff, leaching, de-nitrification, ammonia volatilization and fixation of phosphorous in the soil due to the deficiency or fixation of calcium in the soil (De Datta, S.K.1981). The mechanisms of N loss from the soil-plant system are discussed as below:

(a) Soil Erosion and surface runoff: N adsorbed on soil particles can be lost through wind as well as water erosion. N loss through wind erosion is more common in arid and semiarid climatic regions while, water erosion is most commonly reported mechanism of N loss in humid and sub humid areas. After a heavy rain surface applied nitrate can be dissolved in water and lost through the process of runoff (Fageria, 2002).

(b) Ammonia volatilization: In this chemical reduction process, nitrogen is lost in the gaseous form when urea or ammonium fertilizers are applied on the soil surface. The process of conversion of NH_4^+ into NH_3 gas and its loss to the atmosphere is termed as ammonia volatilization. This mechanism of nitrogen loss is found to be more severe where organic manure and chemical nitrogenous fertilizers (NH_4^+ containing) is surface applied through broadcasting (Bolan and Hedley 2003). Losses of nitrogen as ammonia is occurred in, especially in alkaline soils. High concentration of ammonia is toxic to the nitrification process, resulting in an unusual build-up of nitrites. This mechanism of N loss is more severe in alkaline soil and warm sunny condition, under this condition as much as 20% of N may volatilize and lost to atmosphere within a week (Hutchinson *et al.,* 2003).

$$\underset{\text{Nitrite}}{2HNO_2} + \underset{\text{urea}}{CO(NH_2)_2} \longrightarrow CO_2 + 3H_2O + 2N_2$$

(c) Denitrification : The nitrites may change to gaseous form in the lack of air or by poor drainage. The biochemical reduction of nitrate-nitrogen to gaseous compounds by microorganism is called denitrification. The microorganisms involved are commonly anaerobic forms (Bolan and Hedley, 2003). This mechanism of N loss is most commonly reported under waterlogged condition where lower oxygen level lead to increase in the population of some microorganisms which able to convert nitrate to nitrogen (N2) and nitrous oxide (N_2O), which untimely lost to the atmosphere (Fageria, 2002). This mechanism of N loss is responsible for N losses up to 10-15% of applied nitrogen. Heavy texture soil with poor natural drainage is more susceptible for denitrification losses of nitrogen (Mosier *et al.,* 2001).

$$\underset{\text{Nitrates}}{2NHO_3 \text{ -2(O)}} \longrightarrow \underset{\text{Nitrites}}{2HNO_2 \text{ -2(O),}} \longrightarrow \underset{\text{Nitrous Oxide}}{\text{-}H_2ON_2 \text{ - (O)}} \longrightarrow \underset{\text{Elemental N}}{N_2\text{– (O)}} \longrightarrow \underset{\text{Nitric oxide}}{2NO}$$

(d) Leaching: The nitrate-nitrogen is lost in drainage or with percolating water. When soil is sandy in texture most of leaching losses of N occurs. Nitrate form of N is mobile in nature and not strongly adsorbed on soil particles so it can be easily move beyond the soil profile through the process termed as leaching (Randall *et al.,* 2003). This loss of N mechanism has special significance in high rainfall areas and light texture soils where as much as 25–50% of the N applied can be lost through leaching (Bolan and Hedley, 2003). The amount of nitrogen lost depends upon the climatic and cultural conditions. Quantity of applied N, soil water content and permeability of soil system are important factor which governs the leaching loss of N from crop production system (Davis *et al.,* 2003). In arid and semi-arid regions, such losses are less.

(e) Used by soil microorganisms and weeds: Soil microorganisms readily assimilate nitrate-nitrogen. If microbes have a ready food supply (organic matter) they utilize the nitrates more rapidly. This is one of the reasons; crops get about one-half the nitrogen added in forms of nitrogenous fertilizer. Weeds may also utilize the nitrate-nitrogen added to the soil. Therefore, crops may not get nitrogen in full quantity (Mishra *et al.,* 1972)

Fate of Phosphorous in the field: In the case of phosphorous fertilization, fixation of phosphate is the main problem. Generally phosphorus losses are largely from erosion and surface runoff (Shepherd and Withers 2001). However, P leaching can occur where soil P sorption is low as in sandy soils and with repeated P fertilizer application. The problem of P leaching is accelerated under high input P, and with frequent and heavy rainfall. In a sandy loam soil with low P sorption saturation, P leaching was higher than from clay (Djodjic *et al.,* 2004). Phosphorus from inorganic fertilizer can be leached to beneath 1.1 m soil depth (Eghball *et al.,* 1996).

Nutrient Use and Nutrient Use Efficiency

The objective of nutrient use is to increase the overall performance of cropping systems by providing economically optimum nourishment to the crop while minimizing nutrient losses from the field and supporting agricultural system sustainability through contributions to soil fertility or other soil quality components. NUE addresses some but not all aspects of that performance (Mikkelsen *et al.,* 2012). The most valuable NUE improvements are those contributing most to overall cropping system performance. Therefore, management practices that improve NUE without reducing productivity or the potential for future productivity increases are likely to be most valuable. At the same time, as nutrient rates increase towards an optimum, productivity continues to increase but at a decreasing rate, and NUE typically declines (Barbieri *et al.,* 2008). The extent of the decline will be determined by source, time, and place factors, other cultural practices, as well as soil and climatic conditions.

Interventions for improving nutrient use efficiency (N &P)

Nutrient recovery can be improved through adoption of locally as well as scientifically available means of nutrient management to ensure efficient use of agricultural inputs (chemical fertilizers, land, water, and crops) that will enhance beneficial use of N and P in crops and minimize its losses. Strategies/practices used for nutrient management of crops should be focused on two core principles (1) either it enhance beneficial use of externally applied fertilizer (2) either it conserve soil nitrogen by reducing the quantum of N losses through various mechanisms and ensure higher beneficial use of this conserved N by the subsequent grown crops of the production system (Balasubramanian *et al.,* 2002). The fertilizer industry supports applying nutrients at the right rate, right time, and in the right place as a best management practice (BMP) for achieving optimum nutrient efficiency.

(Majumdar *et al.,* 2013). Various strategies based on above discussed approach for improving nitrogen and phosphorous use efficiency will be discussed below:

(a) Nutrient expert based nutrient management: Proper nutrient management in maize and wheat cropping systems should aim to supply adequate fertilizers based on the demand of the component crops and apply in this manner that minimize loss and maximize the use efficiency (Basso *et al.,* 2011). In this regard nutrient expert is an emerging N management diagnostic tool wherein the input variables such as fertilizers are applied in the right amount, at the right place and at right time (variable rate application) as per demand of the crop-plants (Pampolino *et al.,* 2012).

(i) Right Rate: Most crops are location and season specific depending on cultivar, management practices, climate, etc., and so it is critical that realistic yield goals are established and that nutrients are applied to meet the target yield (Fertilizers Europe, 2011) Over- or under use will result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing remains one of the most powerful tools available for determining the nutrient supplying capacity of the soil, but to be useful for making appropriate fertilizer recommendations, good calibration data is also necessary (IPNI, 2012b).

(ii) Right Time (site specific nitrogen management (ssnm): Greater synchronization between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N (Giller *et al.,* 2004). Split applications of N during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing N use efficiency (Cassman *et al.,* 2002). Tissue testing is a famous method used to assess N status of growing crops, but other diagnostic tools are also available. Chlorophyll meters have proven useful in fine-tuning in-season N management (Francis and Piekielek 1999), and leaf color charts have been highly successful in guiding split N applications in rice and now maize production in Asia (Witt *et al.,* 2005).

(iii) Chlorophyll meter: Chlorophyll meter can be used to estimate the n content of crop ,in general most of the N found in the chloroplast of plant (Olesen *et al.,* 2004). It helps in measuring the leaf chlorophyll content. It has ability to self -calibrate for different soils, climate and crop varieties. It is also recommended to assess the effectiveness of late applied nitrogen in standing crops to increase grain yield and protein content (Singh *et al.,* 2012).

(iv) Leaf color chart: Simple leaf colour chart (LCC) is a simple tool which is a proxy for leaf N is used as an indicator of leaf color, leaf color intensity, leaf N status and right time of N application. LCC is a diagnostic tool which can help farmers for making appropriate decisions regarding the need for nitrogen fertilizer applications in standing crops. Conceptually it is based on the measurement of relative greenness of plant leaves which directly co-related with its chlorophyll content. Nitrogen is a principle component of leaf chlorophyll so its measurement over various phenological stages serves as the indirect basis for nitrogen management rice (Singh *et al.,* 2012).

(v) Right Place: Fertilizer application method has always been critical in ensuring nutrients are used efficiently. Determining the right placement is as important as determining the right application rate. Various placements are available, but most commonly used surface or subsurface applications before or after planting. Prior to planting, nutrients can be broadcast (*i.e.*, applied uniformly on the soil surface and may or may not be incorporated), applied as a band on the surface, or applied as a subsurface band, usually 5–20 cm deep. Commonly, nutrient recovery efficiency tends to be higher with banded applications because less contact with the soil lessens the opportunity for nutrient loss due to leaching or fixation reactions. Placement decisions depend on the crop and soil conditions, which interact to influence nutrient uptake and availability. Adequate and balanced application of fertilizer nutrients is one of the most common practices for improving the efficiency of N fertilizer and is equally effective in both developing and developed countries.

(b) Integrated nutrient management (INM) : INM involves optimum use of indigenous nutrient components *i.e.* crop residues, organic manure, biological N fixation as well as chemical fertilizer and their complementary interactions to increases N and P recovery (Olesen *et al.,* 2004). The positive effects of the integrated use of organic and inorganic nitrogen–phosphorous are either due to optimum Physico-chemical soil environment, or due to better root growth and enhanced supply of secondary and micronutrients (Singh *et al.,* 2012). The proper understanding and exploitation of these positive interactions among the plant nutrient is keys for increasing returns to the farmers in terms of yield as well as soil quality and NUE of applied N (Aulakh and Malhi, 2004). The complementary interaction of N and P with secondary and several micronutrients could lead to considerable improvements in yield and NUE. Therefore, use of balanced and judicious use of nitrogen and phosphorous from all available means will lead to higher productivity.

(c) Increase the use of modified fertilizers: These are fertilizer products that can improve use efficiency of applied nutrients by reducing various losses of nutrients associated with production system and by enhancing their beneficial use in plants. These fertilizers are based on two phenomenon either they can slow the release rate of nutrients or can interfere with nutrient transformation processes and reduce their losses. Slow/controlled release N fertilizers and nitrogen inhibitors are two important classes of fertilizers.

(i) Slow /controlled release fertilizer : The form of applied nitrogenous fertilizers has significant role in controlling various N losses hence, affecting nitrogen availability and recovery. Compare to amide and ammoniums containing N fertilizers, nitrate containing fertilizers are susceptible to leaching. But contrast to this, ammonium and amide containing fertilizers are more prone to volatilization loss than nitrate containing nitrogen fertilizers. A range of slow release fertilizers is now marketed which have the potential to reduce various N losses and improve NUE (Giller *et al.,* 2004). These compounds can reduce N losses due to their potential to delayed N release pattern which may improve the synchronization between crop demand and that of soil N supply. Neem coated urea is widely used and demonstrated slow release N fertilizer in India.

Controlled-release fertilizers can be grouped into compounds of low solubility and coated water-soluble fertilizers. Most slow-release fertilizers are more expensive than water-soluble N fertilizers and have traditionally been used for high-value horticulture crops and turf grass. However, technology improvements have reduced manufacturing costs where controlled release fertilizers are available for use in corn, wheat, and other commodity grains (Blaylock *et al.,* 2005). The most promising for widespread agricultural use are polymer-coated products, which can be designed to release nutrients in a controlled manner. Nutrient release rates are controlled by manipulating the properties of the polymer coating and are generally predictable when average temperature and moisture conditions can be estimated but still controlled release fertilizer is accounted only 0.15% of the total N fertilizer consumption. High cost in manufacturing and non-availability are two principle reasons for limited use of these compounds by farmers from developing countries (Shivay *et al.,* 2001).

(ii) Nitrification inhibitors: Another approach to synchronize release of N from fertilizers with crop need is the use of N stabilizers and controlled-release fertilizers $NH4^{+}$ ion can be adsorbed on soil colloids and retained for a longer period which provide an opportunity for higher nitrogen use efficiency by minimizing leaching and de-nitrification losses of applied N. Addition of nitrification inhibitors can check conversion of ammonium-N into nitrate-N and ensure higher concentration of ammonical form of nitrogen in soil medium, to increase NUE and crop yield (Shivay *et al.,* 2001). Nitrogen stabilizers (e.g., nitrapyrin, DCD [dicyandiamide], NBPT [n-butyl-thio phosphoric triamide]) inhibit nitrification or urease activity, thereby slowing the conversion of the fertilizer to nitrate (Havlin *et al.,* 2005). When soil and environmental conditions are favourable for nitrate losses, treatment with a stabilizer will often increase fertilizer N efficiency.

A group of organic acids in neem seed known as meliacins are responsible for inhibiting nitrification. Urea treated with neem cake inhibited nitrification by 40-74% at the end of 1 and 2 weeks of incubation. The coating technique used coal tar solution in kerosene oil (1kg/2litres, enough for 100 kg urea) as sticker to hold the finely produced neem cake. One quintal urea is transferred to a seed treatment drum and coal tar-kerosene solution is added in parts while rotating the drum. Neem cake (15-20 kg) is then added for use.

(d) Improved method of N application : Among the various methods of N application, deep placement, use of super granules and foliar spray of N fertilizer can enhance the recovery of applied N fertilizer. Broadcasting of nitrogen fertilizers is very common practice leads to large N losses e.g. ammonia volatilization, results in lower nitrogen recovery (McBratney *et al.,* 2003). Use of modified form of N fertilizer (urea super-granules) and deep placement of urea based fertilizers. It has been reported to enhance NUE. Broad casting and deep placement of USG in rice can improve nitrogen recovery. Placement of urea with mud balls technique in the reduced zone of transplanted crop output (Schmidt *et al.,* 2002). Further, foliar feeding of nitrogen either through urea spray, can also improve NUE as it reduce different losses *i.e.* runoff, volatilization, immobilization and de-nitrification prior to being absorbed by the plant (Balasubramanian *et al.,* 2002).

(e) Resource conservation technologies: Resource conserving technologies such as zero tillage (ZT) and permanent bed planting with proper residue management is becoming more popular in many areas of the world, and if adopted for long term basis has been noticed to be helpful in improving soil health (Burgess *et al.,* 2002). Crop production using these technologies resulted in improvement of soil physical, chemical and biological environment, including higher and sustained soil carbon content (Ambus and Jensen, 2001), aggregate stability (Calvino *et al.,* 2003), and change in macro-porosity (Burgess *et al.,* 2002). Better synchronization of N mineralization from degraded crop residue, externally applied fertilizer N to that of crop demand for N can improve NUE of crops planted.

(f) Residue management: The portions of crops left in the field after harvesting is termed as crop residues (Malhi *et al.,* 2011). Crop residues play a critical role in plant growth and development as they affect the quantity of nutrients available to crops (Mohanty and Mishra, 2014). Plant residues are principle sources as well as sinks for carbon and nitrogen cycle (Dinnes *et al.,* 2002). Crop residues supply nitrogen to the plants for longer duration by initially converting it into inorganic form and then mineralize it at later stage of crop when N demand of crop is substantial (Pankhurst *et al.,* 2002).

(g) Green manuring: A wide range of legume species has potential for green manuring. Legumes are superior green manure crops because they have potential to fix atmospheric free N in the soil (Vyn *et al.,* 2000). Annual N accumulation by legumes ranges from 20 kg ha^{-1} to as much as 300 kg ha^{-1} (Singh *et al.,* 2012). The plants should have some important characteristics *viz.* quick growing and short duration crops for easy adjustment into intensive cropping systems, capacity to produce larger dry matter; can fix atmospheric free nitrogen; and they should cultivated with minimum cultural practices (Sharma *et al.,* 2011).

(h) Proper crop rotations: Changing the sequence of crops on the same piece of land is termed as crop rotation (Gan *et al.,* 2003). Adoption of suitable crop sequences is critical for enhancing N recovery in crops. Use of optimum crop sequences ensures efficient use of precise agricultural resources, especially mineral nutrient and soil moisture by crops to sustain the long term stability of production system (Singh *et al.,* 2012). Inclusion of legumes with grain crops is an age old practice and has been recommended as an effective crop management practice for improving soil health and crop system yield (Helmers *et al.,* 2001).

(i) Management of biological stresses: Among the yield limiting factors of crops, biological stress agents such as diseases, insects, and weeds are the most important under diverse agro-ecological regions. It has been reported worldwide that weeds, diseases and insects accounted about 40, 30 and 20 percent of total crops loss before and after harvest, respectively (Albert *et al.,* 1992). Keeping their populations below threshold levels of these biological yield limiting factors can serve as important way to improve N recovery and crop yield. Development of resistant crop cultivars and their incorporation in the modern agriculture to reduce the intensity of losses caused by above mentioned stress agents is most economical approach to reduce risk of agricultural production system. Use of genetically modified crops not only reduces the production cost, but also minimizes environmental consequences associated with lower nitrogen use efficiency (Krupinsky *et al.,* 2002).

(j) Precision farming : Precision farming is an information and technology based farm input management system which aims at the use of technologies and principles to identify, analyse and manage spatial and temporal variability associated with all aspects of agricultural production within fields for maximum profitability, sustainability, enhancing crop performance, protecting land resources and maintain or improve the environment quality (McBratney *et al.,* 2003). Measurement of variability in the field with respect to N and application of right amount of N at right time by the use of variable rate applicator, remote sensing, geographic information systems (GIS) and global positioning systems (GPS) technology may act as important information tools for the farmers to improve NUE under specific conditions of each field.

Ways to increase Phosphorous use efficiency:

i) P fertilizer should have minimum contact with the soil

ii) In acid soils, PUE can be improved by raising pH with application of time.

iii) Surface broadcast in puddling of rice has highest PUE better than placement.

iv) In wheat phosphate placement is more beneficial than broadcast.

v) Drilling and furrow method is efficient in wheat or PUE.

vi) Application of phosphatic fertilizers with organic manures.

vii) Follow band placement rather than broadcasting.

Conclusion

Improving nutrient efficiency is a worthy goal and fundamental challenge facing the fertilizer industry and agriculture in general. Nutrient management is essential in modern crop production systems for improving the long term sustainability. Judicious application of fertilizer -right rate, right time, right place, and right agronomic practice targeting both high yields and nutrient efficiency will benefit farmers, society, and the environment. N management using through SSNM, chlorophyll meter and LCC gives higher grain yield and NUE as compared to blanket N recommendation. Integrated nutrient management and balance fertilization improve not only plant performance, but also NUE of production system. Use of improved scientific interventions with locally available technologies has a positive impact on NUE. Optimal time, rate, methods of application and use of specially formulated forms of fertilizer, including urease and nitrification inhibitors are also potential means for improving NUE. The opportunities are there and tools are available to accomplish the task of improving the efficiency of applied nutrients. However, we must be cautious that improvements in efficiency do not come at the expense of the farmers' economic viability or the environment.

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