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Nutrient Use Efficiency: Concepts, Measurement, and Improvement Strategies

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A crucially essential topic in the assessment of agricultural production systems is nutrient use efficiency (NUE). Numerous agricultural soils across the world lack one or more of the nutrients needed to sustain the growth of healthy, productive plants. Efficiency can be described in a variety of ways, but one simple strategy to boost food production is to cover more ground with crops and farm more intensively, which increases yields per unit of land. Various scientists have reported that there are elemental toxicities by Al, Mn, Fe, S, B, Cu, Mo, Cl, Na, and Si around the world.

Concept Nutrient Use Efficiency

Nutrient use efficiency is a critically important concept for evaluating crop production systems and is greatly impacted by fertilizer management as well as soil and plant- water relationships. Nutrient Use Efficiency (NUE) refers to the ability of a crop to absorb, assimilate, and convert nutrients from the soil or fertilizers into economic yield. It is a measure of how effectively applied nutrients are used by plants, reflecting the relationship between nutrient input and crop output.

Definition

Nutrient use efficiency is defined as the amount of dry matter produced per unit of nutrient applied or absorbed.

Classification of NUE

Nutrient use efficiency can be expressed several ways. Four agronomic indices commonly used to describe nutrient use efficiency are:

i. Partial factor productivity,
ii. Agronomic efficiency,
iii. Apparent recovery efficiency and
iv. Physiological efficiency

i. Partial factor productivity (PFP)

The ratio of yield under fertilizer N and amount of fertilizer N applied is termed as partial factor productivity. The factor gives answer to the question, Is this cropping system productive in comparison to its nitrogen application? The higher value of PFP means more efficient use of nitrogen.

$$\text{Partial Factor Productivity} = \frac{\text{Yield (kg/ha)}}{\text{N applied (kg/ha)}}$$

ii. Agronomic efficiency (AE)

It is defined as the economic production obtained per unit of nutrient applied. It is calculated by the following equation:

$$AE = \frac{\text{Grain yield of fertilized crop in kg} - \text{Grain yield of unfertilized crop in kg}}{\text{Quantity of fertilizer applied in kg}}$$

iii. Physiological Efficiency (PE)

It is defined as the biological production obtained per unit of nutrient applied. It demonstrates how a plant may convert the N it receives from fertilizer into economic output. The yield generated per unit of N received by the plant shoots is the subject of this N utilization efficiency (NUE). It is calculated by the following equation:

$$PE = \frac{(\text{Total dry matter yield of fertilized crop in kg}) - (\text{Total dry matter yield of unfertilized crop in kg})}{(\text{Nutrient uptake by fertilized crop in kg}) - (\text{Nutrient uptake by unfertilized crop in kg})}$$

iv. Apparent Recovery Efficiency (ARE)

One of the more complicated NUE expressions is apparent recovery efficiency (ARE), which is often defined as the difference in nutrient uptake in the plant's above-ground sections between treated and unfertilized crops in relation to the amount of fertilizer applied. Also, it is defined as the quantity of nutrient absorbed per unit of nutrient applied.

$$ARE = \frac{(\text{Nutrient uptake by fertilized crop}) - (\text{Nutrient uptake by unfertilized crop})}{(\text{Quantity of fertilizer applied})}$$

Importance of NUE

- To increase the overall performance of cropping systems.
- Providing economically optimum nourishment to the crop.
- Minimizing nutrient losses from the field and
- Supporting agricultural system sustainability through contributions to soil fertility or other soil quality components.
- NUE is a critically important concept for evaluating crop production systems and can be greatly impacted by fertilizer management as well as soil and plant- water relationships.
- NUE indicates the potential for nutrient losses to the environment from cropping systems to meet the increasing societal demand for food, fibre and fuel.

Current scenario of NUE

The Nutrient Use Efficiency has achieved constancy after the green revolution and now the trend is not at all increasing. Besides, there is a huge demand to increase the NUE since the population is increasing with each passing year and there is no scope of increasing the land under agricultural cultivation.

Nutrient Use Efficiency of different nutrients (Meena *et al.*, 2017)

Nutrient	Efficiency	Cause of low efficiency
Nitrogen	30-50 %	Immobilization, volatilization, denitrification, leaching
Phosphorus	15-20%	Fixation in soils Al - P, Fe - P, Ca-P
Potassium	70-80%	Fixation in clay lattices
Sulphur	8-10%	Immobilization, Leaching with water
Micro-nutrients (Zn, Fe, Cu, Mn, B)	1-2%	Fixation in soil

Techniques to increase nutrient use efficiency (NUE):

1. Fertigation

Application of fertilizer through micro irrigation water. The technique was first started in Israel. In some ways, fertilization is like spoon-feeding plants. Along with a micro irrigation system, it guarantees nutrient availability to the root zone of the plant. It leads to saving the fertilizers by about 30%. The method also ensures precise application and uniform distribution of fertilizers.

2. Nanotechnology

Nanotechnology is defined as "design, characterization, production and application of structure, devices and systems controlling shape, size and composition at the nano- scale." Nano materials are defined as materials that have a single unit, with size between 1 nano meter (nm) and 100 nm.

The term "nano-fertilizer" refers to nutrient-rich nano particles that may quickly reach a target in the rhizosphere or be sprayed onto foliage, directly give vital nutrients for plant development, and have improved nutrient use efficiency. The nano-fertilizers can achieve up to3-fold increase in NUE than in conventional methods. It is also advantageous and can result in 80-100 times less requirement of chemical fertilizers.

3. Nutrient Briquettes

The briquettes are a unique fertilizer concept that differs from traditional fertilizers in that the fertilizer is made into a briquette that is around the size of one's fingertip (or 2.75 g), as opposed to the more popular granular, prill - sized fertilizers or liquid fertilizers. Briquettes are applied to the soil in a special way called banding, where they are placed below the soil's surface between planted rows. Surface applied urea is said to lose up to 35% of its nitrogen, whereas buried briquettes only lose around 4% of it, which is a significant gain in nitrogen use efficiency.

4. Seed priming

The controlled hydration approach known as "seed priming" involves soaking seeds in water or a solution with a low osmotic potential to the point when germination-related metabolic processes start to take place in the seeds, but dramatic emergence does not. The method helps in better establishment of crop, increase in uptake and yields and hence improving the NUE.

Different methods to increase Nitrogen Use Efficiency:

Various strategies for improving nitrogen use efficiency are:

A. Agronomic Strategies
B. Fertilizer-Based Strategies
C. Soil and Crop Management
D. Genetic and Biotechnological Approaches

A. Agronomic Strategies

- Site-specific nutrient management
- Balanced fertilization
- Split application of nutrients
- Precision farming techniques

1. Site-Specific Nutrient Management (SSNM)

Site-specific nutrient management involves applying nutrients based on the actual requirement of crops at a specific location and growth stage rather than blanket fertilizer recommendations. It uses tools such as soil testing, plant tissue analysis, leaf colour charts (LCC), chlorophyll meters (SPAD), and remote sensing. SSNM ensures synchronization between nutrient supply and crop demand, thereby minimizing nutrient losses through leaching, volatilization, and runoff while maximizing crop uptake and yield.

2. Balanced Fertilization

Balanced fertilization refers to the application of nutrients in right proportion and combination based on crop needs and soil nutrient status. Deficiency or excess of any nutrient can limit crop growth and reduce NUE. Balanced use of macronutrients (N, P, K), secondary nutrients (Ca, Mg, S), and micronutrients (Zn, Fe, Mn, B, etc.) improves nutrient interactions, root growth, and metabolic efficiency, resulting in better nutrient uptake and utilization.

3. Split Application of Nutrients

Split application involves dividing the total nutrient dose into multiple applications at critical crop growth stages. This practice is particularly important for mobile nutrients like nitrogen.

Split application reduces nutrient losses due to leaching and volatilization, ensures continuous nutrient availability, and improves synchronization between nutrient release and crop uptake, leading to higher NUE.

4. Precision Farming Techniques

Precision farming uses modern technologies such as GPS, GIS, remote sensing, drones, and variable-rate technology (VRT) to apply nutrients accurately in terms of dose, time, and location. These techniques reduce over-application, optimize fertilizer use, improve nutrient uptake efficiency, and enhance crop productivity while reducing environmental pollution.

B. Fertilizer-Based Strategies

- Use of slow-release and controlled-release fertilizers
- Neem-coated urea and fertilizer inhibitors
- Fertigation and foliar application

1. Use of Slow-Release and Controlled-Release Fertilizers

Slow-release and controlled-release fertilizers are designed to release nutrients gradually over time. Examples include sulfur-coated urea, polymer-coated fertilizers, and neem-coated urea. These fertilizers reduce nutrient losses due to leaching, volatilization, and denitrification by synchronizing nutrient availability with crop demand, thereby improving NUE.

2. Neem-Coated Urea and Fertilizer Inhibitors

Neem-coated urea contains neem oil or neem products that act as nitrification inhibitors, slowing the conversion of ammonium to nitrate. This reduces nitrogen losses through leaching and nitrous oxide emissions. Similarly, urease and nitrification inhibitors delay nitrogen transformations in soil, increasing nitrogen availability to crops for a longer duration and enhancing NUE.

3. Fertigation and Foliar Application

Fertigation involves applying soluble fertilizers through irrigation water, allowing uniform and timely nutrient supply directly to the root zone. Foliar application supplies nutrients directly through leaves, especially micronutrients, during critical growth stages. Both methods improve nutrient availability, reduce soil losses, and enhance nutrient absorption efficiency.

C. Soil and Crop Management

- Integrated nutrient management (INM)
- Organic manures and biofertilizers
- Crop rotation and green manuring

1. Integrated Nutrient Management (INM)

INM combines chemical fertilizers with organic sources such as farmyard manure, compost, green manure, crop residues, and biofertilizers. This approach improves soil physical, chemical, and biological properties, enhances nutrient availability, and provides a sustained nutrient supply, thereby improving NUE and long-term soil fertility.

2. Organic Manures and Biofertilizers

Organic manures improve soil organic matter, water-holding capacity, and microbial activity, leading to better nutrient retention and availability. Biofertilizers such as *Rhizobium*, *Azotobacter*, *Azospirillum*, phosphate-solubilizing bacteria (PSB), and mycorrhizae enhance nutrient fixation, solubilization, and uptake, thus improving nutrient efficiency.

3. Crop Rotation and Green Manuring

Crop rotation, especially with legumes, enhances nitrogen availability through biological nitrogen fixation and improves soil structure. Green manuring crops like *Sesbania* and *Crotalaria* add organic matter and nutrients to the soil upon incorporation. These practices reduce nutrient losses, improve soil fertility, and increase NUE.

D. Genetic and Biotechnological Approaches

- Development of nutrient-efficient crop varieties
- Root architecture modification
- Use of transgenic and molecular breeding techniques

1.Development of Nutrient-Efficient Crop Varieties
Nutrient-efficient varieties can produce higher yields under low nutrient input conditions. These varieties have enhanced nutrient uptake, transport, and utilization efficiency, reducing fertilizer requirements and improving NUE.

2.Root Architecture Modification
Improved root traits such as deeper root systems, higher root length density, increased root hair development, and better root branching enhance nutrient and water uptake. Crop varieties with superior root architecture can access nutrients from deeper and less fertile soil layers, thereby increasing NUE.

3. Use of Transgenic and Molecular Breeding Techniques
Modern biotechnological tools such as marker-assisted selection, genomic selection, and transgenic approaches are used to identify and introduce genes responsible for nutrient uptake, transport, and assimilation. These techniques help develop crop varieties with higher nutrient efficiency, stress tolerance, and sustainable yield performance.

Factors Affecting Nutrient Use Efficiency

Nutrient Use Efficiency is influenced by various kinds of factors such as:

I. Soil properties (texture, pH, organic matter)
II. Climate (rainfall, temperature)
III. Crop genotype
IV. Nutrient source, dose, time, and method of application
V. Management practices

I. Soil Properties

a. Soil Texture

- Soil texture determines nutrient retention, movement, and availability.
- Sandy soils have low nutrient-holding capacity and high leaching losses, resulting in low NUE.
- Clay and loam soils have higher cation exchange capacity (CEC), better nutrient retention, and higher NUE.
- Fine-textured soils hold nutrients longer but may suffer from fixation (e.g., phosphorus in clay soils).

b. Soil pH

- Soil pH strongly influences nutrient solubility and availability.
- Acidic soils cause phosphorus fixation and deficiencies of calcium, magnesium, and molybdenum.
- Alkaline soils reduce availability of micronutrients such as iron, zinc, manganese, and copper.
- Optimum soil pH (generally 6.0–7.5) enhances nutrient availability and improves NUE.

c. Soil Organic Matter

- Soil organic matter improves soil structure, water-holding capacity, and microbial activity.
- Acts as a reservoir of nutrients and releases them slowly through mineralization.
- Enhances nutrient retention and reduces leaching losses.
- Improves NUE by sustaining nutrient supply throughout crop growth.

II. Climate Factors

a. Rainfall

- Rainfall affects nutrient movement and losses.
- Excess rainfall increases nutrient leaching (especially nitrogen) and runoff losses.
- Low rainfall or drought limits nutrient dissolution and root uptake.
- Proper synchronization of fertilizer application with rainfall improves NUE.

b. Temperature

- Temperature influences nutrient mineralization, microbial activity, and plant uptake.

- Low temperatures reduce microbial activity and nutrient availability.
- High temperatures increase volatilization losses of nitrogen and accelerate nutrient decomposition.
- Moderate temperatures favour optimal nutrient uptake and higher NUE.

III. Crop Genotype

- Different crop species and varieties vary in their ability to absorb and utilize nutrients.
- Nutrient-efficient genotypes have better root systems, higher nutrient uptake capacity, and efficient internal utilization.
- Varieties with improved nutrient transport and assimilation mechanisms show higher NUE.
- Crop duration and growth habit also influence nutrient demand and efficiency.

IV. Nutrient Source, Dose, Time, and Method of Application

a. Nutrient Source

- Organic sources provide slow and sustained nutrient release.
- Inorganic fertilizers provide readily available nutrients but may cause losses if mismanaged.
- Coated fertilizers and inhibitors improve nutrient availability and NUE.

b. Nutrient Dose

- Under-application leads to deficiency and poor yield.
- Over-application causes nutrient losses, toxicity, and low NUE.
- Applying nutrients as per soil test recommendations ensures optimum NUE.

c. Time of Application

- Nutrients applied at critical growth stages are utilized more efficiently.
- Early or late applications can result in losses or poor uptake.
- Split application improves nutrient availability and NUE.

d. Method of Application

- Broadcasting may cause higher losses.
- Band placement, deep placement, fertigation, and foliar application improve nutrient contact with roots and reduce losses.
- Proper placement enhances nutrient absorption and NUE.

V. Management Practices

a. Crop Management

- Proper crop spacing, irrigation, and weed control reduce nutrient competition.
- Timely intercultural operations improve root growth and nutrient uptake.

b. Soil and Water Management

- Efficient irrigation practices reduce nutrient leaching.
- Conservation tillage improves soil structure and nutrient retention.

c. Integrated Nutrient Management

- Combining organic and inorganic sources enhances nutrient availability and soil health.
- Improves long-term NUE and sustainability.

Conclusion

Improving Nutrient Use Efficiency (NUE) is essential for sustainable and climate-resilient agriculture, especially in view of rising fertilizer costs, declining soil fertility, and increasing environmental problems such as nutrient losses and greenhouse gas emissions. Efficient nutrient use enhances crop productivity while reducing input costs and environmental damage. Higher NUE can be achieved through an integrated approach that combines sound agronomic practices, advanced fertilizer technologies, improved soil and crop management, and the development of nutrient-efficient crop varieties. Overall, enhancing NUE supports higher yields, better farm profitability, and long-term sustainability, making it a key strategy for meeting future food demands while conserving natural resources.

References

1. Bana *et al.* (2020). *Site-Specific Nutrient Management (SSNM) for enhancing crop productivity and NUE* discusses tools like leaf colour charts, remote sensing and decision support systems.
2. Barkha & Chakraborty, A. (2021). *Effect of integrated nutrient management on nutrient use efficiency of major nutrients: a review*. Plant Archives.
3. Randhawa, M.K., *et al.* (2021). *Nutrient use efficiency as an indicator of nutritional security in rice-wheat systems*. Sustainability.
4. Rawal, N., Pande, K.R., Shrestha, R., & Vista, S.P. (2022). *Nutrient use efficiency (NUE) of wheat as affected by NPK fertilization*. PLoS ONE.
5. Todmal, S.M., *et al.* (2020). *Effect of different slow-release and controlled release fertilizers on nutrient uptake and yield of soybean* (JART).
6. Vijay Singh Meena V.S., Sunita Kumari Meena, Jay Prakash Verma, Ashok Kumar, Abhinav Aeron, Pankaj Kumar Mishraa, Jaideep Kumar Bisht, Arunava Pattanayaka, Muhammad Naveed, M.L. Dotaniya (2017). *Plant beneficial rhizospheric microorganism (PBRM) strategies to improve nutrients use efficiency*: A review. Ecological Engineering 107 (2017) 8–32
7. Wang, C., *et al.* (2022). *Biochar-based slow release of fertilizers for sustainable agriculture*. PMC.
8. Wu, W., *et al.* (2015). *Integrated nutrient management (INM) for sustaining crop production and improving nutrient use efficiency*. Science of the Total Environment.