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Review Article

Recent Advancement on the Technology of Enhancing Fertilizer Use Efficiency and Crop Productivity: A Review

Abdisa Mekonnen

Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, P.O. Box. 2003 Addis Ababa, Ethiopia
***Corresponding author:** abdisamekonen6@gmail.com

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ABSTRACT

Fertilizers play a significant role in securing the production of food crops around the world. In fact, it is estimated that fertilizers currently support 40-60% of all crop production currently. Meeting future food security targets requires the responsible use of fertilizer nutrients. The 4R Nutrient Stewardship guidelines were developed by the fertilizer industry as a process to guide fertilizer Best Management Practices (BMP) in all regions of the world. This approach was required to address the growing concern that fertilizers are applied indiscriminately to the detriment of the environment. Given that farmers purchase fertilizers at world prices in most regions, and these prices have been steadily increasing over time, most users are very cautious about the rates of nutrients they apply. To avoid unnecessary policy intervention by governments, the fertilizer industry needs to be unified in their promotion of BMPs that support improved nutrient use efficiency and environmental sustainability, while supporting the farmer's profitability. This ultimately comes down to developing appropriate recommendations that match crop nutrient requirements fertilizer additions and minimize nutrient losses from fields. This lead to the 4R Nutrient Stewardship concept, applying the Right Source of nutrients, at the Right Rate, at the Right Time and in the Right Place. Right source means matching the fertilizer to the crop need and soil properties. A major part of source is balance between the various nutrients, a major challenge globally in improving nutrient use efficiency. Finally, some fertilizer products are preferred to others based on the soil properties, like pH. Right rate means matching the fertilizer applied to the crop need – simple as that. However, this is far from being a simple concept when you consider the variations in yield goals, previous crop management, crop residue management, influence of legume crops in rotation, etc. Adding too much fertilizer leads to residual nutrients in the soil and losses to the environment. Ultimately, striking a balance between the crop needs, environmental conditions and the farmer's economic situation is required. Right time means making fertilizer nutrients available to the crop when they are needed. Nutrient use efficiency can be increased significantly when their availability is synchronized with crop demand. Split time of application, slow and controlled release fertilizer technology, stabilizers and inhibitors are just a few examples of how fertilizer nutrients can be better timed for efficient crop uptake. Right place means making every effort to keep nutrients where crops can use them. This is an issue which poses the greatest challenge in small holder agricultural systems, where most fertilizer is broadcast applied, and in many cases without incorporation. Research indicates that fertilizer placement can not only improve crop response, but also improve fertilizer use efficiency significantly by lowering nutrient application rates. Adaptations to non-mechanized agriculture have been made in certain regions which clearly support efforts to modify fertilizer placement as a best management practices.

Key words: Nutrient use efficiency, 4R Nutrient Stewardship, best management practice (BMP).

INTRODUCTION

Fertilizer use efficiency has been the focus of agriculture cultivation practices to meet economic and environmental challenges in the world. Unfortunately, available technology for improving FUE is somewhat ineffect as no significant advances in fertilizer technology during the last several decades. According to Esfahani L. and Asadiyeh, (2009) reported, agricultural sector supported with advanced technology is rapidly increased alarmingly and extensively accomplished in many parts of the world, in area of agriculture used as a major source of revenue. This is the application of modern knowledge for practical purposes or the use of machinery to better facilitate a process and reduce the intensive manual labor required in agricultural production.

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Technological applications to the agricultural sector reduce the stress and tedious manual labor involved in agriculture. By using new technologies that supports increment of yield, management practices and reduces cost of production of farm input, in turn translating production input in to output. The advantages of applying modern technology to agricultural productivity are: food security achieved, that means more people would eat better, while eradicating hunger and reducing malnutrition from increased production; improved nutritional contents of the food; eliminates environmental pollution; improved livelihood life quality and living standards as food costs decline and; increase in savings, as the majority of people spend most of what they earn on food (Wiggin, 2004). In most of developing countries, the most common challenges to achieve food security were increasing, due to reduction in agricultural productivity and strategies to reduce poverty. In fact soil fertility is sharing the biggest percentage, so an obvious strategy is maximize fertilizer application and demonstrate good agronomic practices to enhance productivity. According to Tefera *et al*., (2012) national annual fertilizer use grew from 3,500 t to about 140,000 t by the early 1990s, and reached about 200,000, 400,000, 550,000 t in 1994, 2005, and 2010, respectively. The total amount of fertilizer available for application will exceed one million tons in the 2012/13 cropping year.

In Ethiopia, responses about fertilizer responses on major cereal crops started during 1990s through the projects such as the Freedom from Hunger Campaign. The results from this program showed the positive influences of fertilizers addition, and most attention was given on N and P. Therefore, the objective of this review was to assess recent advancement on the technology of enhancing fertilizer use efficiency and crop productivity.

LITERATURE REVIEW

Significance and scope of fertilization for crop production

World food demand is alarmingly increased, as a result of global crop demand will increase100 to 110% from 2005 to 2050 and also 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 have been listed among today’s most critical and deal with emerging issues of researches (Thompson, 2012).

Nutrient use efficiency is a major important critically model for assessment of crop production systems and can be greatly impacted by fertilizer management as well as soil- and plant-water relationships. Nutrient use efficiency indicates the potential for nutrient losses to the environment from cropping systems as managers strive to meet the increasing societal demand for food, fiber and fuel. It measures are not nutrient loss since nutrients can be retained in soil, and systems with relatively low nutrient use efficiency may not necessarily be harmful to the environment, while those with high Nutrient use efficiency may not be harmless. Sustainable nutrient management must be both efficient and effective to deliver expected economic, social, and environmental benefits. As the cost of nutrients climb, profitable use inputs increased emphasis on high efficiency, and the greater nutrient amounts that higher yielding crops remove means that more nutrient inputs will likely be needed and at risk of loss from the system.

Providing society with a sufficient quantity and quality of food at reasonable price requires that costs of production remain relatively low while productivity increases to meet projected demand. Therefore, both productivity and nutrient use efficiency must increase. These factors have spurred efforts by the fertilizer industry to promote systems to fertilizer best management practices such as 4R Nutrient Stewardship, which is focused on application of the right nutrient source, at the right rate, in the right place and at the right time (IPNI, 2012) and the Fertilizer Product Stewardship Program (Fertilizers Europe, 2011). These approaches consider economic, social, and environmental dimensions essential to sustainable agricultural systems and therefore provide an appropriate context for specific nutrient use efficiency indicators. Nutrient use efficiency appears on the surface to be a simple term. However, a meaningful and operational definition has considerable complexity due to the number of potential nutrient sources (soil, fertilizer, manure, atmosphere (aerial deposition), etc.), and the multitude of factors influencing crop nutrient demand (crop management, genetics, weather). The concept is further stressed by variation in intended use of nutrient use efficiency expressions and because those expressions are limited to data available rather than the data most appropriate to the interpretation.

Concept of fertilizer use efficiency

The term efficiency refers as amount of increased in yield of the harvested portion of the crop per unit of fertilizer nutrient applied, at which high productivity or yields are obtained. The concept related to nutrient use efficiency obviously implies nutrients that are specified to generate intended outcome. This can happen in deferent ways, which leads too many deferent versions of what nutrient use efficiency, actually means and how it can be improved. Generally, efficiency is the achievement of an intended or planned outcome with a lowest possible input of costs (yield per unit of nutrient supplied) and it has two components: the ability to extract nutrients from the soil (uptake efficiency) and the ability to convert the nutrients absorbed by the crop into grain (utilization or physiological efficiency). According to Mosier *et al*., (2004) nutrient use efficiency can be expressed in different aspects, they described four agronomic indices commonly used to describe nutrient use efficiency: partial factor productivity (PFP, kg crop yield per kg nutrient applied); agronomic efficiency (AE, kg crop yield increases per kg nutrient applied); apparent recovery efficiency (RE, kg nutrient taken up per kg nutrient applied); and physiological efficiency (PE, kg yield increase per kg nutrient taken up). Crop removal efficiency (removal of nutrient in harvested crop as % of nutrient applied) is also commonly used to explain nutrient efficiency, thereby available data and objectives determine which term best describes nutrient use efficiency.

According to Fixen, (2005) these different terms are provided through which it is with a good overview and with examples of how they might be practiced. A carefully well adjustment of nutrient and environment synchronization will increase the performance of a plant and increase competiveness. From this ecological and evolutionary point of view plants can be called nutrient efficient, if they use the temporal and spatial availability of nutrients for an optimal and balanced vegetative and reproductive growth, which is most suitable to survive and compete in their respective habitat and niche.

Aims of fertilizer use and fertilizer 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 and to increases or sustaining optimal crop yield. According to Mikkelsen *et al*., (2012) the most valuable nutrient use efficiency improvements are those contributing most to overall cropping system performance. Therefore, management practices that improve nutrient use efficiency without reducing productivity or the potential for future productivity increases are likely to be most valuable. If the pursuit of improved nutrient use efficiency impairs current or future productivity, the need for cropping fragile lands will likely increase. Fragile lands usually support systems with lower nutrient use efficiency and use water less efficiently. At the same time, as nutrient rates increase towards an optimum, productivity continues to increase but at a decreasing rate, and nutrient use efficiency 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.

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). According to Glenn *et al*., (2008) stated that predict food demand will double within 30 years equivalent to maintaining a proportional rate of increase of more than 2.4% per year. Improving nutrient use efficiency and improving water use efficiency have been listed among today’s most critical and daunting research issues (Thompson, 2012). Nutrient use efficiency is a critically important concept for evaluating crop production systems and can be greatly impacted by fertilizer management. Nutrient use efficiency indicates the potential for nutrient losses to the environment from cropping systems as managers strive to meet the increasing societal demand for food, fiber and fuel.

Latest Technologies for Fertilizer Use Efficiency

Improving fertilizer use efficiency through Genetic Improvement

Breeding and selecting crop cultivars that make more efficient use of water and fertilizer (including higher N fixation and N partition) while maintaining productivity and crop quality has been a long-term goal of production agriculture. Development of nitrogen-efficient cultivars could help decrease fertilizer N inputs and resulting reactive N losses to air and ground water. These nitrogen nutrient-efficient cultivars could also be useful in regions where limited-resource farmers are unable to afford synthetic nutrient fertilizers. Selection of nutrient efficient genotypes that is the varieties which can extract more nitrogen from soil at lower availability will enhance the production in area of poor livelihoods. Molecular and biotechnological approaches for searching for regulatory targets for manipulation of nutrient use efficiency are strengthened. Unraveling the details of nitrogen signal transduction to provide additional clues to improve nitrogen uptake and assimilation efficiency.

According Khoshgoftarmanesh *et al*., (2011) the case for breeding for greater nutrient efficiency has been argued strongly in the past. If breeding for improved nutrient use efficiency is to be successful, a number of conditions need to be met: (a) there needs to be useful genetic variation in nutrient use efficiency; (b) the genetic basis of the trait needs to be understood; and (c) appropriate selection criteria need to be defined, which often will require an understanding of the important physiological determinants of nutrient efficiency.

Improvement in the crops cultivars by introducing various quality traits responsible for effective nitrogen utilization may also enhance nutrient use efficiency. Some genotypes may produce different grain yields with the same amount of nitrogen uptake. According to Schmidt *et al*., (2002) differences in the efficiency of nitrogen acquisition may arise from (1) differences in the efficiency of absorption and assimilation of NH4+and other nitrogen species and their regulation; (2) the extent and distribution of roots, age of roots, and root induced changes in the rhizosphere affecting nitrogen mineralization, transformation, and transport (Ladha *et al*., 2003). So, proper understanding, identification and incorporation of these traits in various crops through various breeding approaches are also helpful in improving nitrogen use efficiency of crops.

Role of GIS and Remote Sensing in Fertilization

Remote sensing is the art and science of gathering information about the objects or area of the real world at a distance without coming into direct physical contact with the object under study. It is a tool to monitor the earth’s resources using space technologies in addition to ground observations for higher precision and accuracy. The principle behind remote sensing is the use of electromagnetic spectrum (visible, infrared and microwaves) for assessing the earth’s features and has several advantages in the field of agronomical research purpose. The assessment of agricultural crop canopies has provided valuable insights in the agronomic parameters. Remote sensing play a significant role in crop classification, crop monitoring and yield assessment.

The most important fields where we can choose for application of remote sensing and GIS through the application of precision farming are nutrient and water stress management. Detecting nutrient stresses by using remote sensing and GIS helps us in site specific nutrient management through which we can reduce the cost of cultivation as well as increase the fertilizer use efficiency for the crops. Under the conditions of wet tropical and subtropical climates, the risk of nitrogen leaching is more due to spatial variability of soil properties, such as: soil

Table 1: Effects of Different Source of Nutrient on Nitrogen Use Efficiency of Rice

Treatments	Grain yield(t/ha)			Nitrogen Use Efficiency	
	2009	2010	Mean	2009	2010
T1: 50%RDFN+cane trash vermicompost @ 2.5t/ha^{-1}	4.4	5.2	4.80	33.5	40.0
T2: 75% RDFN+ paddy straw Vermicompost @ 2.5t/ha^{-1}	4.8	5.5	5.15	38.4	42.9
T3: 50%RDFN+ paddy straw Vermicompost @ 2.5t/ha^{-1}	4.3	5.0	4.65	30.7	35.9
T4: 100% Chemical Fertilizers	4.6	4.8	4.70	33.1	34.0
T5: Control	2.8	2.4	2.60	-	-
CD (P= 0.05)	0.38	0.44	0.42		

Source: Rao *et al*., (2012).

Table 2: Impact of SPAD meter based nitrogen management on rice performance and nitrogen Recovery.

Treatment	N-rate (kg/ha)	Yield (t/ha)	Partial Factor Productivity
FFP	120.0	5.6	46
SPAD based SSNM	60.0	5.7	95

Source: Singh *et al*., (2012).

Table 3: Leaf color chart guided nitrogen management and its impact of nitrogen recovery efficiency.

Treatments	N applied(kg/ha)			Yield(t/ha)	AE_N
Applied time	Basal	21 DAS	42 DAS		
T1 (control)	0	0	0	0	4.95
T2	0	40	45	85	7.70
T3	30	40	45	115	8.43
LSD(0.05)					0.20

Singh *et al*., (2012) DAS= days after sowing.

organic matter content (Casa *et al*., 2011) water content (Delin and Berglund, 2005) and yield zones (Bramley, 2009) which are having effects on the nitrogen nutrition status of corn plants in the field. This causes the failure of traditional single-rate nitrogen fertilization (TSF) which could over-fertilize some sites while other sites may be under-fertilized. This promotes the use of variable-rate nitrogen fertilization (VRF) based on crop sensors which could increase the nitrogen fertilization efficiency (Li *et al*., 2010). Site-specific nitrogen management refers to the predetermination of appropriate, in terms of space and time, nitrogen prescriptions; in order to increase nitrogen use efficiency and diminish adverse environmental effects (White, 2012).

Real time monitoring of crop nutritional status and yield prediction using satellite; monitoring of crop condition is important to follow crop growth and development dynamics over time. This practice provides timely information that can help identify problem areas affected by various vegetative factors including water status, nutrient distribution and potential disease and weed advance which may manifest only in longer periods of time. In doing so field operations such as fertilizer application and pesticide recommendation can be adjusted in terms of timing and application rate to accommodate the different growth requirement of crops at distinct points of time throughout the growing period for enhanced agricultural productivity and food supply (Defourny *et al*., 2012). Crop nutrient demand is typically dynamic across different growth stages.

According to Wang *et al*., (2012) clearly showed that crop nitrogen status changed constantly over the entire growing period and fertilization strategies should respond to these changes. Crop dependence on nitrogen supply in natural soil is unrealistic as its availability is subjected to soil type, previous crop management and the climate at that particular time (Gastal, 2008). In addition, long-term monitoring records are needed for farmers to observe crop yield pattern and evaluate its sustainability against changing climatic condition, which alters the rainfall distribution and temperature variation from time to time (Defourny *et al*., 2012). Remote monitoring of crop condition and yield prediction can be achieved using satellite and aircraft platforms by combining their multiple image data with suitable process.

Optimizing nutrient use efficiency

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. Omission plot techniques are best methods to determine the amount of fertilizer required for attaining a yield target (Witt and Doberman, 2002). In this method, N, P, and K are applied at sufficiently high rates to ensure that yield is not limited by an insufficient supply of the added nutrients. Target yield can be determined from plots with unlimited NPK. One nutrient is omitted from the plots to determine a nutrient-limited yield. For example, an N omission plot receives no N, but sufficient P and K fertilizer to ensure that those nutrients are not limiting yield. The difference in grain yield between a fully fertilized plot and an N omission plot is the deficit between the crop demand for N and indigenous supply of N, which must be met by fertilizers.

Right time, greater synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for nitrogen. Split applications of nitrogen during the growing season, rather than a single, large application prior to planting, are known to be effective in increasing nitrogen use efficiency (Cassman *et al*., 2002). Right place, application method has always been critical in ensuring fertilizer nutrients are used efficiently. Determining the right placement is as important as determining the right application rate. Numerous placements are available, but most generally involve surface or sub-surface 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 to 20 cm deep. Applied at planting, nutrients can be banded with the seed, below the seed, or below and to the side of the seed. According to Dobermann, (2007) Nutrient Use Efficiency assessment is calculated through varies ways, of them the most common are:

Agronomic Efficiency of Applied Nutrient (AE) = (Y-Y0)/ F
Partial Factor Productivity of Applied Nutrient (PFP) = Y/F
Partial Nutrient Balance (Removal to Use Ratio) (PNB) = UH/F

Apparent crop Recovery Efficiency of Applied nutrient (RE) = (U-U0)/F: F – amount of nutrient applied (as fertilizers, manures, etc.); Y – yield of harvested portion

Table 4: Effects of the integrated use of organic and inorganic fertilizers on grain yield and thousand seed weight of barley

Treatments	Grain Yield(kg ha^{-1})			Thousand Seed weight(g)		
	2015	2016	Mean	2015	2016	Mean
Recommended NP	3396	1566	2481	45.24	45.23	45.24
Conventional compost(N equivalency)	3502	1563	2533	45.62	45.60	45.61
Farmyard manure(N equivalency)	3276	571	1924	42.89	42.87	42.88
Vermicompost(N equivalency)	3405	1007	2206	45.85	45.83	45.84
50:50% Vermicompost: Conventional compost	3394	1086	2240	45.38	45.37	45.38
50:50% Vermicompost: Farmyard manure	3339	666	2003	43.32	43.3	43.31
33:33:33% Vermicompost: Conventional compost: Farmyard manure	3377	559	2118	42.62	42.6	42.61
50:50% Vermicompost: recommended NP	3547	1551	2549	43.99	43.97	43.98
50:50% Conventional compost: recommended NP	3634	1504	2567	43.86	43.87	43.87
50:50% Farmyard manure recommended NP	3372	1178	2275	42.46	42.47	42.47
LSD(0.05)	NS	524	382.68	NS	NS	2.409
CV (%)	9.77	26.46	14.39	5.28	5.37	4.7

Source: Olesen *et al*., (2004): Ns=non significantly different at 5% probability level.

Table 5: Some available methods of enhancing efficiency fertilizers.

Chemical or Compound	Process Affected
Nitrogen Products*	
Dicyandiamide (DCD)	Nitrification
2-chloro-6 (trichloromethyl) pyridine (Nitrapyrin)	Nitrification
N-butyl-thiophosphoric triamide (NBPT)	N volatilization
Malic+ itaconic acid co-polymer with urea	Nitrification, N volatilization
Polymer-coated urea (PCU)	N release
Sulfur-coated urea (SCU)	N release
Polymer + SCU	N release
Urea formaldehyde	N release
NBPT + DCD	Nitrification, N volatilization
Methylene urea + triazone	N release
Triazone + NBPT	N release, volatilization
Phosphorus Products	
Malic +itaconic acid co-polymer with MAP	Decrease mineral precipitation

Source: Merino *et al.,* (2002).

Table 6: Effect of Nutrient Use Efficiency on Wheat.

Treatments	Recovery Efficiency (%)			Agronomic efficiency (kg grain/kg nutrient applied)			Grain yield(Q/ha)
	N	P	K	N	P	K	
Control	0	0	0	0	0	0	12
50%RDP	83.2	32.3	340.5	33	83	125	37
100%RDP	61.6	32.8	218.0	22	55	83	45
125%RDP	45.7	27.3	184.7	19	48	72	48
50% RDP+NM	104.8	43.3	380.5	39	97	145	41
100% RDP+NM	42.5	22.7	153.0	19	47	70	40
CD(P=0.05)				14.4	3.4	13.4	5

Source: Kumar *et al*., (2014)

Table 7: Effect of balanced fertilizers on ANUE and NRE

Treatments	Nutrient applied (kg ha $^{-1}$)	Yield (kg ha -1)	ANUE(kg ha 1)	ANR %
Control	0	1450		
RNP	84.1	3800	28.0	243.3
50 NPS	21.3	2330	41.3	279.0
100NPS	42.6	2960	35.5	290.7
150NPS	63.9	3330	29.4	338.4
200 NPS	85.2	4430	35.0	326.6
250 NPS	106.5	4330	27.1	246.1
50 NPSB	20.3	2200	37.0	377.7
100NPSB	40.6	3180	42.7	314.6
150 NPSB	57.5	3590	37.2	376.8
200 NPSB	81.1	4900	42.5	339.6
250 NPSB	84.1	3800	28.0	243.3

Source: Melkamu *et al*., (2019) Where: ANUE: agronomic nutrient use efficiency, ANR: apparent nutrient recovery and RNP: Recommended nitrogen and phosphorous

of crop with applied nutrient; Y0 – yield in control with no applied nutrient; UH – nutrient content of harvested portion of crop; U – total nutrient uptake in aboveground crop biomass with nutrient applied; U0 – total nutrient uptake in aboveground crop biomass with no nutrient applied.

Factors affecting fertilizer use efficiency

Fertilizer Use Efficiency is a dynamic and complex concept, affected by a number of factors, can be classified into three groups namely factors related to crop fertilizer demand, factors controlling the fertilizer supply to the plants and factors controlling the losses of nitrogen from soil-plant system.

Crop demands for nutrients

Climatic variables i.e. ambient temperature, solar budget, amount of rainfall and relative humidity are the important external factors influencing crop health as well as its demand for nutrient (Hutchinson *et al*., 2003). How the above-mentioned variables and their interactions are going to affect the performance of any crop or cropping sequence greatly relied on the agro-climatic conditions of the region where the crop is grown (Kravchecko *et al*., 2003). The difference in these factors due to seasonal variation will influence the crop growth and yield i.e. variations in solar budget between summer and cold seasons lead to significant differences in rice and maize yield (Mosier *et al*., 2001).

Factors for nutrient supply

Mineralization of nitrogen from soil organic matter and externally applied nitrogen through chemical fertilizers are two important sources to meet nitrogen requirements of plants. Contribution of soil organic matter towards nitrogen supply to the plants is relatively less due to slow rate of mineralization of nitrogen from this source while supply through fertilizer is larger because of their direct availability in simple compounds realized at higher rate of mineralization. The rate nitrogen mineralization of soil is largely influenced by the factors i.e. available moisture, temperature, aeration status and microbial activity. For example, low soil moisture with mild soil temperature can reduce the rate of nitrogen mineralization from organic sources (Giller *et al*., 2004).

Factors for nitrogen fertilizer losses

Nitrogen Use Efficiency is also influenced by different types of losses associated with soil plant system. Though, optimum conditions for plant growth and development can increase plant nitrogen demand but due to large nitrogen losses demand may not be met out, resulting in low recovery of applied nitrogen. Gaseous loss of nitrogen to the atmosphere and leaching of nitrogen beyond the root zone of crops are principle factor responsible for lower nitrogen use efficiency in production system (Mosier *et al*., 2001).

Fertilizer Use Efficiency Strategies

Nitrogen use efficiency strategies

Among all the plant nutrients essential for crop growth, nitrogen is the nutrient which most often limits crop production (Mosier *et al*., 2001). Nitrogen has a unique place in crop production system just because of its large requirement as it has critical role in almost all metabolic activities of plants and its heavy losses associated with soil-plant systems (Ladha *et al*., 2003). To fulfill this large nitrogen requirement of crop plants, globally farmers using around 120 million metric tons of nitrogenous fertilizer each year (FAO, 2014). Farmer needs to apply huge amount of nitrogen fertilizer in agricultural crops because of its lower recovery (3050%) due to its various losses from soil-plant system (Fageria, 2002). Nitrogen is universally deficient in almost all the agricultural soils and cropping systems of the world so, it is essential to use external nitrogen inputs (N fertilizers) to produce the crops for satisfying the ever-increasing demands of human populations (Mohan *et al*., 2015). Though N2 gas shared about 78 % gaseous composition of the atmosphere, but crop plants can’t able to use this element as such unless it is transformed into plant usable forms (Barbieri *et al*., 2000). The concept of nitrogen-use efficiency has been widely used to characterize plant responses to different levels of nitrogen availability. It is important to distinguish the concept of nitrogen-use efficiency and the nitrogen-use efficiency as a phenotypic trait. Several definitions and evaluation methods have been suggested (Fageria *et al*. 2008).

Improved strategies for improving nitrogen use efficiency

Nitrogen recovery can be improved through adoption of locally as well as scientifically available means of nitrogen management to ensure efficient use of agricultural inputs (chemical fertilizers, land, water, and crops) that will enhance beneficial use of N in crops and minimize its losses. Strategies or practices used for nitrogen management of crops should be focused on two core principles (1) either it enhance beneficial use of externally applied fertilizer nitrogen as well as native soil nitrogen during the growing season itself (2) either it conserve soil nitrogen by reducing the quantum of nitrogen losses through various mechanisms and ensure higher beneficial use of this conserved nitrogen by the subsequent grown crops of the production system (Balasubramanian et al., 2002).Various strategies based on above discussed approach for improving nitrogen use efficiency will be discussed below:

A. Site specific nitrogen management (SSNM)

Site specific nitrogen management is a concept which involves field specific management nitrogen strategies that includes quantitative knowledge of field specific variability in crop nitrogen requirement and expected soil N supplying power. The fundamental underlying assumption of this concept is to establish an optimum synchronization between supply and demand of nitrogen for plant growth (Giller *et al*., 2004). On the basis of when and what type of decisions are made, site specific nitrogen management can be grouped in two categories, prescriptive SSNM, (2) corrective SSNM (Dobermann *et al*., 2004).

In former approach of Nitrogen management, the amount and its application time are analyzed prior to sowing based on nitrogen supplying power of the soil, expected crop nitrogen requirement for assumed yield target, expected nutrient efficiency of fertilizer products in use. Contrast to this, corrective nitrogen management strategy involves use of diagnostic tools to assess nitrogen status of standing crop. The interpretation of these recorded data is serving as the basis for decisions about timing and quantity of N applications (Schroeder *et al*., 2000). Chlorophyll meters, nutrient expert and leaf color charts (LCC) are the promising and gaining importance in recent years for corrective nitrogen management in cereals. Using some form of field diagnostic, such as intensive soil sampling, soil sensing, aerial imagery, or yield mapping. Some or all of these measurements can be used to divide fields into management zones or units that can be fertilized independently (Koch *et al*., 2004).

Chlorophyll Meter: Nitrogen status of crops can be estimated through chlorophyll meter since most of plant nitrogen is found in chloroplasts hence, it is closely related to leaf chlorophyll content (Olesen *et al.*, 2004). To quantify nitrogen status of crops the Soil plant analysis development (SPAD) differently known as chlorophyll meter offers relative measurements of leaf chlorophyll content. Chlorophyll meters are able to self-calibrate for different soils, seasons, and 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). Soil plant analysis development meter-based site-specific nitrogen management approach has been extensively demonstrated in Southwest Asia (China, India and Bangladesh). According to Dobermann *et al.*, (2004) reported that compared with traditional local nitrogen management practices, soil plant analysis development meter-based site-specific nitrogen management in rice crop can increases yield, return and net return to the tune of 7, 30, and 12% respectively.

Leaf Color Chart: Leaf color chart is a diagnostic tool which can help farmers for making appropriate decisions regarding the need for nitrogen fertilizer applications in standing crops. Conventionally, farmers use eye observations to know the crop nutrient status particularly nitrogen. The leaf color chart can act as a plant health indicator diagnostic tool particularly to optimize the nitrogen supply of rice based cropping systems. The leaf color chart is economical and easy to use diagnostic tool for precise nitrogen management especially in rice-wheat cropping system. 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. In China, leaf color chart guided nitrogen management in hybrid rice by a group of 107 farmers has been resulted in 25% saving of nitrogen fertilizer without compromising crop yield (Singh *et al.*, 2012).

Simple leaf color chart is a simple tool which is a proxy or agent for leaf Nitrogen is used as an indicator of leaf color, intensity and leaf nitrogen status, and the time at which (right time) of its application According to Singh *et al.*, (2012) reported the critical value for semi dwarf high yielding varieties is 4.0, if the average value fall below 4.0, top dressing nitrogen fertilizer (20-30kg/ha) to correct the deficiency of nitrogen.

B. Integrated nitrogen management (INM)

Integrated nitrogen management involves optimum use of indigenous N components i.e. crop residues, organic manure, biological nitrogen fixation as well as chemical fertilizer and their complementary interactions to increases nitrogen recovery (Olesen *et al.*, 2004). The positive effects of the integrated use of organic and inorganic nitrogen 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 nitrogen use efficiency of applied nitrogen (Aulakh and Malhi, 2004). The complementary interaction of nitrogen with secondary and several micronutrients could lead to considerable improvements in yield and nitrogen use efficiency.

C. Technologies enhanced nitrogen fertilizer use efficiency

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 philosophy either they can slow the release rate of nutrients or can interfere with nutrient transformation processes and reduce their losses. Slow/controlled release nitrogen fertilizers and nitrogen inhibitors are two important classes of fertilizers.

Nitrification inhibitors

This includes products such as nitrapyrin and dicyandiamide. NH_4^+ ion can be adsorbed on soil colloids and retained for a longer period which provides an opportunity for higher nitrogen use efficiency by minimizing leaching and de-nitrification losses of applied nitrogen. Addition of nitrification inhibitors can check conversion of ammonium- nitrogen into nitrate- nitrogen and ensure higher concentration of ammonical form of nitrogen in soil medium, to increase nitrogen use efficiency and crop yield. Dicyandiamide (DCD), a commercially available and largely demonstrated nitrification inhibitor suitable for use in rice cultivation (Bharti *et al.*, 2000). These products suppress Nitrosomonus bacteria in the soil (with different degrees of effectiveness) by slowing or stopping the conversion of ammonium to nitrite. The inhibitors break down over periods of days to months, depending on temperature and moisture conditions. The methods indicates that, nitrification inhibitors is when applied to soils in conjunction with nitrogen fertilizers or animal wastes, have beneficial effects on reducing nitrate leaching and nitrous oxides emissions, and as a result increasing plant growth resulted in increasing nitrogen use efficiency (Merino et al.,2002).

Urease inhibitors

N-(n-butyl) thiophosphoric triamide (NBPT) and ammonium thiosulfate (ATS). NBPT blocks the function of the urease enzyme, preventing formation of NH4+ from urea. This reduces the potential for ammonia volatilization allowing time for rain or irrigation to move urea into the soil. NBPT breaks down over periods of days to weeks, depending on temperature and moisture conditions. ATS has shown short term effects on urease inhibition. According to Webb, (2001) shows that fertilizer urea can be less efficient that means lower plant yield per unit nitrogen applied. The major reason for this is that the soil pH in the vicinity of urea granules increases as results of hydrolysis, facilitating the volatilization of ammonia to the atmosphere. Urea can damage seedlings and inhibit germination because of the accumulation of high concentrations of NH_4^+ (Watson, 2000). By slowing the rate of hydrolysis, nBPT can reduce this effect (Malhi *et al.*, 2003).

Slow release N fertilizers

These products fall into two broad categories: coatings and chemical formulations. Coatings physically slow down dissolution and in some cases influence chemical properties near the fertilizer granule. The form of applied nitrogenous fertilizers has significant role in controlling various nitrogen losses hence, affecting nitrogen availability and recovery. The chemical formulation include different elements in the fertilizer product which decrease the solubility or conversion of the material to N forms that then are converted in the N cycle. Compare to amide and ammoniums containing nitrogen 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. In the above both cases, the intent is to match the supply of N from fertilizer to crop N demand. A range of slow release fertilizers is now marketed which have the potential to reduce various nitrogen losses and improve nitrogen use efficiency (Giller *et al*., 2004). These compounds can reduce nitrogen losses due to their potential to delayed nitrogen release pattern which may improve the synchronization between crop demand and that of soil nitrogen supply. Neem coated urea is widely used and demonstrated slow release nitrogen fertilizer in India. But, still controlled release fertilizer is accounted only 0.15% of the total nitrogen 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).

For coated products, sulfur or polymer coatings can be applied to soluble fertilizer. Sulfur-coated urea (SCU) has been available for many years but is not widely used due to cost. The sulfur coating slowly breaks down allowing water into the granule which dissolves the urea. The release rate for polymer-coated urea (PCU) is determined by the polymer chemistry, coating thickness, coating process and temperature. This release can be highly controlled and can be designed to match plant uptake. Fertilizer is released by diffusion through the coating. Different chemical formulations include urea formaldehyde and methylene urea which are mixtures of urea and methyl-urea chains of various lengths. These can be formulated in either solid or liquid products. The N release characteristics are controlled by the chain length.

Technology for enhance Phosphorus use efficiency

Polymer coatings slow the release of P from the fertilizer and are designed to increase P use efficiency. The effectiveness depends on the thickness of the polymer coating and temperature, but can vary with soil type and moisture. Coated P may extend P availability into the second year after application. Young corn plants take up half of their P when they have only accumulated a quarter of their growth. Slow release P products would need to provide enough P during this critical time. Another technology claimed to improve P availability is Avail® (common product name). It includes the addition of high capacity exchange resins or polymers which bind cations from the soil solution and hinder the formation of less soluble phosphates which is purported to maintain P locally in a more plant-available form. These polymers are organic molecules which can be influenced by soil micro-organisms, moisture and temperature. Avail® can be added to either dry or liquid fertilizers at the manufacturing plant or distribution location.

D. Improved method of nitrogen application

Among the various methods of nitrogen application, deep placement, use of super granules and foliar spray of nitrogen fertilizer can enhance the recovery of applied nitrogen fertilizer. Broadcasting of nitrogen fertilizers is very common practice leads to large nitrogen losses e.g. ammonia volatilization, results in lower nitrogen recovery (McBratney *et al*., 2003). Use of modified form of nitrogen fertilizer (urea super-granules) and deep placement of urea based fertilizers has been reported to enhance nitrogen use efficiency. At Australia, from large scale demonstration it has been reported that recovery efficiency was 37% for broadcasting and 49% for deep placement in rice; hence deep placement of fertilizers can improve nitrogen recovery (Balasubramanian *et al*., 2002). Placement of urea with mud balls technique in the reduced zone of transplanted puddled rice field also improves nitrogen recovery and gave better crop output (Schmidt *et al*., 2002). Further, foliar feeding of nitrogen either through urea spray, can also improve nitrogen use efficiency 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. 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, analyze 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 nitrogen and application of right amount of nitrogen 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 nitrogen use efficiency under specific conditions of each field. Remote or local nitrogen sensors can be used in sophisticated management approaches to assess crop needs for supplemental nitrogen (Schmidt *et al*., 2002). These practices include the timely and precise application of nitrogen fertilizer to meet plant needs varying across the landscape.

Phosphorous use efficiency

Phosphorus is an important element for crop production and it is deficient in most agricultural soils all over the world (FAO, 2000). Most of the phosphorus accumulated in cereal crops and grain legumes is in the grain and it is depleted from crop fields through continuous crop harvests (Sanchez *et al*., 1996).

Among the different types of phosphorus fertilizers known so far, high analysis fertilizers such as diammonium phosphate (DAP) have become very popular, especially in developing countries which depend on importing fertilizers

(Lu *et al.*, 1987). In Ethiopia, for instance DAP is the popular fertilizer source of phosphorus that has been imported and used regularly analytical grade selection among the various phosphorus source fertilizers tested at on-farm fertilizer trials through the fertilizer program of the Freedom From Hanger Campaign (FFHC) (Mengesha, 1999). Phosphorus (P) is classified as the second most important element for crop production. It is known to be involved in many physiological and biological processes of plants (Tisdale *et al*., 2002). It is a component of adenosine diphosphate (ADP) and adenosine triphosphate (ATP), the two compounds involved in most significant energy transformations in plants. Adenosine triphosphate, synthesized from ADP through respiration, contains a high energy phosphate group that drives most biochemical processes requiring energy. The uptake of some nutrients and their transport within the plant as well as the synthesis of new molecules, are energy-using processes that ATP helps to implement (Tisdale *et al.*, 2002).

Phosphorus has very useful effect on cell division and albumen formation, flowering and fruiting including seed formation and crop maturation. It also enhances root development and strengthening of straw of cereal crops and helps to prevent lodging and improve the quality of crops (FAO, 1984). Phosphorus storage occurs in seeds to prepare them for germination and early growth prior to extensive root development. Early tillering under phosphorus fertilization was significantly higher when plants developed both root systems than only primary or adventitious (Annioux, 1996). Phosphorus is present in plants in various concentrations depending on types of species, age and the nature of plant tissues (Russell, 2002). The largest amount of phosphorus is found in seed and fruit part of the plant (Brady and Weil, 2002). From the total phosphorus taken up by biomass of wheat at 40 kg P/ha, the level where maximum grain yield was produced, 75% was found in grain (Gurmessa, 2002).

According to Tisdale *et al*., (2002) reported there are many methods of fertilizer placement, among which they reviewed only five popular ones. These are broadcast, point placement at a side, applying with the seed, side drilling and banding methods. However, in Ethiopia where cropping involves the use of rudimentary farm implements, and hand application of fertilizers, only three of these methods of fertilizer placements; broadcasting, row drilling and point application, are known so for. In all placement cases, care should be taken to avoid contact between the fertilizer and the seed or the plant. When used by machines, disastrous results have been reported because of poor adjustment of equipment (Tisdale *et al*., 2002). According to Syers *et al.*, (2008) recently proposed that the balance method be used to assess fertilizer efficiency, Phosphorus use efficiency also calculated according to the following equation:

$$PR(\%) = \frac{\text{P taken up by crop (fertilized soil} - \text{P taken up by crop(unfertilized soil}}{\text{Amount of phosphorous applied}}\text{x100}$$

Measures of fertilizer use efficiency assessment

An excellent review of nutrient use efficiency measurements and calculations was written by (Dobermann, 2007). Nutrient use efficiency can be assessed by many different ways, of them the following are the major ones.

Partial factor productivity (PFP)

Partial factor productivity (PFP) is a simple production efficiency expression, calculated in units of crop yield per unit of nutrient applied. It is easily calculated for any farm that keeps records of inputs and yields. It can also be calculated at the regional and national level, provided reliable statistics on input use and crop yields are available. However, partial factor productivity values vary among crops in different cropping systems, because crops differ in their nutrient and water needs.

Agronomic efficiency (AE)

Agronomic efficiency is calculated in units of yield increase per unit of nutrient applied. It more closely reflects the direct production impact of an applied fertilizer and relates directly to economic return. The calculation of AE requires knowledge of yield without nutrient input, so is only known when research plots with zero nutrient input have been implemented on the farm. If it is calculated using data from annual trials rather than long-term trials, nutrient use efficiency of the applied fertilizer is often underestimated because of residual effects of the application on future crops. Estimating long-term contribution of fertilizer to crop yield requires long-term trials.

Partial nutrient balance (PNB)

Partial nutrient balance is the simplest form of nutrient recovery efficiency, usually expressed as nutrient output per unit of nutrient input (a ratio of "removal to use"). Less frequently it is reported as "output minus input." PNB can be measured or estimated by crop producers as well as at the regional or national level. Often the assumption is made that a PNB close to 1 suggests that soil fertility will be sustained at a steady state. However, since the balance calculation is a partial balance and nutrient removal by processes, such as erosion and leaching are usually not included, using a PNB of 1 as an indicator of soil fertility sustainability can be misleading, particularly in regions with very low indigenous soil fertility and low inputs and production, such as Sub-Saharan Africa. Also, all nutrient inputs are rarely included in the balance calculations, thus the modifier, partial, in the term. Biological N fixation, recoverable manure nutrients, biosolids, irrigation water, and the atmosphere can all be nutrient sources in addition to fertilizer.

Values well below 1, where nutrient inputs far exceed nutrient removal, might suggest avoidable nutrient losses and thus the need for improved nutrient use efficiency (Snyder and Bruulsema, 2007). A PNB greater than 1 means more nutrients are removed with the harvested crop than applied by fertilizer and/or manure, a situation equivalent to "soil mining" of nutrients. This situation may be desired if available nutrient contents in the soil are known to be higher than recommended. However, in cases where soil nutrient concentration is at or below recommended levels, a PNB >1 must be regarded as unsustainable (Brentrup and Palliere, 2010).

Physiological efficiency (PE)

Physiological efficiency (PE) is defined as the yield increase in relation to the increase in crop uptake of the nutrient in above-ground parts of the plant. Like AE and RE, it needs a plot without application of the nutrient of interest to be implemented on the site. It also requires measurement of nutrient concentrations in the crop and is mainly measured and used in research.

Conclusion and recommendation

An adequate and balanced supply of essential nutrients is a basis of improvements in crop productivity. Nutrient efficiency will become increasingly important in the future as farmers strive to achieve higher levels of productivity and maintain profitable enterprises in the face of increasing fertilizer prices and under the influence of a changing climate. The strategies to improve nutrient use efficiency will differ depending on past nutrient management practices. In areas where depleted in soil fertility and the crops are continually suffered for an undernourishment, increases in soil fertility through soil improvement and fertilizer use will support increases in productivity, while in areas where fertilizer has been applied in excess of the crops requirements, better use of the soil nutrient bank and a more sustainable use of fertilizer will be needed. In both cases, breeding for improved nutrient use efficiency can play an important role in increasing the nutrient use efficiency of the system, although the specific breeding objectives to achieve this may differ. Selection of nutrient efficient genotypes that is the varieties which can extract more nutrients from soil at lower availability will enhance the production of the crops.

The other mechanisms through which increasing nutrient use efficiency is by using the 4R Nutrient Stewardship concept, applying the right source of nutrients, at the right rate, at the right time and in the right place. Right source means matching the fertilizer to the crop need and soil properties. Right rate means matching the fertilizer applied to the crop at optimum dose needed. Right time means making fertilizer nutrients available to the crop when they are needed. Right place means making every effort to keep nutrients where crops can use them. Nutrient use efficiency can be increased significantly when their availability is synchronized with crop demand. This is an issue which poses the greatest challenge in small holder agricultural systems, where most fertilizer is broadcast applied, and in many cases without incorporation. Research indicates that fertilizer placement can not only improve crop response, but also improve fertilizer use efficiency significantly by lowering nutrient application rates with synchronizing crop demand.

As a recommendation, most crops are location and season specific depending on cultivar, management practices, climate, etc. so there is the problem over or under application of nutrients will result in reduced nutrient use efficiency or losses in yield and crop quality. To reduce this problem, the most powerful tools available for determining the nutrient supplying capacity of the soil is soil testing and awareness creation for farmers and development agents contributes for yield increment. In general how they apply the 4Rs that is right source, right rate, right time and right place of best management practices (BMP). Over- or under-application will result in reduced nutrient use efficiency or losses in yield and crop quality.

Nutrient use efficiency has influenced by many factors, majorly lack of specific genetic modified crops for nutrient use efficiency, in order to address this, in my suggestion specifically, gene for nutrient use efficiency should be exploited through biotechnology and molecular approaches, that is searching and manipulation should be to improve the genetic makeup of the crops towards nutrient use efficiency.

The other one is applying improved technology like remote sensing and GIS is very important for farmers, because to decide site- specific nutrient management and water stress management, in turn it increases fertilizer use efficiency of the crops. The main concepts that I recommends our farmers is using of best practices that comprises the 4Rs stewardship approaches, because it play a great role in the nutrient use efficiency of the crops, for achieving maximum production and optimum nutrient efficiency by using selection of right source, rate, time and place.

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