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# Fertilizer Overuse Crisis in Intensive Farming: Strategies for Sustainable Nutrient Management

*Sandeep Chauhan and Santosh Korav
Department of Horticulture , School of Agriculture, Lovely Professional University,(Phagwara) Jalandhar-,Punjab,144411, Punjab, India
*Corresponding Author's email: sonuchauhan58102@gmail.com

Intensive agriculture , focused by demands for higher food production , has led to systematic over application of synthetic nitrogen, phosphorus ,and potassium fertilizers across global cropping systems.This article inspect the scale and effect of fertilizer overuse including greenhouse gas emissions, water eutrophication , soil degradation,and economic losses and assess evidence based solutions such as precision agriculture ,4R nutrient stewardship, biofertilizers, and real time crop sensing . A practical decision framework is presented to guide farmers and agronomists toward more systematic and sustainable nutrient management strategies. This concludes that adopting smarter fertilization approaches is not only an environmental crucial but an economic necessity for long-term food security.

**Keywords:** precision agriculture, nutrient stewardship, eutrophication, soil health

## Introduction

It is estimated that by 2050, the population will grow up to about 9.7 billion people, putting immense strain on agriculture to increase food production through the use of limited land resources. High-intensity farming, featuring intensive plant varieties, mechanized systems, and extensive external inputs, has proven highly effective in increasing agricultural production during the past few decades. But this success was purchased at the high price of fertilizer overuse, becoming one of the major concerns of our age both environmentally and economically. According to data by IFA (2023), the worldwide use of nitrogen fertilizers increased from about 85 million tons in 2000 to almost 140 million tons during the period from 2000 to 2023. The applications of phosphorus and potassium also steadily increased throughout the same time frame. However, often less than 50% of applied nutrients become absorbed by crops, which can be true for nitrogen fertilizers and is even lower for phosphorus. Nitrogen excess can be lost asammonia or transformed by soil bacteria to nitrous oxide (N2O), which is 298 times more powerful as a greenhouse gas than CO2 over the course of a century. Excess nutrients enter bodies of water, causing algae blooms and dead zones due to hypoxia in streams and coastal waters. Soil acidification caused by the excessive use of ammonium fertilizers adversely affects microbial flora and soil quality. Solving the issue of excessive fertilization calls for a change of perspective from the widespread practice of fertilization based on history to informed and precisely planned fertilization according to crops. This article describes the problem and examines solutions along with developing a framework of action.

## The Scale of problems

### Economic losses from excessive use

An estimated US$ 200 billion is spent by farmers across the globe per year on fertilizer, but a significant part of this expenditure ends up in waste due to the inefficient use of these resources. In South Asia, research conducted by IRRI and CIMMYT has indicated that the rice-wheat production system uses excess amounts of nitrogen, between 40-80 kg/ha compared to what the crops require, resulting in high costs without a proportionate increase in yields.

**Environmental Impacts**

Environmental impacts of excessive fertilizer use can be seen in a number of interrelated area:

•Greenhouse gas emissions: The production and usage of artificial nitrogen fertilizers is responsible for around 1 to 2 percent of all anthropogenic emissions in CO2 equivalents if considering nitrous oxide emissions and energy consumption in the fertilizer production process.

•Contamination of water sources: Excessive nitrates have been found in drinking water in Europe, China, and South Asia, and have even exceeded the recommended WHO standard concentration limit of 10 mg/L NO3-N. Phosphorus enrichment causes eutrophication, resulting in more than 400 marine dead zones throughout the world.

•Soil degradation: Long-time application of urea and ammonia fertilizers leads to soil acidification, inhibition of mycorrhiza, and decreased organic matter turnover in soils, thereby destroying its fertility.

•Destruction of biodiversity: Volatilized ammonia alters plant species composition by changing nutrients in neighboring ecosystems.

## Smarter Nutrient Management Strategies

**Nutrient Management 4R Framework**

4R Nutrient Stewardship is a set of principles aimed to promote efficient nutrient management practices through the use of the Right fertilizer source at the Right rate at the Right time, and at the Right place. The 4R Nutrient Stewardship framework was developed by the International Plant Nutrition Institute (IPNI) in collaboration with other partners in the fertilizer industry.

Application of 4R concepts has been found to lead to an increase of nitrogen efficiency by 15–30% with no reduction of crop productivity. Split application of nitrogen, which means application of two or three doses of nitrogen in accordance with crop development stages, leads to a decrease of ammonia losses due to ammonia volatilization in comparison to pre-planting application of one dose of nitrogen. Application of phosphorus in bands close to roots improves phosphorus efficiency by 20–40%. For example, in rice-wheat systems, split nitrogen application at tillering and panicle initiation improves efficiency.

**Precision agriculture and Variable Rate Technology**

Precision agricultural technologies make it possible to conduct a nutrient management strategy on-site and according to a more detailed scale. Some of the important methods in this area include:

• Soil EC mapping through the use of sensors installed on field equipment. Such a method allows us to indirectly measure soil composition by measuring its electrical conductivity and thereby estimating the soil ability to store nutrients.

• Remote sensing by satellite or drones, as well as vegetation indices like NDVI and NDRE to assess the nitrogen content in crops.

• GPS-controlled machinery allowing varying fertilizer spreading based on prescription maps made from multiple data layers concerning soils and vegetation.

• Chlorophyll meters and optical sensors like GreenSeeker and Yara N-sensor providing real-time assessments of canopy reflectance and consequently fertilizer needs.

**Efficient Fertilizer Technology**

Efficient fertilizers are technologies that alter the rate of nutrient release or block nutrient transformations to achieve synchronization between nutrient supply and plant demands. There are three main types: slow-release and controlled-release fertilizers (CRFs) based on polymer and sulfur coating technology, urease inhibitors that block the hydrolysis of urea to ammonia, and nitrification inhibitors including 3,4-Dimethylpyrazole phosphate and

Dicyandiamide that block ammonium oxidation to nitrate, minimizing greenhouse gas emissions and leaching potential.

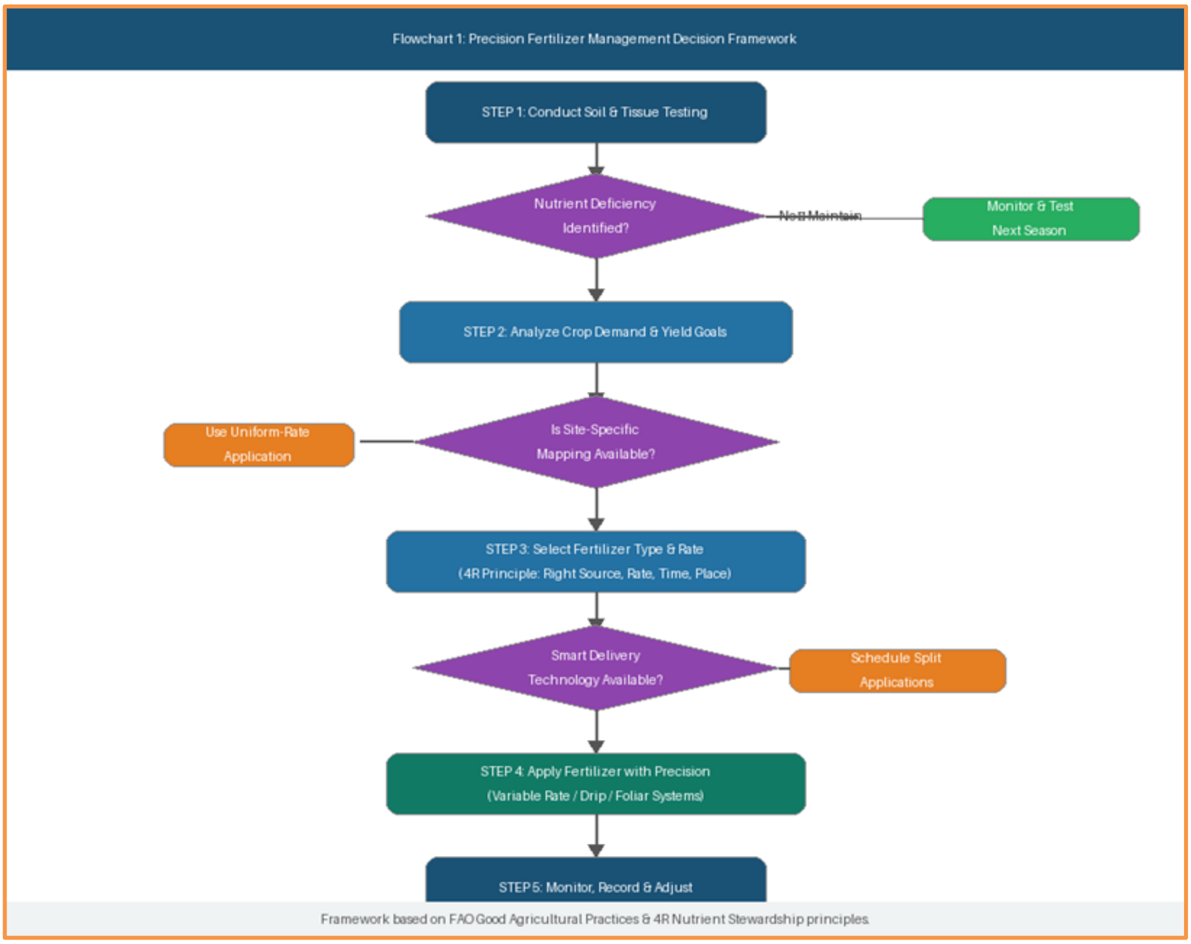
Polymer-coated urea formulations used as single shots for irrigated maize crops at the planting stage showed similar yield potential as conventional urea fertilizers applied in split shots but required reduced labor input and decreased N2O emissions by 35% (Hyatt et al., 2021).

**Biofertilizers and Organic Management**

Nitrogen fixation by both free-living and symbiotic microorganisms (Rhizobium, Azospirillum, Azotobacter) provides an endless and environmentally friendly source of nutrients. Modern biofertilizers containing beneficial bacteria, mycorrhizae, and phosphorus-solubilizing microorganisms may partially replace artificial fertilizers and improve soil quality at the same time. For legume-cereal rotations, biological nitrogen fixation by residues from soybean and chickpeas could provide 50–150 kg/ha N for cereals, thus significantly cutting artificial nitrogen needs.The approach called integrated nutrient management (INM), which implies using organic sources (compost, farmyard manure, crop residues) combined with selected artificial fertilizers, performs better than the use of either of the two input types alone. Integrated nutrient management methods enhance soil organic carbon content, moisture retention capacity, and nutrient availability, resulting in 25–40% fewer synthetic fertilizers compared to control plots in India, Sub-Saharan Africa, and Latin America.

## Decision Framework for Precision Fertilizer Management

The practical application of the above strategies on a farm can only be achieved through a systematic approach to decision making, taking into account factors such as the nature of the soils, technologies available, and needs of crops as well as economics. Below is a Flowchart of a decision tree showing how this can be done based on FAO Good Agricultural Practices and 4R nutrient stewardship principle



Precision Fertilizer Management Decision Framework. The five-step process guides practitioners from soil testing through application method selection to monitoring, integrating 4R principles at each decision node (FAO, 2022).

**Implementation Tips for Framework**

The framework follows an iterative approach, not a sequential one. Data obtained from the monitoring process in Step 5 is immediately used to fine-tune soil testing and prescriptions for the upcoming year. In data-abundant areas where satellite images are available and where information about planters exists, Steps 2 and 3 could be partly automated using decision support systems like climate,fieldview,granular insights, and IFFCO Kisan. Where resources are scarce, the use of this framework is still feasible by using soil test kits and advisory services at the village level.

## Challenges and Obstacles to Adoption

While there is overwhelming scientific support for better fertilization practices, adoption by small-scale farmers and even large-scale farms is still far from satisfactory. Some of the major obstacles are as follows:

•Limited awareness and extension support: Farmers still rely on their traditional methods or those suggested by dealers without considering soil analysis reports because of poor extension service coverage and limited literacy regarding agronomy.

•High costs of precision technology: Precision technology such as soil probes, drones, and variable-rate applicators involves substantial financial outlay that could be unaffordable for small-scale farmers unless they have access to favorable financing options.

•Subsidy distortions: Fertilizer subsidy systems in agricultural countries such as India, China, and parts of Africa have traditionally led to over-application through separating application rates from cost considerations, which makes changes politically challenging.

•Yield risks from reduced inputs: Farmers unfamiliar with reduced fertilizer input may be concerned about potential yield risks, and hence demonstrations on smaller plots are essential before any adoption process can begin.

It will be necessary to coordinate efforts between government policies, private sector initiatives, extension services, and farmers' associations to address these challenges. Subsidy reforms aimed at supporting soil testing facilities, biological fertilizers, or vouchers for more efficient use of fertilizers can help create economic incentives towards sustainable practices.

## Conclusion

The fertilizer overuse problem is a disaster on two fronts: environmental and economic. Around the world, millions of tons of fertilizer nutrients are wasted every year through evaporation, erosion, and runoff, causing harm to soil health, pollution, climate change, and other ecological damages, failing to benefit the crops meant to receive the fertilizers. There have been many proven solutions to this fertilizer overuse problem, including precision agriculture, the 4R concept, enhanced-efficiency fertilizers, bio-fertilizers, and integrated nutrient management. The decision model outlined in this paper can serve as a valuable tool in implementing such solutions. Nonetheless, technology alone will not solve the problem. The right policy environment, agricultural extension programs, and local research initiatives are just as important to the process. The move towards better fertilizer practices does not mean lowering production levels. On the contrary, the new benchmark for agricultural performance will be yield per unit of fertilizer input, not yield per hectare of land.

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