



Poor Fertilizer Use Efficiency: A Major Setback to Sustainable Agriculture in India

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Fertilizer-driven intensification, underpinned by high-yielding varieties and synthetic N-P-K inputs, has been central to India's food security since the Green Revolution, enabling near self-sufficiency from prior chronic grain deficit. Since the 1970s, fertilizer consumption has grown at >7% CAGR without commensurate gains in unit-area use efficiency, with several intensively cultivated states now exceeding crop requirement by 25–35%. Fertilizer Use Efficiency (FUE) — the fraction of applied nutrient recovered in crop biomass — remains suboptimal: apparent recovery efficiency is estimated at 30–50% (N), 15–20% (P), and 50–70% (K). Unrecovered nutrients are lost via ammonia volatilization, nitrification–denitrification, leaching, runoff, fixation, and erosion, each governed by distinct edaphic and hydrological controls. These losses elevate input costs, deplete soil organic carbon and microbial biomass, and contaminate groundwater and surface water. Declining marginal yield response to fertilizer application further indicates diminishing returns, implying that productivity gains can no longer be achieved through input escalation alone. This review synthesizes agronomic, environmental, and policy dimensions of India's FUE deficit and argues that balanced nutrient stoichiometry, integrated nutrient management, and precision application are the principal levers for reconciling productivity, profitability, and sustainability.

“Increasing FUE is not just about producing more — it is about earning more, spending less, and protecting the soils for future generations.”

Current Fertilization Scenario

Aggregate fertilizer consumption in India has risen >20-fold since the Green Revolution, yet marginal productivity per kg applied nutrient has declined — a diminishing fertilizer response. The response ratio has fallen from 10–13 kg grain/kg nutrient (1970s) to <5 kg/kg today (MoAFW, 2025), reflecting native fertility depletion, disrupted nutrient cycling under intensive cropping, and widening nutrient-ratio imbalance. National consumption averages 130–150 kg NPK/ha, masking sharp regional variation: Punjab (220–250 kg/ha), Haryana (200–210 kg/ha), and western UP (165–180 kg/ha) lead (MoCF, 2023; FAI, 2023; Kumar et al., 2026), with skewed N application disrupting N:P:K equilibrium and producing only transient growth gains linked to yield stagnation over successive cycles (Bhagat et al., 2026). Southern paddy states (Andhra Pradesh 130–140, Tamil Nadu 110–120 kg/ha) also exceed the national mean, while rainfed Rajasthan, Madhya Pradesh, and north-eastern states remain well below it. The economic burden is substantial: India imports ~25–30% of urea, 55–60% of DAP, and nearly all potash, with subsidy outlays of ₹1.7–1.9 lakh crore annually, scaled to tonnage dispensed rather than recovered. ICAR-IISS (>250,000 samples, 2017–2023) linked N-dominated fertilization in the north-western Indo-Gangetic Plain to significant SOC depletion — most severe in Punjab, Haryana, and western UP — while balanced N:P:K states like Bihar retained better soil carbon (ICAR-IISS, 2025). Total consumption reached 610 LMT in 2025 (led by UP: 120, AP: 45, TN: 40, Maharashtra: 35, Karnataka: 30 LMT), against foodgrain and horticultural output of 353.96 and 362.09 LMT respectively in 2024–25 (MoAFW, 2025).

Table 1. State-wise Fertilizer Use, Soil Carbon Status and Foodgrain Productivity

State	NPK Consumption (kg/ha)	Soil Organic Carbon Status	Foodgrain Productivity (approx., kg/ha)
Punjab	220–250	Low; declining (intensive rice–wheat)	4,800–5,200
Haryana	200–210	Low; declining	4,200–4,700
Uttar Pradesh (western)	165–180	Low–Medium; declining	3,000–3,500
Andhra Pradesh	130–140	Medium	2,800–3,200
Tamil Nadu	110–120	Medium	3,000–3,300
Bihar	150–210 (more balanced N:P: K)	Relatively better	2,300–2,600
Rajasthan / Madhya Pradesh	<80	Medium–Low (arid/semi-arid)	1,200–1,800
All-India average	130–150	Mixed; declining in intensive belts	2,300 (all-crop average)

Sources: FAI Fertiliser Statistics (2023); Ministry of Chemicals & Fertilizers, Rajya Sabha replies (2023); ICAR-IISS (2023); Agricultural Statistics at a Glance (2024).

Nutrient-Specific Recovery Efficiency

FUE encompasses several indices — agronomic efficiency, apparent recovery efficiency, physiological efficiency, and partial factor productivity — through which subsequent interventions operate.

Nitrogen dominates use and loss: of ~44 Mt applied annually, only 30–50% is recovered; the rest is lost via volatilization, nitrification–denitrification, and leaching, especially in flooded/coarse-textured soils. National recovery is ~35–40% (ICRIER, 2026), with losses largely entering groundwater as nitrate.

Phosphorus inefficiency is chemical: only 15–20% of applied P is taken up in-season, as 70–85% is immobilized as calcium or Fe/Al phosphates depending on soil pH (Dwivedi *et al.*, 2017), though this fixed P remains recoverable via biological mobilization.

Potassium has the highest recovery efficiency (50–70%), but Indian practice under-applies K — replacing only ~one-third of crop removal — causing reserve drawdown ("K-mining"). ~72% of soils are now K-deficient, reflecting subsidy bias toward N rather than K-specific inefficiency.

Table 2. Nutrient Loss Profile in India

Nutrient	Annual Use (2022–23)	Loss to Volatilization / Leaching / Fixation	Potential Yield Gain with Better FUE
Nitrogen (N)	~44 MT	50–70% lost	30–35%
Phosphorus (P)	~17.8 MT (P ₂ O ₅)	70–85% fixed/immobilized	15–20%
Potassium (K)	~5.6 MT (K ₂ O)	~65% of K removed not replenished	50–70%
Micronutrients	<1 MT (Zn, B, etc.)	Deficient in 40–50% of soils	40–60%

Total annual fertilizer use (N+P₂O₅+K₂O): 67.7 million tonnes (2022–23). Sources: FAI Fertiliser Statistics 2023; ICAR Annual Report 2022; Dobermann (2007).

Determinants of Low FUE

Low FUE arises from interacting biophysical, socioeconomic, and institutional factors:

- 1. Imbalanced stoichiometry** — heavier urea subsidy encourages over-application of N relative to P and K, skewing the applied ratio to 8:3.2:1 against the recommended 4:2:1 (Economic Survey of India; FAI, 2023), which depresses physiological efficiency since N assimilation is co-limited by P and K.
- 2. Inadequate soil testing** — fewer than 30% of farmers use soil-test-based recommendations; most apply blanket doses regardless of actual nutrient status (ICAR-NBSS&LUP, 2021).
- 3. Low soil organic carbon** — over 60% of Indian soils have SOC below the critical 0.5% threshold, weakening cation exchange capacity and nutrient buffering (ICAR-NBSS&LUP, 2021).
- 4. Suboptimal placement and timing** — broadcasting limits NUE to ~30%, versus 50–55% with split application and band/deep placement.
- 5. Neglect of integrated sources** — reduced use of farmyard manure, compost, and biofertilizers curtails microbial nutrient cycling that chemical inputs alone cannot sustain.
- 6. Soil health degradation** — low SOC and weak microbial activity constrain root proliferation and nutrient interception.
- 7. Limited mechanization** — manual broadcasting produces uneven placement and higher volatilization losses than precision applicators or fertigation.
- 8. Cropping-system homogeneity** — continuous rice–wheat rotation intensifies nutrient mining relative to diversified rotations with legumes (Dwivedi *et al.*, 2017).
- 9. Policy and market distortion** — asymmetric urea versus P/K subsidy has entrenched the skewed NPK ratio.
- 10. Weak extension outreach** — despite over 24 crore Soil Health Cards issued since 2015, limited on-ground extension capacity means recommendations often go unimplemented (ICAR-NBSS&LUP, 2021).

Environmental and Agronomic Consequences

Sustained N: P₂O₅: K₂O imbalance — from 4.3:2:1 (2009–10) to 10.9:4.4:1 (2024–25) — corresponds with declining nitrogen recovery, now estimated at 35–40% (ICRIER, 2026), with the residual fraction largely lost to nitrate leaching. The CGWB (2024) reports unsafe groundwater nitrate levels across 440 districts, associated with infant methemoglobinemia and chronic thyroid dysfunction. Concurrently, soil organic carbon has fallen below the 0.75% critical threshold in ~75% of 2024–25 Soil Health Card samples, with widespread S, Zn, and Fe deficiency reflecting prolonged N-centric fertilization. Denitrification losses further contribute to N₂O emissions (GWP₁₀₀ ≈ 265–298 × CO₂), while nutrient runoff drives eutrophication and aquatic biodiversity loss (Ladha *et al.*, 2020). These trends — soil fertility decline, yield stagnation, elevated pest pressure, water contamination, and rising input costs — indicate a trajectory correctable only through systematic nutrient-efficiency management.

Strategies to Improve FUE

Decades of research across ICAR institutes, State Agricultural Universities, IRRI, and CIMMYT have produced a validated toolkit for raising FUE.

A. Soil testing — establishes the diagnostic baseline, calibrating dosage to actual soil-supplying capacity rather than blanket convention.

B. The 4R Nutrient Stewardship framework — (Right Source, Right Rate, Right Time, Right Place), developed by the International Plant Nutrition Institute, is the global standard for FUE optimization. In India it is operationalized through the Soil Health Card programme under PMKSY, which has analysed over 24 crore soil samples since 2015.

Table 3. The 4R Framework Applied to Indian Fertilizer Management

The '4R'	Principle	Examples
Right Source	Match fertilizer type to crop & soil need	Neem-coated urea; DAP vs. SSP
Right Rate	Apply based on soil test / crop need	Soil Health Card recommendations

The '4R'	Principle	Examples
Right Time	Apply when crop can absorb nutrients	Split N application at tillering + panicle
Right Place	Band, incorporate, or inject near root zone	Furrow placement; fertigation

The 4R Nutrient Stewardship framework applied to Indian fertilizer management.

C. Integrated Nutrient Management (INM) — combines inorganic fertilizers with organic manures, biofertilizers, and residue management. Trials show 50% Recommended Dose of Fertilizer (RDF) plus farmyard manure (5–10 t/ha) and biofertilizers (Rhizobium, phosphate-solubilizing bacteria, Azotobacter) can match or exceed 100% chemical RDF yields while raising SOC and microbial biomass. In legumes, Rhizobium fixes 40–120 kg N/ha/season — equivalent to 90–260 kg urea/ha — while PSB mobilizes fixed soil phosphorus, cutting phosphatic fertilizer needs by 25–50% without yield penalty.

“INM is not a compromise — it is the most scientifically advanced and economically rational approach to crop nutrition in the 21st century.”

D. Nano-fertilizers — Nano Urea, a liquid formulation with nitrogen encapsulated in 20–50 nm particles, was developed by IFFCO and approved in 2021. Applied as foliar spray and absorbed through leaf stomata, it enables slower, physiologically synchronized N release. Trials across 94 locations and 11 crops showed a single 500 ml bottle (~4% N) can substitute for one 45 kg bag of conventional urea per acre, cutting N input by up to 50% while maintaining yield; its NUE of 80–90% is nearly double that of prilled urea (Adhikari *et al.*, 2022).

Table 4. Conventional Urea versus Nano Urea

Parameter	Conventional Urea	Nano Urea (Foliar)
N Content	46% (solid)	4% (liquid, 500 ml/bottle)
Application Method	Soil broadcast/incorporation	Foliar spray at critical stages
NUE Estimate	30–40%	80–90%
GHG Emission (N ₂ O)	Significant	Negligible
Cost Comparison	₹266–270/bag	~₹240/bottle (1 bag equivalent)

*Comparison of conventional urea vs. Nano Urea. Source: Adhikari *et al.*, 2022.*

E. Coated and slow-release fertilizers — Neem-coated urea (NCU), mandatory for domestic sale since 2015, inhibits soil urease activity, slowing hydrolysis and reducing volatilization by 20–25%; ICAR data show NUE gains of 5–10 percentage points. Polymer- and sulfur-coated formulations extend this principle for high-value horticulture.

F. Fertigation — delivering dissolved nutrients through drip irrigation to the root zone, achieves NUE of 80–95% for nitrogen and 70–85% for potassium. Under PM Krishi Sinchayee Yojana, drip coverage reached over 58 lakh hectares by 2024.

G. Crop diversification — rotating cereals with legumes and oilseeds improves nutrient cycling and reduces N dependency via biological fixation (Dwivedi *et al.*, 2017).

H. Precision nutrient management — using leaf colour charts and GPS-guided applicators improves NUE by 10–15 percentage points over blanket dosing.

I. Efficient irrigation — through micro-irrigation reduces the volume of water — and dissolved nutrient — lost to runoff and percolation.

J. Farmer awareness and extension — via expanded Soil Health Card outreach and Krishi Vigyan Kendra training, closes the knowledge-to-practice gap (ICAR-NBSS&LUP, 2021).

Policy Landscape

Over the past decade, India has launched several programmes targeting FUE at scale.

Table 5. Key Government Policy Interventions for FUE

Scheme / Policy	Launched	FUE Relevance
Soil Health Card (SHC) Scheme	2015	Site-specific fertilizer recommendations; 24 crore cards issued

Scheme / Policy	Launched	FUE Relevance
Neem Coated Urea Mandate	2015	100% domestic urea sales as NCU; reduces volatilization by 20–25%
PM-PRANAM Scheme	2023	Incentivizes states to reduce fertilizer use through alternatives
PMKSY – Har Khet Ko Pani	2015	Drip expansion enables fertigation; 58 lakh ha covered
Nano Urea Approval (IFFCO)	2021	Liquid N foliar spray; 80–90% NUE; ~₹240/bottle

Key Government of India policy interventions for FUE improvement.

The PM-PRANAM scheme, launched in 2023, is structurally distinctive: it provides fiscal grants to states demonstrating measurable reductions in chemical fertilizer consumption through biofertilizers and organic amendments — aligning subsidy incentives with efficiency outcomes rather than input volume, a reversal of the subsidy structure that historically contributed to the imbalance documented above.

Conclusion

Fertilizer use efficiency (FUE) is crucial for enhancing agricultural productivity, reducing input costs, and minimizing environmental impacts in India. Integrated approaches, including soil-test-based fertilization, 4R nutrient stewardship, INM, biofertilizers, and advanced fertilizer formulations, can improve nutrient-use efficiency. Effective implementation of government initiatives, supported by extension services and farmer adoption, is essential for achieving sustainable outcomes. Improving FUE is vital for ensuring food security, increasing farm profitability, and promoting climate-resilient agriculture in India.