**Improvement of nutrient use efficiency: conventional to modern approach**

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**ABSTRACT**

The fertilizer industry, as well as agriculture in general, faces the fundamental challenge of improving nutrient efficiency. Modern crop production systems require efficient nutrient management practices to increase the long-term sustainability. Optimum use of nutrient inputs (fertilizers) by crops is essential for sustainable agricultural production. With increasing world demands for food and energy, this is set to become an ever-increasing priority. Fertilizers are costly inputs and their unbalanced usage cause several environmental problems. There is an absolute requirement to maximize the efficiency of fertilizers through agronomic and plant breeding approaches. Nutrient use efficiency is defined as the yield obtained per unit of fertilizer input or in terms of recovery of fertilizer applied. Therefore, the improvement in yields must be matched by the appropriate increase in nutrient uptake as the yields are improved at the expense of mineral nutrient content. Several complex processes contribute to the overall nutrient use efficiency, and all are multigenic and developmentally and environmentally modulated. Multidisciplinary approaches involving traditional breeding and biotechnology can help improve the situation in the future. Therefore, this chapter provides a brief knowledge about various approaches to enhance the nutrient use efficiency by crops.

Keywords- Nutrient use efficiency, sustainable agricultural production, long-term sustainability.

**INTRODUCTION**

It is a global issue to meet societal food demands as it has been predicted that food demands worldwide would rise by 100–110% between 2005 and 2050 (Tilman et al., 2011). Some have predicted that food demand will double within 30 years (Glenn et al., 2008), which equates to maintaining a proportional rate of increase of more than 2.4% per year, while some have predicted that the world will need 60% more cereal production between 2000 and 2050 (FAO, 2009). It is extremely difficult to supply such demand sustainably, particularly considering historical grain yield trends that have been linear for nearly 50 years with slopes of only 1.2 to 1.3% of 2007 yields (FAO, 2009). For more than a century, mineral fertilizers have sustained worldwide agriculture, thus global population and prosperity (Smil, 2001; Stewart et al., 2005). Fertilizers are crucial in ensuring the production of food crops all over the world. In fact, it is believed that fertilizers today contribute to the 40–60% of the world's crop production. (Johnston and Bruulsema, 2014). Their contribution to boosting agricultural yields has prevented the conversion of millions of hectares of natural ecosystems to farmland (Balmford et al., 2005). The use of nutrients in agricultural systems that is insufficient, unbalanced, improper, or excessive is still a concern. Low agricultural yields in regions of the developing world are mostly due to nutrient mining. In other cases, the management techniques employed fail to achieve excellent congruence between nutrient supply and crop nutrient demand, causing nutrients such as nitrogen (N) and phosphorus (P) to frequently travel outside the boundaries of the agricultural field (van Noordwijk and Cadisch, 2002). Such losses could result in severe consequences if they go unchecked (Mosier et al., 2001). Consequently, improving fertilizer use efficiency remains a significant problem for global agriculture. This chapter aims to provide an overview of different approaches that has been utilized and advanced for the enhancement of nutrient (mineral fertilizers) use efficiency.

**CONCEPT OF NUTRIENT USE EFFICIENCY**

Multiple mineral nutrients are required by crops for growth, and a limitation in any may impair yields and nutritional quality. In intensive cropping systems fertilization with major macronutrients such as nitrogen to maximize yield is followed routinely, and in all agricultural systems replenishment of the soil with minerals mined by the crops is required for sustainability. Specific fertilization with micronutrients may be required depending upon underlying soil types and geology, both for optimal crop growth and to supply healthy products for human and animal nutrition; this particularly applies to micronutrients such as Fe, Zn and Se. Application of fertilizers is a major cost, both to the agricultural industry in terms of financial costs for production and transport, and also to society in terms of the carbon footprint and as potential watercourse and atmospheric pollutants. Maximum fertilizer use efficiency is therefore both environmentally and economically essential. It has been estimated that nitrogen use efficiency worldwide for cereals is only 33% (Raun and Johnson, 1999), indicative of a huge waste of resources. Some major nutrients are a nonrenewable resource as for example, there are finite limits on minable rock phosphate reserves (Cordell et al., 2009; Hawkesford, 2012)

Nutrient use efficiency (NUE) is a critically important concept in the evaluation of crop production systems. It can be greatly impacted by fertilizer management as well as by soil- and plant-water management. The basic 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. NUE addresses some, but not all, aspects of that performance. Therefore, system optimization goals necessarily include overall productivity as well as NUE. The most appropriate expression of NUE is determined by the question being asked and often by the spatial or temporal scale of interest for which reliable data are available.

Global temporal trends in NUE vary by region. For N, P and K, partial nutrient balance (ratio of nutrients removed by crop harvest to fertilizer nutrients applied) and partial factor productivity (crop production per unit of nutrient applied) for Africa, North America, Europe, and the EU-15 are trending upwards, while in Latin America, India, and China they are trending downwards. Though these global regions can be divided into two groups based on temporal trends, great variability exists in factors behind the trends within each group. Numerous management and environmental factors, including plant water status, interact to influence NUE (Fixen et. al, 2015*).*

Sustainable nutrient management must therefore, be both efficient and effective to deliver anticipated economic, social, and environmental benefits.

Providing society with a sufficient quantity and quality of food at an affordable price requires that costs of production remain relatively low while productivity must increase to meet the projected demand. Therefore, both productivity and NUE must increase. These factors have spurred efforts by the fertilizer industry to promote approaches for best management practices for the efficient utilization of fertilizers. These approaches consider economic, social, and environmental dimensions essential to sustainable agricultural systems and therefore, provide an appropriate context for specific NUE indicators. NUE 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 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 NUE expressions and because these expressions are limited to data available rather than the data most appropriate for interpretation (Fixen et. al, 2015).

**THE OBJECTIVE OF NUTRIENT USE AND NUTRIENT USE EFFICIENCY**

The goal of nutrient use is to improve the cropping system performance by providing economically optimal nourishment to the crop along with minimized nutrient losses from the field and sustaining the agricultural system by contributing to soil fertility or other soil quality components. Some of these aspects are addressed by NUE, but not the whole (Mikkelsen et al., 2012). The most beneficial improvements of NUE are those that contribute the most to the overall cropping system performance. Therefore, the most beneficial management practices are probably those that boost NUE without decreasing the productivity or the possibility for future productivity increases. The need for cropping fragile lands will probably rise if the quest of improved NUE reduces present or future productivity. Typically, fragile lands support less efficient water usage and lower NUE systems. Likewise, productivity continues to rise but at a slower rate, and NUE typically decreases as the nutrient rates rise towards an optimum (Barbieri et al., 2008). The magnitude of the decline will be determined by source, time, and place factors, as well as other cultural practices and soil and climatic conditions. Table 1 depicts common NUE terms, as defined by Dobermann (2007) along with their applications and limitations. The primary question addressed by each term and the most typical use of the term are also listed.

**Table 1. Common NUE terms and their application (after Dobermann, 2007).**

|  |  |  |  |
| --- | --- | --- | --- |
| Term | Calculation | Question addressed | Typical use |
| Partial factorproductivity | PFP = Y/F | How productive is this cropping system in comparison to its nutrient input? | As a long-term indicator of trends. |
| Agronomicefficiency\*\* | AE = (Y-Y0)/F | How much productivity improvement was gained by use of nutrient input? | As a short-term indicator of the impact of applied nutrients on productivity. Also used as input data for nutrient recommendations based on omission plot yields. |
| Partial nutrientbalance | PNB = UH/F | How much nutrient is being taken out of the system in relation to how much is applied? | As a long-term indicator of trends; most useful when combined with soil fertility information |
| Apparentrecoveryefficiency bydifference\*\* | RE = (U-U0)/F | How much of the nutrient applied did the plant take up? | As an indicator of the potential for nutrient loss from the cropping system and to access the efficiency of management practices. |
| Internalutilizationefficiency | IE = Y/U | What is the ability of the plant to transform nutrients acquired from all sources into economic yield (grain, etc.) | To evaluate genotypes in breeding programs; values of 30-90 are common for N in cereals and 55-65 considered optimal. |
| Physiologicalefficiency\*\* | PE = (Y-Y0)/(U-U0) | What is the ability of the plant to transform nutrients acquired from the source applied into economic yield? | Research evaluating NUE among cultivars and other cultural practices; values of 40-60 are common. |

Here, Y = Yield of harvested portion of crop with nutrient applied; Y0 = Yield with no nutrient applied; F = Amount of nutrient applied; UH = Nutrient content of harvested portion of the crop; U = Total nutrient uptake in aboveground crop biomass with nutrient applied; U0 = nutrient uptake in aboveground crop biomass with no nutrient applied; Units are not shown in the table since the expressions are ratios on a mass basis and are therefore unitless in their standard form. P and K can either be expressed on an elemental basis (most common in scientific literature) or on an oxide basis as P2O5 or K2O (most common with in industry).

\*\* Short-term omission plots often lead to an underestimation of the long-term AE, RE or PE due to residual effects of nutrient application.

**The cause for low NUE and declining response to nutrient fertilizers can be grouped as follows (NAAS, 2005)**

1. Low nutrient supply and soil fertility are the main causes of low NUE. There may be various possible reason behind this like, susceptibility of nutrient fertilizers to losses by various mechanisms. imbalanced use of fertilizers, poor management of secondary nutrients and micronutrients, fertilizer application in inappropriate rate, time and method etc. Low soil organic carbon status due to high acidity, salinity, sodicity, water logging also causes decrement of soil fertility.

2. Agronomical practicesalways play a crucial role in nutrient uptake and in their efficient use by the plant.Delayed sowings/plantings, poor weed management, inefficient irrigation management, large scale monoculture and non-inclusion of legumes in cropping systems, inadequate plant protection, lack of more efficient nutrient using genotypes, lack of HYVs at affordable price and at the right time etc. are some example of practices through which NUE decreases.

**CONVENTIONAL APPROACH TO ENHANCE FERTILIZER USE EFFICIENCY (FUE)**

With time, various efforts have been made for increasing the FUE. According to XIANG et al. 2008,the commonly used measures to increase the FUE in agricultural systems are described as follows:

1. **Right rate**: When the level of nutrient fertilizer application is low, the crop yield will increase with increasing amount of fertilizer. When the amount of fertilizer exceeds a certain limit, the crop yield starts decreasing. At the same time, nutrient loss will increase with the increased application rate of fertilizer, and the nutrient use efficiency will drop. Hence, the amount of fertilizer applied should be controlled in a right range.
2. **Control of fertilizer application along with water**: Water is essential in the process of nitrogen circulation and absorption by crops. In practical terms, adequate nitrogen and water application should be considered together, as should crop growth characteristics at different stages. A comprehensive approach is often advantageous for increasing the FUE. Certain new approaches to paddy field management, such as 'application of fertilizers without water stand in fields' and ‘stimulation of N movement with water,' are frequently used for improving the FUE.
3. **Deep placement and split application.** One of the finest methods to increase the effectiveness of fertilizer application is deep placement. As reported by Gao and Lu, 2006 and Huang and Pu, 2006, deep placement of urea and ammonium bicarbonate boosted crop yields by 2.7-11.6% when compared to the surface application, and it also increased nitrogen use efficiency by 7.2-12.8%. Split application can improve the nitrogen use efficiency and reduce the nitrogen losses as compared to one-time treatment.
4. **Balanced fertilization**. A balanced supply of all the essential elements (macro-, secondary and micro- nutrients) for the growth of crops can be ensured through their balanced application. This method can prevent fertilizer inefficiency brought on by nutrient imbalance. Controlling the ratio of various nutrients and striking a balance between the amount of fertilizer applied and the crop’s demand at each stage of crop growth is the main goal of this strategy.

With the development of technology and science, new techniques and approaches have been applied in the agricultural production practice. Apart from traditional methods, new techniques have been developed such as site-specific real-time nitrogen management, slow release-controlled release fertilizers**,** site specific precision nutrient management, and urease nitrification inhibitor. These techniques play an important role in decreasing the fertilizer loss and increasing the FUE.

**MODERN APPROACHES TO ENHANCE FERTILIZER USE EFFICIENCY**

**4R Nutrient Stewardship**

4R Nutrient Stewardship is based on a sound understanding of nutrient dynamics. The 4R Nutrient Stewardship framework promotes the application of nutrients using the right source (or product) at the right rate, right time and right place (Figure 1). The framework was established to help convey how fertilizer application can be managed to ensure alignment with economic, social and environmental goals. The objectives of farmers, specifically the soil, climate, crop, management system and logistics all have an overarching impact on the success of such practices and need to be considered when selecting fertilizer BMPs for an individual farm.

The fertilizer industry formulated the 4R Nutrient Stewardship recommendations as a strategy to direct fertilizer Best Management Practices (BMP) across the world. The need for this strategy emerged from the growing concern that fertilizers are being used carelessly to the detriment of the environment. The majority of users are extremely cautious about the rates of nutrients they apply due to the fact that farmers purchase fertilisers at high prices in the majority of places and these prices have been gradually rising over time. The fertiliser industry must join hands in its advocacy of BMPs that support increased nutrient use efficiency, environmental sustainability, and farmer profitability in order to prevent needless policy intervention by governments. The objective is to formulate appropriate recommendations that balance fertilizer applications with crop nutrient requirements and reduce nutrient losses from fields. As a result, the 4R Nutrient Stewardship concept was developed, which involves delivering nutrients from the Right Source with the Right Rate, at the Right Time, and on the Right Place. The fertilizer must be matched to the crop needs and soil characteristics means the right source. A major part of source is balance between the various nutrients, challenge globally in improving nutrient use efficiency. Finally, based on the properties of the soil, some fertilizer products are preferred to others.  The right rate refers to matching the fertiliser applied to the crop’s need. When you take into account the various production targets, crop residue management, preceding crop management, influence of legume crops in rotation, etc., this is far from being a straightforward concept. A surplus of fertilizers applied to the soil results in accumulation of nutrients in the soil, which thus affects the soil ecology. In the end, it comes down to finding a balance between the crop's requirements, the environment, and the farmer's financial status. Making fertilizer nutrients availability to the crop when they are needed refers to Right time. When nutrient supply and demand are in sync, nutrient use efficiency can be considerably boosted. Slow and controlled release fertilizer, split time of application, stabilizers and inhibitors are just a few examples of how fertilizer nutrients can be timed in better way for efficient crop uptake. Making every effort to retain nutrients where crops can utilize them is referred to as right place.

**Figure 1. 4R Nutrient Stewardship by**

**Slow/control release fertilizers**

These are the newest and most technologically advanced methods of nourishing crop plants and nursery crops with fertilizers (Chandra et al. 2019). In comparison to conventional fertilizers, their steady pattern of nitrogen release better satisfies plant requirements, reduces leaching, and consequently increases fertilizer usage efficiency. These fertilizers have recently gained popularity across the globe because they contain plant nutrients in a form that either makes them available to the plant for a longer period of time than more typical "rapidly available" fertilizers like ammonium nitrate, urea, or potassium chloride, or delays their availability for plant uptake after application (AAPFCO. 1997).

Different techniques can be used to slow down the release of plant nutrients from fertilizers; the end product is referred to as slow- or controlled-release fertilizers. The fertilizers can be divided into two categories: controlled and slow release fertilizers (Trenkel, 1997). One category represents encapsulated/coated fertilizer products like Sulphur/polymer-coated urea (SCU/PCU), while the second group consists of modified urea and urea aldehydes like urea formaldehyde (UF), isobutylidene diurea (IBDU), and crotonylidene diurea (CDU) (Chien et al., 2009). In addition to these two, a third category consists of stabilized nitrogen products, such as nitrification or urease inhibitors, which prevent the transformation of nitrogen into forms that are prone to quick losses.

Because the nutrients are supplied gradually over the course of the growing season, using them may result in a significant reduction in the amount of energy and time required to grow crops. The main technique for producing controlled-release fertilisers is to encapsulate a typical soluble fertilizer with a protective layer made of a water-insoluble, semi-permeable, or impermeable-with-pores substance. This controls the rate of dissolution and synchronises the release of nutrients with the needs of the plants (Trenkel. 2010). Table 2 contains some example of different slow/ controlled fertilizer:

**Table 2. Different slow / controlled fertilizer (Trenkel, 2021)**

|  |  |  |
| --- | --- | --- |
| **Type**  | **Chemical name**  | **Common Name**  |
| **Slow-release** | Isobutylidene diurea  | I B D U |
| Urea formaldehyde  | UF  |
| Crotonylidene diurea | CDU |
| **Controlled release** |   | Sulphur coated urea (SCU) |
| Neem coated urea (NCU) |
| Polymer coatedurea (PCU). |
| **Nitrification inhibitors** | 2-chloro-6-trichloromethyl-pyridine | N-serve or Nitrapyrin |
| 4-amino-1,2,4-6-triazole-HCl | ATC |
| Dicyandiamide | DCD |
| Thiourea | TU |
| 1-mercapto-1,2,4-triazole | MT |
| 2-amino-4-chloro-6-methyl-pyramidine | AM |
| Ammoniumthiosulphate  | ATS |
| 1-amide-2-thiourea | ASU |
|  | Neem |
| **Urease inhibitor** | Phenyl phosphorodiamidate | PPDA |
| N-butyl thiophosphoric triamide  | NBPT |
| Phenyl mercuric acetate  | PMA |

**Biofortification**

Biofortification is a viable and cost-effective method of delivering micronutrients to the populations which don’t have exposure to diverse diets and other micronutrient interventions. The process which increases the density of vitamins and minerals in a crop with the help of plant breeding, transgenic techniques, or agronomic practices is known as biofortification. Agronomic techniques are nothing but adjusting the crop management strategies to improve nutrient concentration in the targeted part of the crops. The management practices could target particular element by improving soil organic matter status to increase nutrient availability in soil (Benkeblia and Hefferon, 2020). This approach is non-genetic; however, it has been very effective in improving the nutritional status in many crops (Table 3). Nevertheless, factors such as targeted species, form of the fertilizer and method of application affects the efficacy of this approach (Mao *et al.,* 2014). According to De Valença et al. (2017), soil and foliar application of fertilizers are the most efficient ways to increase the concentration of nutrients in cereal crops. However, factors including application methods (soil/foliar), properties of soil, fertilizer composition, the targeted crop's ability to utilize nutrients efficiently, and nutrient bioavailability have an impact on the biofortification process (Lawson et al., 2015). Moreover, frequency of application of fertilizers is the key to improve the nutrient concentration in the targeted part rather than annual application which is why sometimes it becomes a costly affair.

Genetic biofortification applies both conventional breeding along with genetic engineering methods to develop food crop with improved nutrient concentrations with reduced anti-nutrients levels, and increased bioavailability of nutrients (Bouis, 2003). Even if there are cases of successful biofortification through breeding, constraints like low yield (Bänzinger and Long, 2000) and cost (Bouis, 2003) hampers its successful implementation. Except, some cereals biofortification through breeding has shown less significance. Transgenesis and genome editing are recent intervention used in biofortification of crop. With the help of these techniques crops with higher Fe, Zn and Ca content, and reduced phytate concentration have been developed. Provitamin a rich tomato has been developed through transgenic technology ((Benkeblia and Hefferon, 2020). In spite of its effectiveness for biofortification stringent regulatory norms pose a problem for its wider application.

When there is little or no genetic variation in nutrient content among plant varieties, the transgenic approach can be a viable option for the development of biofortified crops. It is based on access to an infinite genetic pool for the transfer and expression of desirable genes from one plant species to another, regardless of their taxonomic or evolutionary status. Furthermore, when a specific micronutrient does not occur naturally in crops, transgenic approaches remain the only viable option for fortifying these crops with the specific nutrient. The development of transgenic crops depends upon the capacity to identify and define gene function and then use these genes to alter the plant metabolism. For utilizing alternate routes for metabolic engineering, pathways from bacteria and other organisms can also be introduced into the crops. Transgenic techniques can also be used simultaneously to incorporate genes that increase the concentration of micronutrients, their bioavailability, and reduce the concentration of antinutrients (inhibit the bioavailability of nutrients in plants) (Garg et al., 2018).

**Precision agriculture for precise nutrient management**

Precision Agriculture is thought as "smart farming" or "precision farming “could be a key component of sustainable intensification. This contains a collection of technologies that combines sensors, improved equipment, records systems to optimize manufacturing by using accounting for variability and uncertainties inside agricultural structures (Simegn et al., 2021). This approach can't only decrease costs, but can even increase yields. Furthermore, accurately applying chemicals and fertilizers only where needed reduces the potential for ground and surface pollution (Krishnan et al., 2016). PA technology is a combination of application of different advanced technologies and all these combinations are mutually inter related. Basically, PA has four components namely Geographical Information System (GIS), Global Positioning System (GPS), Remote Sensing (RS), and Variable Rate Technology (VRT) (Figure 2). which contributes for precise use of inputs.

**Best Management Practices (BMPs) for enhancing NUE**

1. **Integrated plant nutrient management**

A less expensive and more sustainable way to increase productivity is to replace some of the inorganic fertilizers with organic sources of nutrients, this will help mitigate the high cost of fertilizers as well as the relatively higher fertilizer losses that cause environmental pollution and yield decline over the course of the year. The crop production cannot be sustained at a higher level to fulfil the demands of the expanding population using just organic sources of nutrients. The usage of inorganic fertilizers and organic nutrient sources, such as manures, green manures, crop residues, bio fertilizers, etc., must be combined in a synergistic way. This system is known as the Integrated Plant Nutrient Supply (IPNS) System. The physical, chemical, and biological health of the soil is maintained and improved by an integrated nutrient supply system, which also increases the availability of both applied and native soil nutrients during the growing season of the crops. By encouraging carbon sequestration and limiting nutrient losses to water bodies and the atmosphere, this helps to prevent soil erosion and deterioration of water and environmental quality. Additionally, organic nutrient sources function as slow release fertilizer by coordinating the supply of nutrients from the labile soil and applied nutrient pools with the nutrient demand made by plants, both in time and location (Das et al., 2016).

1. **Balanced fertilization**

The continual mining of soil without proper replenishment to the recommended value is a major cause of the low and diminishing crop response to fertilizers. The continued application of N fertilizers either alone or with insufficient P and K has resulted in the mining of native soil P and K. In India, crops are estimated to remove approximately 28 million tonnes of NPK each year, whereas only 18 million tonnes or possibly less are added as fertiliser. This results in a net negative balance of 10 million tonnes. Furthermore, due to prolonged use of intensive cropping methods and high analysis fertilizers without enough addition of organics, soil is continuously losing S and micronutrients (Zn, B, Fe, and Mn).

Balanced fertilizer use at the macro level in India is generally equated with a nutrient consumption ration of 4:2:1 (N: P2O5: K2O). The N: P2O5: K2O ratio is as wide as 30.8: 8.8: 1 in Punjab, 48.2,14.9:1 in Haryana and 53.0:19.3:1 in Rajasthan compared with all India average of 6.9:2.6:1 (FAI.2004-05). Balanced fertilizer i.e., use of fertilizer nutrients in right proportion and in adequate amounts are considered as promising agro-techniques for sustaining yield, increase fertilizer use efficiency and restoring soil health. Continuous heavy application of only one nutrient disturbs the nutrient balance and leads to depletion of other nutrients as well as to under-utilization of fertilizer N. the response of a crop to N not only depends on the status of N but also on the deficiency or sufficiency of other associated plant nutrients. Thus, balanced use of all nutrients is essential because no agronomic manipulation can produce high efficiency out of an unbalanced nutrient use.

**Figure 2. Components of Precision agriculture**

1. **Use of biofertilizers**

Majority of the soil management practices employed today rely on fertilizers with an inorganic chemical base, which poses a substantial risk to both human health and the environment. Due to their potential contribution to food safety and sustainable crop production, the use of balanced microorganisms as biofertilizers has become of utmost importance in the agriculture industry. Eco-friendly approaches have inspired a wide range of applications of plant growth promoting rhizobacteria (PGPRs), cyanobacteria, endo- and ectomycorrhizal fungi, and many other useful microscopic organisms, which have resulted in an improved nutrient uptake, plant growth, and plant tolerance to abiotic and biotic stress (Bhardwaj et al., 2014). Biofertilizers, also known as plant growth promoting rhizobacteria (PGPR), keep the soil environment rich in all types of micro- and macronutrients through nitrogen fixation, phosphate and potassium solubilization or mineralization, the release of plant growth regulating substances, the production of antibiotics, and the biodegradation of organic matter in the soil.

1. **Customized fertilizer**

In many countries, blanket fertilizer recommendations for different crops have caused poor nutrient supply, low nutrient use efficiency and limited crop response. In contrast, soil and area specific, customized fertilizers may help to sustain soil health by ensuring appropriate fertilization. Hence, specific customized fertilizers should be promoted to counteract the problem of expanding multi-nutrient deficiencies in Indian soils (Majumdar et al. 2018)

Customized fertilizers are defined as multi-nutrient carriers designed to contain macro, secondary and/or micronutrient both from inorganic sources and/or organic sources. These are manufactured through a systematic process of granulation with stringent quality checks, satisfying the crop’s nutritional needs, specific to site, soil and stage validated by a scientific crop model, capability developed by an accredited fertilizer manufacturing/ marketing company.

In order to overcome the limitations of soil test-based blanket fertilizer recommendations, the concept of SSNM was introduced which is specific to soils and crops, yield oriented and takes into account nutrient interactions with the aid of models such as Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) and Soil Test Crop Response (STCR). Undoubtedly, customized fertilizers can magnify the prospects of SSNM and precision agriculture. Tata Chemicals Ltd (TCL), launched the ‘Paras Farmoola', the country's first ever customized fertilizer product specifically targeted at farmers in western-central Uttar Pradesh (UP), several others companies like Nagarjuna Fertilizers and Chemicals Ltd (NFCL), Deepak Fertilizers, Coromandel International Ltd., etc. Some examples of customized fertilizers are mentioned in Table 3.

**Table 3. Some customized fertilizers as approved by GoI as on 1 November 2011 (FAI, 2011)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sr. no.** | **Formulations** | **Company**  | **Area** | **Crop** |
|  | 8N15P15K0.5Zn0.15B  | Tata Chemicals Ltd | Western UP | Rice |
|  | 10N18P25K3S0.5Zn  | Tata Chemicals Ltd | Western UP | Wheat |
|  | 15N32P8K0.5Zn  | NFCL | Andhra Pradesh | Rice |
|  | 10N20P10K5S2Mg0.5Zn0.3B0.2Fe  | Deepak Fertilizers | Nasik, Pune, Ahmednagar, Aurangabad | Grape (basal) and sugarcane |
|  | 15N15P15K5S2Mg0.5Zn0.3B0.2Fe  | Deepak Fertilizers | Nasik, Pune, Ahmednagar, Aurangabad, Dhule, Jalgaon | Grape, cotton, onion, banana, potato |
|  | 20N15K0.5Zn0.2B Corom. Int | Coromandel International Ltd | Andhra Pradesh | Maize |
|  | 8N18P26K6S1Zn0.1B  | Indo-Gulf | Uttar Pradesh | Potato |

1. **Conservation agriculture (CA)**

A concept for resource-efficient crop production, known as conservation agriculture focuses on strengthening the above- and below-ground natural and biological processes. It is a group of management techniques that preserves soil biodiversity by preventing soil erosion and degradation through maintaining a continuous soil cover by surface retention of agricultural crop residues along with zero/no till or reduced tillage. CA prioritizes increasing yields and profitability to achieve a balance of agricultural, economic, and environmental benefits. It claims that the social and economic benefits of combining production and environmental protection, such as lower labor and input costs, outweigh the benefits of just production. Farmers can help to make the world a healthier place to live by reducing their use of fossil fuels, pesticides, and fertilizers, as well as preserving environmental integrity and services, by using CA. It focuses on reversing the deterioration processes associated with traditional agricultural practices such as intensive agriculture and crop residue removal/burning. As a result, it focuses on preserving, improving, and maximizing natural resources through integrated management of available soil, water, and biological resources, as well as external inputs (Bala and Singh, 2021; Saharawat et al. 2010). Therefore, it can help in improving the nutrient (fertilizers) use efficiency.

1. **Nano Technology**

Nanotechnology is the revolutionary technology where the particle size ranges between 1 and 100 nm at least in one dimension. Due to their high surface area and high reactivity better penetration into the cell these can activate plant and microbial activities resulting in more nutrient use efficiency. Nanoparticles may trigger enzymes and polysaccharide release and act as effective catalysts in plant and microbial metabolism. These are commonly referred to as a generic technology that offers better built, safer, long-testing, cost effective and smart products that will find wide applications in agriculture. Nanotechnology based products and their applications in agriculture may include Nano nutrients, Nano pesticides, nanoscale carriers, Nano sensors, Nano chips, Nano cellulose, Nano barcode, quantum dots, etc. In the past few decades, use efficiencies of N, P, and K fertilizers have remained constant as 30-35%, 15-20% and 35-40%, respectively, leaving a major portion of added fertilisers to accumulate in the soil or enter into aquatic system causing eutrophication. In order to address issues of low fertilizer use efficiency, imbalanced fertilization, multi-nutrient deficiencies and decline of soil organic matter, it is indeed need of the day to evolve the nanobased fertiliser formulations with multiple functions. Realizing that the effective use of modern technology is needed to improve the nutrient use efficiency (Tarafdar et al., 2013). Nanotechnology has the potential to transform agricultural systems through nanostructure formulation of fertilizers with mechanisms of targeted delivery, controlled release, and conditional release, or more precise release of active ingredients in response to the environmental triggers and biological demands. The term "nano-fertilizers" refers to the fertilizers based on nanoparticles that deliver nutrients precisely for maximum plant growth after stimulating plant capability, have higher use efficiency, exploit plant inaccessible nutrients in the rhizosphere, and can be applied through foliar spray or delivered into the rhizosphere in real time. Previous research has shown that using nanofertilizers boost the efficiency with which nutrients are used while drastically reducing the application doses, frequency, and cost of fertilizers. As a result, nanotechnology holds enormous promise for attaining sustainable agriculture, particularly in underdeveloped nations. The delayed release of nutrients into the crops by the nanofertilizers increases their availability during the entire crop growth cycle. This is an important mitigation measure as it prevents loss of Nitrogen through the process of denitrification, volatilization, leaching, and fixation in the soil particularly into Nitrate (NO3-) and Nitrate (NO3-) forms of Nitrogen. Data shows that the nano-clay based fertilizer formulations that can release nitrogen for around 1000 hours have comparable effects with the traditional fertilizers that release nitrogen for only 500 hours (Al-Juthery et al., 2021). Similarly, Nano-fertilizers possess certain unique properties, which assist in more effective nutrient use by plant. Out of them, few are as follow:

1. The tiny size of the nano-fertilizers makes them useful in providing sites for plant food metabolism, while having high surface area enhances their action. This results in more plant development through less consumption of essential nutrients.
2. They are extremely soluble in water.
3. The particle size of nano-fertilizers is very small (less than 100 nm), which means the penetration rate of micro-nanos is increased in the plant system.
4. Nano fertilizer particles have greater surface area and smaller particle size than the surface area of plant roots and leaves. This improves the penetration into the plant system from the applied surfaces, resulting in increased utilization and bioavailability of the nano-fertilizers.
5. Lesser the particle size, more surface area and more particles per volume is used by applicators of the chemicals. This increases performance and effectiveness.
6. The micro-particles being combined with fertilizers provide greater absorption and supply of plant nutrients to crops.

**CONCLUSION**

Farmers, society, and the environment can be benefited from the precise application of fertilizers at the proper rate, time, location, and by following such agronomic practices that aim at high yields and reduced nutrient losses and improved nutrient use efficiency. In comparison to recommending generalized nutrient application, nutrient management employing site specific nutrient management , results in higher grain yield and NUE. The NUE of the production system can be improved by integrating the nutrient management practices and balanced fertilization in addition to plant performance. Utilizing more advanced scientific interventions along with locally accessible technologies can help in improving the NUE.

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