Nutrient Use Efficiency in Rainfed Agro–ecosystems: Concepts, Computations and Improvement Interventions

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Why is nutrient use in crop production indispensable?

Most agricultural soils in India have low native fertility. Successful and sustained crop production on these soils requires regular nutrient inputs through chemical fertilizers and/or organic manures to replenish soil nutrient reserves depleted by crop removal and other losses. It is essential to recognize that even in rainfed production systems with relatively low productivity level, the quantity of nutrient removal is quite substantial and exceeds addition. Furthermore, the quantum of nutrients available for recycling via crop residues and animal manures is grossly inadequate to compensate for the amounts removed in crop production. Thus, mineral fertilizers have come to play a key role in areas with low fertility soils, where increased agricultural production is required to meet growing food demand.

Chemical fertilizers as source of plant nutrients are considered as the major contributor to enhancing crop production and maintaining soil productivity. Over the last 35 years, additional nutrients applied as manufactured fertilizers have been responsible for about 50 per cent of the yield increases in developing countries including India. Though the consumption of chemical fertilizers in India increased steadily over the years, the use efficiency of nutrients applied as fertilizers continues to remain awfully low (40-50% for N, 20-25% for P and 2-5% for Zn, Fe & Cu) owing to nutrient losses from the soils or conversion of nutrients into slowly cycling/recalcitrant pools within the soil. Further, at national level the partial factor productivity (PFPf) and incremental use efficiency (IUEf) of fertilizers used in food grain production have been gradually declining over the years (Fig. 1). This has become a matter of great concern and a challenge to be addressed on priority.

India's National Agricultural Policy lays much emphasis on enhancing use efficiency of agricultural inputs of which fertilizers represent an important and expensive component. When nutrient inputs are used inefficiently both cost of cultivation and threat for biosphere pollution increase. Thus, economic and ecological considerations highlight the compulsive need for more efficient use of nutrients in crop production.

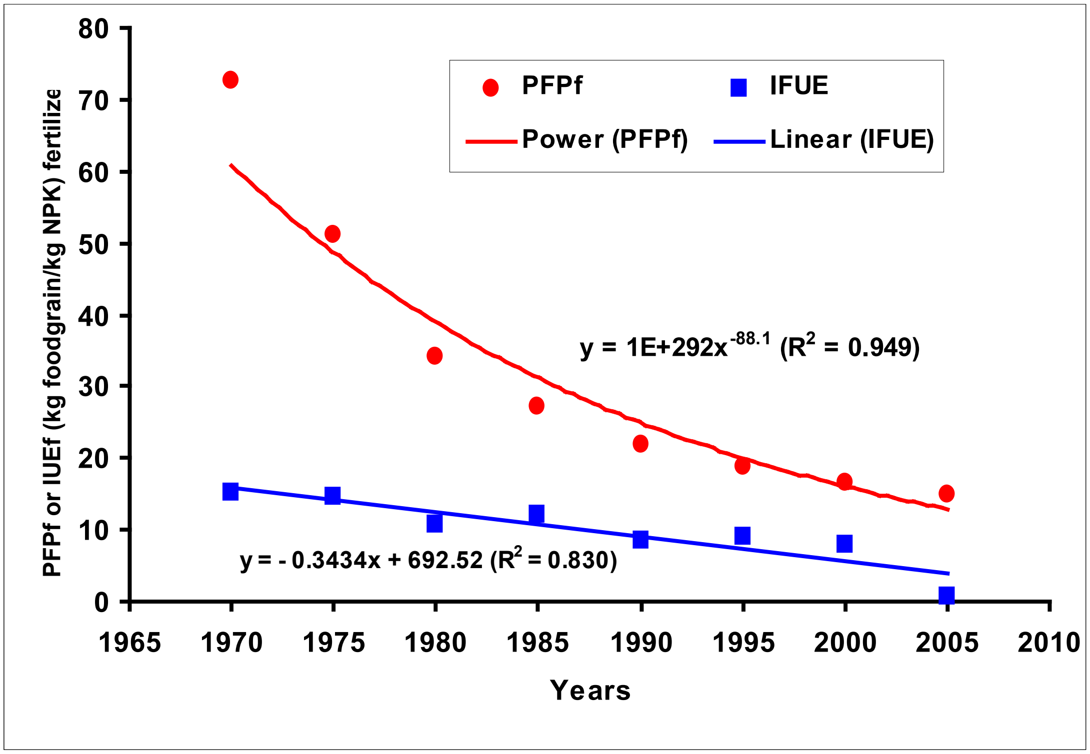

Fig. 1: Partial factor productivity (PFPf) and incremental use efficiency (IUEf) of fertilizers in foodgrain production in India during 1970-2005

What does increased nutrient use Efficiency (NUE) imply?

Increased nutrient use efficiency implies the following:

- Lesser nutrient need for obtaining a given level of production
- More produce per unit of nutrient applied
- Lower cost of production per unit of produce
- Higher returns per rupee invested on nutrient use
- Reduced risk of environmental pollution

Economic significance of increased NUE at national level

Since fertilizer nutrients are expensive and used in large quantities at national level, any increase in use efficiency will lead to a substantial cut in nutrient requirement and huge economic benefit at national level. For example, At the present level of fertilizer consumption (14.05 M t N and 5.66 M t P2O5 in 2006-07) and with use efficiency of 50% for N and 20% for P, increase in the efficiency of N and P use by just 2 percentage units would lead to a saving of 5.38 lakh tonnes of N and 5.15 lakh tonnes of P, which together translate to a saving of Rs.14,920 million annually. This amply highlights the importance of enhancing nutrient use efficiency. This staggering annual economic benefit is in addition to reduced risk of environmental pollution.

Computation of nutrient saving and monetary benefits accruing at national level due to a target increase in NUE

Let

Efficiency of nutrient use at present, %	= Ep
Efficiency of nutrient use desired, %	= Ed
Annual consumption of nutrient at the present efficiency, Mt	= Cp
Annual consumption of nutrient at the desired efficiency, Mt	= Cd

It follows

$$Cd = (Cp * Ep)/Ed$$

Difference in nutrient consumption at present and desired levels of efficiency

$$= Cp - Cd$$

$$= Cp - (Cp * Ep/Ed)$$

$$= \frac{(Cp*Ed) - (Cp*Ep)}{Ed}$$

$$= \frac{Cp\ (Ed - Ep)}{Ed}$$

If the efficiency is to be increased by 'n' percentage units (Ed = Ep + n), then

$$\text{Annual savings in nutrient consumption} = \frac{Cp * n}{Ep + n}$$

$$\text{Annual monetary benefit accruable (million Rs.)} = \frac{Cp * n}{Ep + n} \times \text{Nutrient cost in Rs./t}$$

Measures of nutrient use efficiency

The nutrient use efficiency is measured in different ways depending upon the perspective in which it is computed and considered. The agronomists, soil scientists, plant physiologists and agricultural economists use different expressions/measures for nutrient use efficiency. Taking phosphorus (P) as an example of plant nutrients, different measures of nutrient use efficiency can be defined as follows:

- **P use efficiency (kg kg^{-1}):** Ratio of grain yield to P supply, where P supply includes P from all sources.

- **P uptake efficiency (kg kg^{-1}):** Ratio of total P uptake to P supply, where total P uptake includes P in above and below ground plant parts.

- **P utilization efficiency (kg kg^{-1}):** Ratio of grain yield to total P uptake

Since the P supply from all sources and the total P uptake by plant (i.e. uptake in above and below ground plant parts) are difficult to measure, the common practice is to consider increments in yield and uptake as a result of fertilizer P applied and compute the incremental efficiencies.

Incremental efficiency measures

The Agronomic Efficiency, Recovery Efficiency and Physiological Efficiency are the most commonly used efficiency parameters with biological significance. For computation of these incremental efficiencies of P, the following data are required.

Let

Amount of P applied	=	A_P	(kg ha^{-1})
Economic Yield without P application	=	Y_0	(kg ha^{-1})
Economic Yield with P application	=	Y_P	(kg ha^{-1})
Increase in yield due to P application	=	$(Y_P - Y_0) = \Delta Y$	(kg ha^{-1})
P Uptake by crop without P application	=	PU_0	(kg ha^{-1})
P Uptake by crop with P application	=	PU_P	(kg ha^{-1})
Increase in P uptake due to P application	=	$(PU_P - PU_0) = \Delta PU$	(kg ha^{-1})

Agronomic Efficiency of P (AE_P): It is the increase in crop yield per unit of P applied (i.e. ratio of the increase in yield to the amount of P applied) and expressed as kg kg^{-1}.

$$\mathbf{AE_P = \frac{(Y_P - Y_0)}{A_P} = \frac{\Delta Y}{A_P}}$$

Recovery Efficiency of P (RE_P): It refers to the increase in P uptake by plant (above ground parts) per unit of P applied. The recovery efficiency is generally expressed in percentage terms (%).

$$RE_P = \frac{(PU_P - PU_0)}{A_P} \times 100 = \frac{\Delta PU}{A_P} \times 100$$

Physiological Efficiency of P (PE_P): It indicates the efficiency with which the plant utilizes the absorbed P to produce economic yield. It is the ratio of the increase in yield to the increase in P uptake, and expressed as kg kg^{-1}.

$$PE_P = \frac{(Y_P - Y_0)}{(PU_P - PU_0)} = \frac{\Delta Y}{\Delta PU}$$

Economic Efficiency of P (EE_P): When agronomic efficiency (AE_P) is expressed in monetary terms, it becomes EEP. It can be equated with most popularly used Benefit: Cost Ratio.

$$EE_P = \frac{\Delta Y}{A_P} \times \frac{\text{Value of the produce (Rs.)}}{\text{Cost of the nutrient}}$$

Partial factor productivity for P (PFP_P) (kg kg^{-1}): The partial factor productivity from applied P is the ratio of grain yield to amount of P applied.

$$PFP_P = Y_P / A_P$$

$$= \frac{(Y_0 + \Delta Y)}{A_P}$$

$$= \frac{Y_0}{A_P} + \frac{\Delta Y}{A_P}$$

$$= Y_0 / A_P + AE_P$$

Relationship among nutrient use efficiency measures

The agronomic efficiency represents the product of recovery efficiency and physiological efficiency as derived below:

$$RE_P * PE_P = \frac{\Delta PU}{A_P} \times \frac{\Delta Y}{\Delta PU}$$

$$= \frac{\Delta Y}{A_P}$$

$$= AE_P$$

Determinants of nutrient use efficiency

Nutrient use efficiency depends on the following factors and needs to be interpreted with reference to these factors:

- Crop/variety
- Soil type
- Rate (dose) and time of application
- Source of nutrient
- Management (soil, crop and water management)

Rainfed Agro-ecosystems – NUE Improvement Interventions

The hunger and poverty in perpetuity are idiosyncratic features of farming community in dryland/rainfed regions. In India, the rainfed agriculture represents 60% of net cultivated area and contributes about 40% to our food basket and has a role to play in augmenting future fortunes of agriculture. Productivity levels of rainfed agro-ecosystems are generally low owing to an array of production constraints. Some important production constraints having direct or indirect bearing on nutrient use efficiency are briefed below.

- Moisture deficits and excesses at some point of crop growing season
- Soil and nutrient losses through soil erosion by water and wind
- Low soil organic carbon stocks and less biological activity and diversity
- With exception of Vertisols, most rainfed soils are coarse textured with low water and nutrient retentive capacity.
- Poor and declining soil fertility. High degree of phosphate fixation in most dryland/rainfed soils (Alfisols, Oxisols, Vertisols)
- Inadequate and imbalanced fertilizer use
- Inappropriate time and method of fertilizer application
- Emergence and spread of micro and secondary nutrient deficiencies

- Soil salinity and sodicity problems
- Soil compaction/hardsetting/crusting impeding root growth and seedling emergence

Interventions for crop productivity enhancement and NUE improvement

The soil-water-crop management practices that promote crop productivity at same level of fertilizer use are expected to enhance NUE. Similarly, all the management practices that minimize nutrient/fertilizer requirement while achieving desired productivity targets would also lead to increased nutrient use efficiency. Some management interventions for crop productivity enhancement and consequently increased NUE are listed hereunder:

- Identify management interventions with high carbon sequestration potential to promote SOC storage critical for optimum soil processes.
- Improved plant genotypes with high yield potential and adaptability
- Soil and water conservation to minimize nutrient losses
- Customized fertilizers and fertilization for enhanced NUE
- Fertilisation practices in moisture stressed production systems systems must be tailored to moisture availability so that the added nutrients are utilized more efficiently.
- Exploit water-nutrient synergy for greater productivity and use efficiency
- Integrated nutrient management and balanced fertilization including secondary & micronutrients for improving soil fertility and productivity
- Strategic interventions for abiotic and biotic stress management