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A Silent Storm: Why India Must Act on Nitrogen Pollution and Climate Change

Nitrogen pollution mitigation could offset 5–10 per cent of Global Greenhouse Gas (GHG) reductions needed to stay within the global warming target. In India, where agriculture is the largest source of N_2O emissions, coordinated nitrogen policies can yield enormous climate co-benefits.

Nutrients lie at the core of the triple planetary crisis—pollution, biodiversity loss, and climate change. Though essential for food production, both organic and industrial nutrients, when mismanaged, contribute to soil degradation and environmental pollution, particularly through excess nitrogen (N). This has disrupted biogeochemical cycles, pushing them beyond planetary boundaries.

Nitrogen is indispensable to life. It is a building block of proteins, nucleic acids, and chlorophyll. Yet, reactive nitrogen (Nr) forms like ammonia (NH_3), nitrate (NO_3-), nitrous oxide (N_2O), and nitrogen oxides (NO_x) are now being released at rates that exceed the capacity of Earth's ecosystems to absorb them, causing widespread environmental damage. Nitrous oxide is a greenhouse gas that is 300 times more potent than carbon dioxide. The challenge is particularly acute in South Asia, where high-input agriculture, dense populations, and poorly managed waste systems are

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creating a nitrogen overload.

India, home to 1.4 billion people and a significant contributor to global agricultural output, finds itself at the centre of this storm. A 2018 *Nature India* report labelled the country a global hotspot for nitrogen pollution, citing low nitrogen use efficiency (NUE), excessive urea application, and unregulated livestock and waste emissions as key contributors. Global estimates show that only half of the nitrogen applied in agriculture is utilised by crops. The rest is lost to the environment, contaminating water, air, and ecosystems. The environmental cost of nitrogen pollution in India is estimated to be around USD 78 billion annually (Sutton et al., 2017).

India's agricultural intensification relies heavily on nitrogen (N) fertilisers, but the system is inefficient. An assessment finds India applies about 17 million tonnes of nitrogen fertiliser per year, yet plants absorb only roughly 33 per cent of the N added to the major cereal crops (rice and wheat). In other words, about two-thirds of applied N remains in the soil or escapes to the environment. This enormous 'loss' of fertilizer N translates into a massive pollutant load: nutrients leach into groundwater and surface water or volatilise into air. Nutrient-tracking studies show that key states in India's grain belt—Punjab, Haryana, Western Uttar Pradesh and nearby regions— carry the highest N surpluses. For example, recent data indicate nitrogen surplus in Punjab reached an astonishing 234 kg N/ha/yr by 2017 (up from approx 24 kg N/ha in 1966), and in Haryana it rose to 276 kg N/ha/yr. These 'breadbasket' states, plus Bihar, Telangana, Andhra Pradesh and West Bengal, consistently exhibit far higher N surpluses per hectare than the national average.

Large surpluses also arise from India's internal trade of crops. One recent analysis mapped N flows via interstate grain trade: states like Maharashtra, Uttar Pradesh, Tamil Nadu and Karnataka send crops (with embedded N) to deficit regions, while Punjab and Haryana accumulate N surpluses of about 710 gigagrams/year. In other words, agricultural trade is effectively concentrating nitrogen pollution in production zones. Converting these nutrient surpluses into emission estimates showed that domestic rice/wheat trade alone gives rise to roughly 42.8 Gg N/year of N_2O emissions, with over 70 per cent of that coming from just four leading producing states (Haryana 28.3 per cent, Punjab 20.0 per cent, Chhattisgarh 12.4 per cent, Andhra Pradesh 12.3 per cent). These figures illustrate that inefficiency in fertiliser use—especially in Punjab, Haryana and parts of UP—is driving large environmental loads of reactive nitrogen.

Poor farm-level practices exacerbate the problem. Many farmers (an estimated 70 per cent nationally) apply fertiliser without adequate soil testing or adherence to recommended doses. Subsidies and price controls make urea and other N-fertilisers cheap, so farmers often 'overapply' nitrogen. For example, a recent survey in South Asia found 55 per cent of rice farmers were applying more N than needed, suggesting the region could save approx 18 kg N/ha on average without yield loss. Over-application in the Indo-Gangetic plain is already causing nutrient build-up: soil studies in parts of Punjab, Haryana and western UP have found nitrate levels in wells two or more times above safe limits. In Haryana, for instance, the average nitrate (NO_3^-) concentration in shallow well water was 99.5 mg/L, nearly double the 50 mg/L threshold set by the World Health Organisation. Such contamination highlights that India's nitrogen use efficiency is low and

generating large pollution burdens.

Further, there is robust scientific consensus that nutrient pollution—driven by fossil fuel combustion, fertiliser overuse, and wastewater from agriculture and industry—is intensifying air and water pollution, accelerating biodiversity loss, soil degradation, ozone depletion, and contributing significantly to climate change. However, governance remains fragmented, and integrated global frameworks for nitrogen and phosphorus are lacking despite their profound cross-sectoral impacts.

The Government of India has acknowledged this silent crisis and has taken numerous proactive measures. Fertiliser industries are now mandated to meet strict emission norms with 24x7 Continuous Emission Monitoring Systems (CEMS) in place. The Indian Council of Agricultural Research (ICAR) promotes neem-coated urea, soil test-based nutrient management, and the 4R principle of nutrient stewardship—right source, right rate, right time, and right place. The Soil Health Card Scheme has been instrumental in collecting data and guiding farmers on balanced fertiliser application.

Urban nitrogen loads are being addressed through upgrades in sewage treatment infrastructure under schemes such as AMRUT and the National Mission for Clean Ganga. Meanwhile, real-time air quality monitoring by the Central and State Pollution Control Boards has identified nitrogen oxides as major urban pollutants. Stricter vehicle emission norms (BS-VI), fuel upgrades, and enforcement of pollution control in industries have also been rolled out.

Despite these efforts, the urgency for integrated action is mounting. Nitrogen pollution mitigation could offset 5–10 per cent of global greenhouse gas (GHG) reductions needed to stay within the global warming target. In India, where agriculture is the largest source of N_2O emissions, coordinated nitrogen policies can yield enormous climate co-benefits. While India's Nationally Determined Contributions (NDCs) currently do not make specific reference to nitrogen, the scope for incorporating it in future strategies remains considerable.

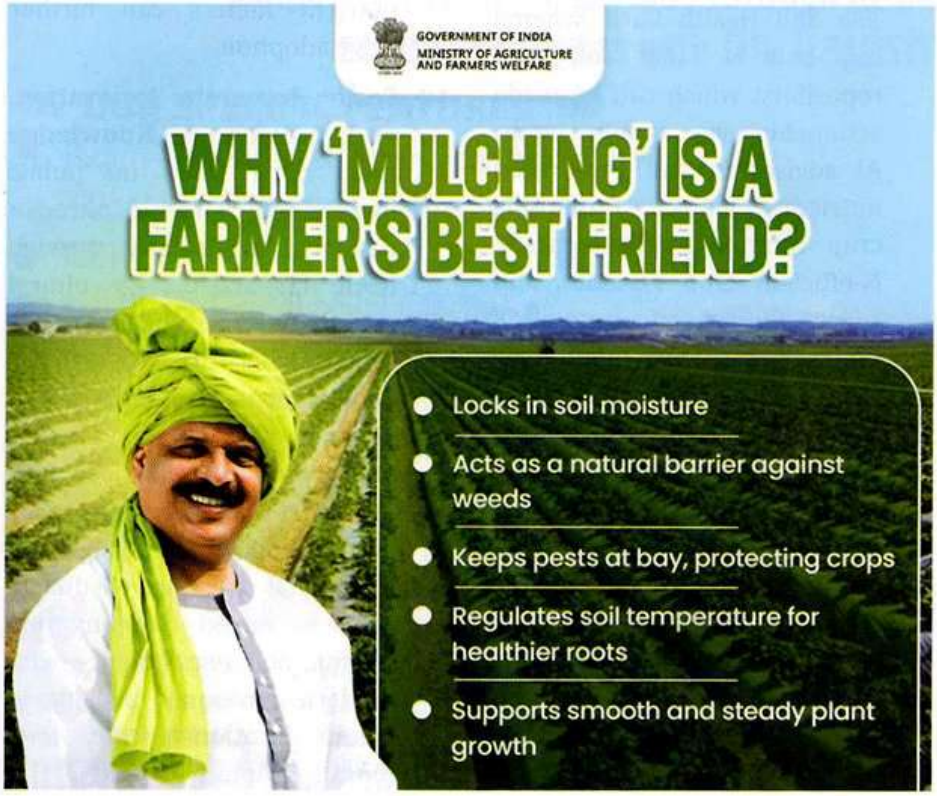
China set a target for a zero increase in fertiliser use in 2015, which has shown results. The EU's Nitrates Directive limits nitrogen application in vulnerable zones and has seen improvements in groundwater quality and farm efficiency. Sri Lanka's abrupt ban on synthetic fertilisers in 2021, however, led to sharp declines in crop yields and farmer protests, highlighting the dangers of blanket bans without transition support.

While the climate gains of managing nitrogen pollution are significant, the greater value lies in local air and water quality improvements, making it politically attractive for countries prioritising domestic benefits. However, challenges remain in policy design, farmer behaviour change, and avoiding pollution trade-offs, requiring integrated, context-specific nitrogen management.

To secure India's agricultural future and reduce the growing risks of nitrogen pollution, a set of actionable and coordinated strategies are needed. These must be

rooted in India's development goals while aligning with climate, health, and water security priorities.

1. **Strengthen Collaborative Partnerships with Agriculture:** India can deepen its partnerships across the agriculture sector to reduce nutrient losses. Taking cues from global models like the EPA–USDA collaboration, ICAR, state agriculture universities, *Krishi Vigyan Kendras* (KVK), and private innovators could collaborate to build strong field-level networks. This will help target nutrient management interventions—such as promoting neem-coated urea or precision application—in areas where pollution is most severe, like the Gangetic basin. Highlighting success stories from progressive farmers and state-led initiatives (e.g., Andhra Pradesh's natural farming programme) can inspire others to adopt cleaner practices.
2. **Support States and Rural Communities with Integrated Water Strategies**: The One Water approach—treating all water sources (groundwater, surface water, and wastewater) holistically—can guide nutrient management. States should be encouraged to use integrated nutrient budgeting across sectors like agriculture, wastewater, and rural sanitation. Special support must go to small, rural, and disadvantaged communities, such as tribal districts in Odisha or Northeast India, with financing options to adopt biofertilisers, drip irrigation, or decentralised waste management systems that reduce nitrogen runoff.
3. **Use India's Environmental Regulations to Drive Progress and Innovation:** India's existing legal frameworks—such as the Water (Prevention and Control of Pollution) Act and the Environment Protection Act—can be strengthened to include numeric standards for nitrate levels in lakes, rivers, and groundwater. Just as the Clean Water Act enables states in the US to implement Total Maximum Daily Loads (TMDLs) for pollutants, Indian states could use similar basin-level plans. The Central and State Pollution Control Boards must be empowered to incentivise innovation in effluent standards, especially in food processing and agro-industries.
4. **Launch a National Nitrogen Mission:** A dedicated National Nitrogen Mission should be created to provide high-level, cross-sectoral coordination across the Ministries of Agriculture, Environment, Health, and Water. The mission can set national goals to improve Nitrogen Use Efficiency (NUE), reduce nitrous oxide (N_2O) emissions, and enhance soil and water quality. The mission should fund research on nitrification inhibitors, mobile soil labs, and innovation pilots.
5. **Integrate Nitrogen into India's Climate Commitments:** Currently, N_2O emissions are not included in India's Nationally Determined Contributions (NDCs). Including these emissions would reflect the full environmental cost of nitrogen use and could open doors to international climate finance. For example, setting a goal to reduce nitrogen fertiliser emissions by 20 per cent over 10 years could become part of India's national climate reporting under the Paris Agreement.
6. **Reform Fertiliser Subsidies for Efficiency**: India spends



roughly Rs 2 lakh crore annually on fertiliser subsidies, mostly on urea. A phased shift to Direct Benefit Transfers (DBT)—linked to soil health data—can incentivise precise and balanced fertiliser use. The government should also promote slow-release, neem-coated, sulphur-coated urea and support the scaling of biofertilisers and organic inputs through public-private partnerships.

7. **Strengthen Regulation and Enforcement in Pollution Hotspots:** Areas like Punjab and Western Uttar Pradesh are facing serious groundwater nitrate contamination. These zones require stricter nitrogen application caps, akin to the EU's Nitrate Directive. River basin authorities like those managing the Yamuna or Ganga should be empowered to include nitrogen load limits and enforce compliance through digital tracking and field inspections. At the same time, farmers must be supported with advisory services and demonstration plots to transit smoothly.

8. **Promote Integrated Soil Remediation, Nutrient and Soil Health Management** The Soil Health Card Scheme has built a large soil data repository, which can be made actionable via mobile apps, AI advisories, and geo-tagged nutrient maps. Promoting crop rotations with legumes, N-efficient crop varieties, and conservation agriculture will optimise nitrogen input. The 4R strategy (Right Source, Right Rate, Right Time, Right Place) should be embedded in KVK training programs and state-level extension efforts. States can establish Nitrogen Management Hubs to incubate, test, and scale up farmer-centric innovations. State Pollution Control Boards can house remediation hubs to promote remediation technologies for nitrogen pollution including constructed wetlands, denitrifying bioreactors, and permeable reactive barriers. These systems use natural or engineered processes to convert harmful nitrates into harmless nitrogen gas and are effective in treating runoff, wastewater, and groundwater in both urban and agricultural settings.

9. **Raise Awareness and Create Market-Based Incentives** Public campaigns are needed to highlight the risks of nitrogen overuse—such as health issues, groundwater contamination, and crop losses. Certification schemes like 'Low Nitrate Vegetables', when linked to e-commerce or institutional buyers (e.g., hospitals, midday meal schemes), can create demand-driven incentives for farmers. Government support for precision agriculture tools like remote sensors, decision dashboards, and handheld nutrient meters can further drive adoption.

10. **Scale Research, Innovation, and Indigenous Knowledge** India must ramp up public investment in nitrogen research, particularly through ICAR, IITs, and the agricultural university system. There's great scope to support the development of climate-smart, nitrogen-efficient crop varieties, affordable diagnostic kits, and real-time tracking tools. Equally important is integrating traditional farming wisdom—such as mixed cropping and organic soil enrichment—with modern agronomic insights to create location-specific, low-input solutions.

Nitrogen is both a miracle nutrient and a potential menace. If used judiciously, it can drive agricultural productivity and ensure food security. If mismanaged, it degrades soil, air, and water, and undermines climate goals. India has already laid the foundation for nitrogen reform through regulatory frameworks, subsidy reforms, and international cooperation.

Yet the scale of the challenge calls for more. A National Nitrogen Mission can coordinate fragmented efforts, while integration into NDCs will enhance global accountability. Trade-offs of promoting green ammonia and its related emission impacts need consideration. Smart subsidies, strong regulation, and farmer-centric extension will ensure that nitrogen remains a boon, not a burden.

Nitrogen pollution in India is a silent storm gathering strength. Under current practices, every harvest season adds more nitrogen waste to our soils, waters and atmosphere. If unchecked, the fallout will deepen India's water contamination, degrade soils, worsen air quality and further complicate India's path toward achieving its climate commitments. But the situation is also an opportunity: improved nitrogen management can raise crop productivity, reduce greenhouse emissions, and save subsidy money—in short, a win-win for agriculture, health and the climate. For India to chart a truly sustainable future, this powerful yet underused lever for addressing climate change is an option. Policymakers should act now: develop a cohesive national, multi-sectoral nitrogen strategy, align it with climate commitments, and reform incentives so that use of this 'miracle nutrient' is efficient, not excessive. It is through coordinated policy action that India can weather this silent storm—ensuring ecological stability and long-term growth.

With improved nitrogen management, India can move closer to a sustainable future—boosting yields, safeguarding ecosystems, and delivering cleaner air and water to millions. The time to act is now. Let India lead the way in making this invisible crisis a visible policy priority. ❑

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