



# International Journal of Research in Agronomy

E-ISSN: 2618-0618

P-ISSN: 2618-060X

© Agronomy

NAAS Rating (2026): 5.20

[www.agronomyjournals.com](http://www.agronomyjournals.com)

2026; 9(5): 98-106

Received: 12-02-2026

Accepted: 18-03-2026

The authors' details and affiliations are provided below, following the reference section

## Integrated nutrient management and its impact on soil health, nutrient use efficiency and crop productivity

Aakash Kumar Saini, Jyoti Kahar, Lalit Krishna Yadav, Pradeep Chouhan, Priya Niva Kujur, Rohitash Meena, Sidharth Sankar Acharya, Shikha Goswami, Nikhil Yadav and Urmila Choudhary

DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i5b.5484>

### Abstract

Integrated Nutrient Management (INM) is a sustainable approach that combines the judicious use of chemical fertilizers, organic manures, crop residues and bio-fertilizers to maintain soil fertility, enhance nutrient use efficiency and improve crop productivity. Continuous reliance on inorganic fertilizers alone has led to soil degradation, nutrient imbalances and declining factor productivity, highlighting the need for integrated strategies. INM improves soil health by enhancing soil physical properties such as structure, porosity and water holding capacity, while also enriching soil organic carbon and microbial activity. The combined application of organic and inorganic nutrient sources ensures a balanced and synchronized nutrient supply, reduces nutrient losses through leaching, volatilization and fixation, and increases nutrient availability to plants. As a result, nutrient use efficiency is significantly improved, leading to better plant growth, higher yield attributes and enhanced crop productivity. In addition, INM contributes to improved crop quality and supports long-term sustainability of agricultural systems by minimizing environmental pollution and promoting efficient resource utilization. The approach is particularly beneficial in diverse cropping systems where it helps maintain soil fertility and economic profitability. Therefore, the adoption of INM practices plays a crucial role in achieving sustainable agricultural production, improving soil resilience and ensuring food and nutritional security under changing climatic conditions.

**Keywords:** Integrated nutrient management, soil health, nutrient use efficiency, crop productivity, organic manures

### Introduction

Integrated Nutrient Management (INM) has emerged as a key strategy for sustainable agriculture, aiming to maintain soil fertility, enhance crop productivity, and minimize environmental degradation through the balanced integration of organic, inorganic, and biological nutrient sources (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Panta & Parajulee, 2021; Selim, 2020). It involves the judicious and efficient use of chemical fertilizers, organic manures, crop residues, green manures, and biofertilizers to synchronize nutrient supply with crop demand, improve nutrient-use efficiency, and sustain soil productivity over the long term (Paramesh *et al.*, 2023; Ali *et al.*, 2024; Panta & Parajulee, 2021; Shah & Wu, 2019; Chejara *et al.*, 2021). Rather than replacing mineral fertilizers, INM integrates them with renewable organic resources and beneficial microorganisms to develop resilient and environmentally sound nutrient management systems (Yadav *et al.*, 2025; Wu & Baoluo, 2015; Selim, 2020; Chejara *et al.*, 2021)<sup>[10, 42, 43]</sup>.

Conceptually, INM combines traditional practices such as farmyard manure application, composting, crop rotation, and biological nitrogen fixation with modern approaches including site-specific nutrient management, decision-support tools, smart or slow-release fertilizers, and biofertilizer technologies (Yadav *et al.*, 2025; Ali *et al.*, 2024; Panta & Parajulee, 2021; Shah & Wu, 2019; Selim, 2020). This integrated approach optimizes the cycling of macro- and micronutrients while reducing losses through leaching, runoff, volatilization, and immobilization, thereby improving soil physical, chemical, biological, and hydrological properties (Paramesh *et al.*, 2023; Ali *et al.*, 2024; Panta & Parajulee, 2021; Al-Shammary *et al.*,

### Corresponding Author:

Aakash Kumar Saini

Ph.D. Scholar, Division of Soil Science, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India

2024; Shah & Wu, 2019) [2, 42, 54, 71].

Research evidence indicates that INM can enhance crop yields by approximately 8-150% compared with fertilizer-only practices, while improving water-use efficiency, grain quality, soil organic carbon, microbial biomass, aggregate stability, and water-holding capacity (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Panta & Parajulee, 2021; Al-Shammery *et al.*, 2024). It also lowers production costs, greenhouse gas emissions, and reactive nitrogen losses, contributing to food security, farm profitability, and environmental protection (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Kumari *et al.*, 2025; Shah & Wu, 2019) [42, 43].

Although synthetic fertilizers have played a crucial role in increasing food production since the Green Revolution, their excessive and imbalanced use has resulted in soil degradation, nutrient imbalances, acidification, loss of organic matter and biodiversity, and contamination of natural resources (Wu & Baoluo, 2015; Dobermann *et al.*, 2022; Shah *et al.*, 2025; Khambalkar *et al.*, 2025; Pahalvi *et al.*, 2021; Tyagi *et al.*, 2022; Bisht & Chauhan, 2020). Long-term fertilizer experiments demonstrate that integrated systems combining mineral fertilizers with organic amendments sustain soil health and crop yields more effectively than sole chemical fertilization (Khambalkar *et al.*, 2025; Al-Shammery *et al.*, 2024). Therefore, INM provides a scientifically sound and sustainable nutrient management framework that supports yield stability, resource recycling, and reduced environmental impacts in modern agriculture (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Panta & Parajulee, 2021; Shah & Wu, 2019; Selim, 2020; Chejara *et al.*, 2021) [2, 8, 9, 10, 17, 25, 40, 42, 43, 68].

### Definition and Objectives of Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) refers to the balanced and judicious use of organic, inorganic, and biological nutrient sources to ensure optimum crop nutrition, sustain soil fertility, and minimize environmental degradation. The approach emphasizes the efficient utilization of locally available resources in combination with mineral fertilizers to maintain long-term agricultural productivity. The major objectives of INM include sustaining or enhancing crop yields over time, improving nutrient use efficiency, recycling organic wastes, reducing the cost of chemical fertilizers, and safeguarding soil and water quality (Selim, 2020; Kumari *et al.*, 2025; Sharma *et al.*, 2025; Chejara *et al.*, 2021). By integrating multiple nutrient sources, INM promotes soil health, environmental sustainability, and economic profitability in cropping systems [10, 24, 49].

### Core Principles and Key Components of Integrated Nutrient Management (INM)

#### Core Principles of INM

Integrated Nutrient Management (INM) is founded on the principle of balanced nutrient use, whereby nutrient inputs are carefully aligned with crop demand and inherent soil nutrient supply. This approach helps to avoid nutrient deficiencies, toxicities, and imbalances that can adversely affect crop productivity and soil health (Selim, 2020; Kamboj *et al.*, 2024; Sharma *et al.*, 2025) [24]. Another fundamental principle is the integration of multiple nutrient sources, which emphasizes the combined use of mineral fertilizers, organic manures, crop residues, and biofertilizers rather than dependence on a single nutrient input. Such integration enhances nutrient use efficiency and supports sustainable soil fertility management.

INM also promotes site-specific nutrient management (SSNM),

wherein nutrient application strategies are tailored according to soil test values, crop type, climatic conditions, and locally available resources. This targeted approach improves nutrient recovery, minimizes losses, and enhances crop productivity. Furthermore, INM maintains a strong sustainability focus, aiming to improve soil organic matter content, stimulate biological activity, and protect environmental quality while ensuring economic feasibility and long-term agricultural productivity (Selim, 2020; Kumari *et al.*, 2025; Yadav *et al.*, 2025; Shahid, 2024) [24, 49, 54, 66, 71].

### Integrated nutrient management and soil health: effects on physical, chemical, biological properties and carbon sequestration

#### Soil physical properties

Across different crops and soil types, Integrated Nutrient Management (INM), which combines organic amendments, mineral fertilizers, and sometimes biofertilizers, has been shown to significantly improve soil physical properties. Long-term application of INM practices generally reduces soil bulk density while increasing soil porosity and water-holding capacity due to enhanced soil organic matter and improved aggregation. Although short-term studies sometimes report only numerical improvements, treatments involving farmyard manure (FYM) or vermicompost combined with recommended doses of NPK fertilizers often show lower bulk density and higher water-holding capacity compared with the sole use of chemical fertilizers, even when differences are not always statistically significant (Madhurya *et al.*, 2022; Bindu *et al.*, 2024; Meena *et al.*, 2016) [7, 16, 29, 31, 36, 38].

Higher application rates of composted manures can further enhance soil structural properties, particularly in arid and semi-arid environments. These organic inputs promote the formation of stable soil aggregates, increase total porosity, improve hydraulic conductivity, and enhance soil water-holding capacity. Overall, INM contributes to the development of more stable soil aggregates and greater macroaggregate formation, thereby improving soil aeration, infiltration, and resistance to compaction compared with systems relying solely on mineral fertilizers (Al-Suhaibani *et al.*, 2020; Sandhu *et al.*, 2020; Nath *et al.*, 2023; Kurmi *et al.*, 2025) [29, 38, 51].

#### Soil chemical properties

Integrated nutrient management also plays a crucial role in improving soil chemical fertility. Numerous studies have reported that INM increases soil organic carbon and the availability of essential nutrients such as nitrogen, phosphorus, potassium, and micronutrients. At the same time, INM practices often result in slight reductions in soil pH and electrical conductivity compared with the exclusive application of mineral fertilizers, contributing to improved nutrient availability and balanced soil chemical conditions (Urmi *et al.*, 2022; Dhaliwal *et al.*, 2021; Paramesh *et al.*, 2023; Al-Suhaibani *et al.*, 2020; Sandhu *et al.*, 2020; Singh *et al.*, 2020; Meena *et al.*, 2016) [3, 16, 36, 43].

Long-term experiments in cropping systems such as maize-wheat and rice-wheat have demonstrated that integrating FYM with mineral fertilizers can increase soil organic carbon from approximately 0.4-0.5% to about 0.6-0.7%, along with higher levels of available N, P, and K. These systems also show improved concentrations of DTPA-extractable micronutrients, including zinc, copper, iron, and manganese (Dhaliwal *et al.*, 2021; Sandhu *et al.*, 2020). Short-term studies similarly report increased soil organic carbon, improved cation exchange

capacity, and enhanced nutrient availability when 25-50% of mineral nitrogen is substituted with FYM or vermicompost combined with biofertilizers (Madhurya *et al.*, 2022; Bindu *et*

*al.*, 2024; Tomar & Saikia, 2022; Prakash *et al.*, 2024; Meena *et al.*, 2016) [7, 16, 31, 36, 51, 67].

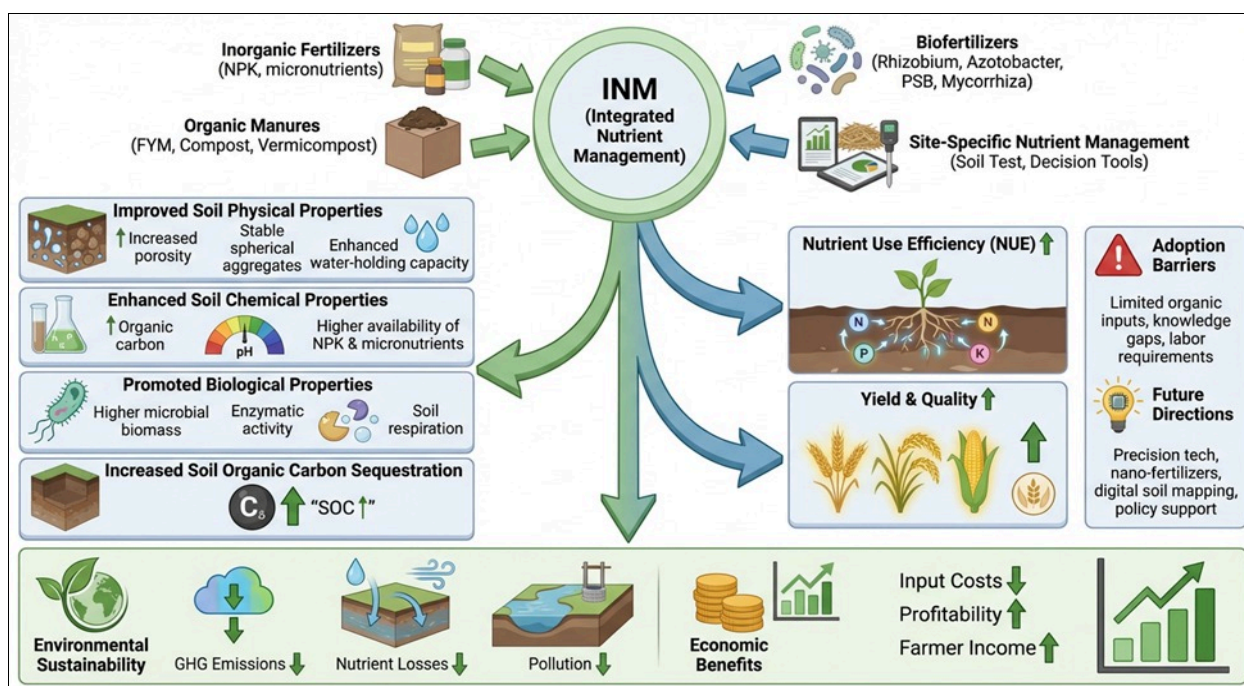


**Fig 1:** Integrated nutrient management (INM) and its effects on soil health, nutrient use efficiency, and crop productivity

### Soil biological properties

INM strongly enhances soil biological activity by increasing microbial biomass, soil respiration, and enzymatic activities such as dehydrogenase, phosphomonoesterase, and urease compared with soils receiving only chemical fertilizers. These improvements are largely attributed to the addition of organic substrates that stimulate microbial growth and provide energy sources for soil microorganisms.

Studies in cropping systems such as rice, dolichos bean, and maize-wheat indicate that treatments combining 25-50% of the recommended NPK dose with enriched compost, vermicompost, or FYM along with biofertilizers produce the highest levels of microbial biomass carbon and enzyme activities. These improvements reflect enhanced nutrient cycling and better soil biological functioning under integrated nutrient management practices (Dhaliwal *et al.*, 2021; Paramesh *et al.*, 2023; Tomar & Saikia, 2022; Mallikarjun & Maity, 2018; Gupta & Bordoloi, 2024) [16, 20, 32, 43, 67].

### Soil organic carbon sequestration

Integrated nutrient management also contributes significantly to soil organic carbon (SOC) sequestration and long-term soil sustainability. Long-term rice-wheat experiments have demonstrated that replacing a portion of mineral nitrogen with organic sources such as FYM, green manure, or crop residues increases SOC stocks and carbon sequestration rates. For instance, SOC sequestration rates of approximately 0.29 Mg C ha<sup>-1</sup> yr<sup>-1</sup> have been reported under integrated nutrient management compared with about 0.13 Mg C ha<sup>-1</sup> yr<sup>-1</sup> under sole NPK fertilization (Sandhu *et al.*, 2020) [51].

Very long-term experiments spanning more than three decades across different soil orders have further confirmed sustained increases in total organic carbon, particulate organic carbon, and microbial biomass carbon, along with higher carbon management indices under INM practices (Das *et al.*, 2025). In

addition, short- to medium-term studies in rice-based and arid cropping systems indicate that the incorporation of organic manures and composts within integrated nutrient management strategies increases SOC stocks and enhances carbon sequestration potential in agricultural soils (Urmi *et al.*, 2022; Al-Suhaibani *et al.*, 2020) [3, 15, 69].

### Integrated Nutrient Management and Nutrient Use Efficiency

Integrated Nutrient Management (INM) is widely recognized for improving nutrient use efficiency (NUE) of major nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients, while simultaneously reducing nutrient losses compared with sole chemical fertilization. NUE refers to the efficiency with which applied nutrients are converted into crop yield and can be expressed through different indices, including agronomic efficiency, apparent recovery efficiency, physiological efficiency, and utilization efficiency (Begizew, 2020; Congreves *et al.*, 2021). It integrates both nutrient uptake efficiency, which represents the ability of plant roots to capture nutrients from the soil, and utilization efficiency, which reflects the capacity of plants to convert absorbed nutrients into biomass or economic yield (Begizew, 2020; Congreves *et al.*, 2021) [5, 13]. Studies across various cropping systems have demonstrated that INM enhances nitrogen use efficiency by increasing fertilizer-use efficiency and apparent nitrogen recovery. Integrated approaches involving the combined application of organic manures, mineral fertilizers, and biofertilizers often allow up to 50% reduction in mineral nitrogen application without yield reduction, particularly in systems such as rice-wheat, wheat, cotton-green gram, and rice (Darjee *et al.*, 2022; Ramteke & Gabhane, 2023; Bhardwaj *et al.*, 2023; Midya *et al.*, 2021; Urmi *et al.*, 2022; Begizew, 2020). INM also contributes to reduced nitrogen losses, including ammonia volatilization, nitrate leaching, and denitrification. For example, integrated treatments

involving NPK fertilizers along with biofertilizers such as *Azotobacter* and mycorrhiza have been reported to lower reactive nitrogen losses and reduce emissions of nitrous oxide and other greenhouse gases without compromising crop productivity (Wu & Baoluo, 2015; Darjee *et al.*, 2022; Paramesh *et al.*, 2023; Suchitha *et al.*, 2025; Selim, 2021)<sup>[5, 6, 14, 37, 46, 69]</sup>.

Integrated nutrient management further enhances the use efficiency of phosphorus and potassium by improving nutrient uptake and availability. Substitution of 25-50% of mineral nitrogen with organic sources such as farmyard manure, gliricidia, or compost, in combination with biofertilizers, has been shown to increase NUE of N, P, and K in various cropping systems. Additionally, the integration of organic amendments with mineral fertilizers improves phosphorus fractionation and increases labile phosphorus pools in soil, thereby enhancing phosphorus availability and utilization by crops (Ramteke & Gabhane, 2023; Singh *et al.*, 2025; Midya *et al.*, 2021; Chauhan & Bhatt, 2025)<sup>[9, 37, 43, 46]</sup>.

Long-term application of INM also improves the availability and uptake of micronutrients such as iron (Fe), zinc (Zn), copper (Cu), and manganese (Mn). Studies have reported increased DTPA-extractable micronutrient concentrations and improved nutrient translocation from vegetative plant parts to grains under integrated nutrient management practices compared with sole NPK fertilization (Bhardwaj *et al.*, 2023; Selim, 2021; Saha *et al.*, 2019)<sup>[48]</sup>.

Several mechanisms explain the positive influence of INM on nutrient use efficiency. The synchronization of nutrient supply with crop demand is improved through the combined use of slow-release organic sources and readily available mineral fertilizers, thereby reducing nutrient losses and enhancing uptake efficiency (Bhardwaj *et al.*, 2023; Begizew, 2020; Selim, 2021). INM also promotes soil biological activity and carbon availability, which enhances nutrient mineralization, enzyme activity, and nutrient cycling, particularly for nitrogen and phosphorus (Wu & Baoluo, 2015; Paramesh *et al.*, 2023; Bhardwaj *et al.*, 2023; Singh *et al.*, 2025; Selim, 2021). Furthermore, organic amendments help to reduce phosphorus fixation by forming complexes with iron and aluminum in the soil and increasing labile and organically bound phosphorus fractions, thereby improving phosphorus use efficiency in rice-based cropping systems (Singh *et al.*, 2025)<sup>[5, 6, 43]</sup>.

### **Integrated Nutrient Management in Cropping Systems: Focus on Cereals, Pulses/Oilseeds, Horticulture, and Cropping Sequences**

Integrated Nutrient Management (INM) refers to the judicious and combined use of organic, inorganic, and biological nutrient sources to sustain crop productivity, maintain soil health, enhance profitability, and minimize environmental pollution. In recent years, INM has increasingly been advocated at the cropping system level rather than for individual crops, as system-based nutrient strategies improve nutrient cycling, resource-use efficiency, and long-term sustainability.

#### **Growth of INM Research across Crops and Systems**

The scientific literature on INM has expanded steadily over the past decade, reflecting growing interest in sustainable nutrient management. Early work documented system-level benefits in cereal-based rotations. Subsequent studies strengthened evidence on yield enhancement, soil quality improvement, and economic returns. More recent research highlights diversified cropping systems, climate-smart nutrient strategies, and the role of biological inputs (Mangaraj *et al.*, 2022; Paramesh *et al.*,

2023; Sarwar *et al.*, 2023; Jat *et al.*, 2023; Ondrašek *et al.*, 2023; Kushwah *et al.*, 2023; Ali *et al.*, 2024; Surve *et al.*, 2024; Kamboj *et al.*, 2024; Jastrzębska, 2025; Saini *et al.*, 2025; Kumari *et al.*, 2025; Suchitha *et al.*, 2025; Yadav *et al.*, 2025)<sup>[16, 22, 23, 24, 30, 33, 39, 53, 54, 65, 66, 71]</sup>.

#### **INM in Cereal-Based Cropping Systems**

In cereal systems such as rice, wheat, maize, and barley, INM consistently improves grain yield, soil organic carbon (SOC), microbial biomass, and soil physical properties compared with sole chemical fertilization (Wu & Baoluo, 2015; Sharma *et al.*, 2019; Antil & Raj, 2019; Dhaliwal *et al.*, 2021; Paramesh *et al.*, 2023; Sarwar *et al.*, 2023; Saini *et al.*, 2025; Kamboj *et al.*, 2024). For instance, in rice-rice systems, the integration of farmyard manure (FYM) with recommended fertilizer doses increased grain yield, soil carbon stock, energy-use efficiency, and net economic returns relative to fertilizer-only treatments (Paramesh *et al.*, 2023). Similarly, meta-analytical evidence from rice-wheat systems shows higher productivity and profitability under INM than under inorganic-only, organic-only, or unfertilized controls (Sharma *et al.*, 2019). Long-term experiments in maize-wheat rotations further demonstrate improvements in SOC, available N, P, K, and soil structural stability under combined FYM and fertilizer application (Dhaliwal *et al.*, 2021)<sup>[4, 16, 24, 43, 49, 53]</sup>.

#### **INM in Pulse and Oilseed Cropping Systems**

System-based INM practices also enhance productivity in pulse- and oilseed-based rotations. In peanut-wheat systems, the application of 75-100% recommended fertilizer dose (RDF) combined with FYM and plant growth-promoting rhizobacteria (PGPR) significantly increased system productivity, profitability, and net energy returns (Jat *et al.*, 2023). Inclusion of legumes, such as greengram in rice-greengram sequences, under INM regimes (e.g., 50% RDF through fertilizers and 50% N through FYM along with phosphate-solubilizing bacteria) has been shown to improve soil nutrient balance and overall system performance due to biological nitrogen fixation and residual nutrient effects (Mangaraj *et al.*, 2022; Suchitha *et al.*, 2025)<sup>[23, 33, 65]</sup>.

#### **INM in Horticultural and Cash Crop Systems**

In horticultural crops and cash crops such as cotton, sugarcane, and potato, INM improves yield attributes, nutrient uptake efficiency, produce quality, and physiological performance while reducing nutrient leaching and greenhouse gas emissions (Paramesh *et al.*, 2023; Ali *et al.*, 2024; Surve *et al.*, 2024; Kumari *et al.*, 2025). The integration of composts, biofertilizers, and biostimulants within INM frameworks has gained particular importance in fruit and vegetable production, including protected cultivation and soilless systems, where nutrient-use efficiency and environmental sustainability are critical (Ali *et al.*, 2024; Surve *et al.*, 2024)<sup>[43, 66]</sup>.

#### **INM in Cropping Sequences, Rotations, and Intercropping**

System-level nutrient management strategies involving crop rotations, sequential cropping, and intercropping are increasingly recognized as more sustainable than single-crop fertilization approaches. The incorporation of legumes into cereal-dominated systems enhances nitrogen availability, improves utilization of residual nutrients, and stabilizes yields under rainfed conditions. Moreover, recent reviews emphasize that aligning INM practices with crop rotation patterns, intercropping arrangements, and local agro-ecological

conditions can optimize nutrient cycling of macro- and micronutrients while reducing reactive nitrogen losses and greenhouse gas emissions (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Antil & Raj, 2019; Yadav *et al.*, 2025) [4, 33, 65].

### **Integrated Nutrient Management (INM) as a pillar of sustainable, climate-smart agriculture**

#### **Role in Climate-Smart Agriculture**

INM is widely described as a climate-smart strategy: it maintains yields while reducing greenhouse gas (GHG) emissions and enhancing resilience. Reviews report 8-150% yield increases vs. conventional fertilizer use, alongside higher water-use efficiency and better grain quality and soil health (Wu & Baoluo, 2015; Paramesh *et al.*, 2023; Yadav *et al.*, 2025; Sharma *et al.*, 2022; Saini *et al.*, 2025). In rice and other systems, INM cuts GHGs by lowering synthetic N use, increasing soil organic matter and stimulating microbes that improve nutrient cycling and stress tolerance (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Yadav *et al.*, 2025; Marzouk *et al.*, 2024; Urmi *et al.*, 2022). INM thus supports all three CSA pillars: productivity, adaptation, and mitigation (Wu & Baoluo, 2015; Yadav *et al.*, 2025; Marzouk *et al.*, 2024; Sharma *et al.*, 2025; Sharma *et al.*, 2022) [35, 43, 49, 71].

#### **Reduction in Environmental Pollution**

By partially substituting mineral fertilizers with manures, composts, residues and biofertilizers, INM reduces nutrient losses via leaching, runoff, volatilization and denitrification (Paramesh *et al.*, 2023; Wu & Baoluo, 2015; Panta & Parajulee, 2021; Urmi *et al.*, 2022). Modeling and field syntheses show lower reactive N losses and substantially reduced GHG emissions under advanced INM at equal yields (Wu & Baoluo, 2015; Paramesh *et al.*, 2023; Sharma *et al.*, 2022; Urmi *et al.*, 2022). One review reports a 1,355% reduction in methane relative to conventional nutrient management in cropped fields (Paramesh *et al.*, 2023). INM also lowers risks of water contamination and heavy nutrient surpluses while safely recycling organic wastes into compost (Wu & Baoluo, 2015; Panta & Parajulee, 2021; Urmi *et al.*, 2022; Saini *et al.*, 2025) [42, 43, 49, 69].

#### **Soil Fertility Sustainability & Long-Term Productivity**

Repeated INM applications build soil organic matter, improve bulk density, aggregation and water-holding capacity, and enhance microbial activity, sustaining fertility over time (Paramesh *et al.*, 2023; Kumari *et al.*, 2025; Choudhary *et al.*, 2025; Sharma *et al.*, 2022; Urmi *et al.*, 2022; Saini *et al.*, 2025). Long-term and rotation studies show stable or rising yields, better nutrient-use efficiency, and improved nutrient balance compared with fertilizer-only systems (Wu & Baoluo, 2015; Sharma *et al.*, 2025; Sharma *et al.*, 2022; Antil & Raj, 2019; Urmi *et al.*, 2022). INM is thus framed as a long-term approach to sustainability, reconciling high productivity with soil and environmental protection (Wu & Baoluo, 2015; Sharma *et al.*, 2025; Sharma *et al.*, 2022; Saini *et al.*, 2025) [4, 12, 43, 69].

#### **Integrated Nutrient Management (INM): Economic Benefits**

Integrated Nutrient Management (INM) contributes significantly to farm profitability and economic sustainability by improving crop yields, enhancing fertilizer-use efficiency, and reducing dependence on costly chemical fertilizers. Systematic evidence across cereals, pulses, oilseeds, and horticultural crops indicates that INM generally increases the benefit-cost (B:C) ratio and farmer income, often at comparable or even reduced input costs.

#### **Cost-Benefit Ratio and Profitability**

Numerous studies demonstrate that INM or optimized nutrient management practices enhance profitability by 10-20% or more compared with farmers' conventional fertilizer practices, largely due to higher productivity and improved nutrient-use efficiency (Chivenge *et al.*, 2021; Gholkar *et al.*, 2022; Gyanwali *et al.*, 2022; Paramesh *et al.*, 2023; Sarwar *et al.*, 2023; Ren *et al.*, 2025; Manohar *et al.*, 2025). Long-term experimental evidence supports these findings. In a 40-year rice-wheat system, the INM treatment comprising 50% inorganic nitrogen and 50% farmyard manure (FYM) in rice followed by 100% recommended fertilizer dose (RDF) in wheat recorded the highest net returns and B:C ratio, highlighting the economic superiority of integrated nutrient strategies over fertilizer-only approaches (Manohar *et al.*, 2025). Similarly, in rice-rice systems in India, the combined use of FYM and chemical fertilizers increased net returns from USD 1508 to USD 1776 ha<sup>-1</sup>, along with improvements in soil quality and energy-use efficiency (Paramesh *et al.*, 2023). In maize-wheat cropping systems, the application of 75% recommended NPK combined with biochar enhanced system productivity and economic sustainability relative to full mineral fertilization (Sarwar *et al.*, 2023) [11, 19, 21, 34, 43, 53].

#### **Reduction in Fertilizer Input Costs**

A major economic advantage of INM is the partial substitution of mineral fertilizers with locally available organic inputs, which reduces fertilizer expenditure without compromising yield. Farmer-participatory nutrient management trials in wheat reported a 24.7% reduction in fertilizer use and a 15.6% decrease in fertilizer cost compared with conventional farmer practices (Ren *et al.*, 2025). Meta-analytical evidence on site-specific nutrient management sharing similar objectives with INM shows that optimizing fertilizer inputs can reduce nitrogen application by about 10% while increasing profitability by 15% across major cereal crops such as maize, rice, and wheat (Chivenge *et al.*, 2021). Review studies further emphasize that INM is a cost-effective nutrient management approach, as the use of manures, crop residues, and biofertilizers lowers reliance on purchased fertilizers and stabilizes production costs (Selim, 2020; Chejara *et al.*, 2021; Saini *et al.*, 2025; Kamboj *et al.*, 2024) [10, 11, 24, 49].

#### **Effects on Farmer Income**

By combining higher yields with optimized input costs, INM directly contributes to increased net farm income and livelihood security. In wheat, farmer-participatory nutrient management increased net income by 14.5% (approximately USD 236 ha<sup>-1</sup>) compared with farmers' standard fertilizer practice (Ren *et al.*, 2025). In vegetable production, cauliflower grown with 50% NPK combined with vermicompost achieved a B:C ratio of 3.19, allowing a 50% reduction in chemical fertilizer use without sacrificing profitability (Gyanwali *et al.*, 2022) [21]. Similarly, intercropping systems benefit economically from INM practices. For instance, mungbean-sorghum intercropping with compost or FYM integrated with nitrogen and phosphorus fertilizers produced the highest net income (about PKR 225,000 ha<sup>-1</sup>) and a B:C ratio of around 1.9, outperforming other nutrient management options (Fayyaz *et al.*, 2024) [18].

#### **Synthesis**

Overall, the economic evidence indicates that INM enhances resource-use efficiency, yield stability, profitability, and long-term soil productivity, making it a financially viable and

environmentally sustainable nutrient management strategy for diverse cropping systems (Selim, 2020; Chivenge *et al.*, 2021; Paramesh *et al.*, 2023; Saini *et al.*, 2025; Kamboj *et al.*, 2024; Ren *et al.*, 2025) [11, 24, 43, 49, 54].

**Constraints and Challenges in Adoption of Integrated Nutrient Management (INM)**

Despite the proven agronomic, economic, and environmental advantages of Integrated Nutrient Management (INM), its large-scale adoption remains constrained by several practical and institutional challenges. One of the major limitations is the limited availability and inconsistent quality of organic nutrient sources, such as farmyard manure, compost, crop residues, and biofertilizers. In many regions, these inputs are either insufficient to meet crop nutrient demand or are diverted for alternative uses such as fuel or livestock feed. Another significant constraint is the lack of awareness, technical knowledge, and skill among farmers regarding balanced nutrient application and integrated approaches. Adoption of INM requires understanding of nutrient synchronization, soil testing, and appropriate combinations of organic, inorganic, and biological inputs. Inadequate training and weak extension support often result in continued reliance on conventional fertilizer practices. INM practices are also associated with higher labour requirements and time consumption, particularly for collection, preparation, transport, and application of bulky organic materials. Smallholder farmers with limited labour resources may therefore prefer readily available mineral fertilizers. Furthermore, policy and institutional gaps hinder the widespread implementation of INM. Limited incentives for organic input production, inadequate supply chains for biofertilizers, weak soil-testing infrastructure, and insufficient integration of INM

into national nutrient management programs restrict its adoption. Strengthening extension services, market linkages, and policy support is therefore essential for scaling up INM-based systems.

**Future Prospects and Research Needs**

Future research and development efforts should focus on improving the efficiency, scalability, and farmer acceptability of INM strategies. One promising direction is the integration of precision nutrient management technologies, including sensor-based nutrient diagnostics, decision-support tools, and variable-rate fertilizer application. These approaches can optimize nutrient use efficiency and reduce environmental losses. The development and validation of nano-fertilizers and advanced biofertilizers also offer significant potential for enhancing nutrient availability, crop productivity, and stress tolerance while reducing input requirements. Research is needed to assess their long-term impacts on soil health, nutrient cycling, and environmental safety. Another important priority is digital soil fertility mapping and geospatial nutrient management planning, which can support site-specific recommendations and improve fertilizer-use efficiency at regional and national scales. Integration of remote sensing, GIS, and big-data analytics can facilitate real-time monitoring of soil fertility trends and nutrient balances. In addition, policy support for sustainable nutrient management is crucial. This includes incentives for organic resource recycling, promotion of integrated nutrient packages, strengthening soil-testing services, and capacity building through farmer training and participatory research. Long-term system-based experiments are also needed to evaluate the cumulative impacts of INM on productivity, soil carbon sequestration, nutrient-use efficiency, and climate resilience.

**Table 1:** Major components of Integrated Nutrient Management (INM) and their functional roles in sustainable crop production

| Component                                                  | Main roles in INM                                                                                                                                                                                                                     | Citations                                                                                                                                                         |
|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Inorganic fertilizers                                      | Supply readily available macro- and micronutrients such as N, P, K, and Zn; enable precise nutrient management when guided by soil testing; optimized use prevents soil degradation and environmental pollution.                      | (Selim, 2020; Urmi <i>et al.</i> , 2022; Kamboj <i>et al.</i> , 2024; Chejara <i>et al.</i> , 2021) [10, 24, 54, 69]                                              |
| Organic manures (FYM, compost, vermicompost, green manure) | Provide nutrients along with organic carbon; improve soil structure, water-holding capacity, microbial activity, and carbon sequestration; can partially substitute mineral fertilizers, with vermicompost often being nutrient-rich. | (Sande <i>et al.</i> , 2024; Urmi <i>et al.</i> , 2022; Dhaliwal <i>et al.</i> , 2021; Surve <i>et al.</i> , 2024; Sarvade <i>et al.</i> , 2025) [16, 50, 66, 69] |
| Biofertilizers (Rhizobium, Azotobacter, PSB, Mycorrhiza)   | Enhance biological nitrogen fixation; solubilize and mobilize phosphorus and other nutrients; promote root growth and nutrient uptake; reduce dependence on chemical fertilizers.                                                     | (Saini <i>et al.</i> , 2025; Sande <i>et al.</i> , 2024; Yadav <i>et al.</i> , 2025; Singh & Patel, 2020) [49, 50, 52, 71]                                        |
| Crop residue management and recycling                      | Return nutrients and organic carbon to the soil; improve soil biological activity and structure; reduce environmental pollution from residue burning; complement mineral fertilization.                                               | (Selim, 2020; Saini <i>et al.</i> , 2025; Purohit <i>et al.</i> , 2020; Sarvade <i>et al.</i> , 2025; Kumawat <i>et al.</i> , 2025) [28, 45, 49, 52, 54]          |
| Site-specific nutrient management (SSNM)                   | Uses soil testing, decision-support tools (e.g., Nutrient Expert), and local agro-ecological information to optimize nutrient source, rate, timing, and method of application, thereby improving nutrient recovery and crop yield.    | (Urmi <i>et al.</i> , 2022; Kamboj <i>et al.</i> , 2024; Yadav <i>et al.</i> , 2025; Sharma <i>et al.</i> , 2025; Surve <i>et al.</i> , 2024) [24, 66, 69, 71]    |

**Table 2:** Major impacts of Integrated Nutrient Management (INM) on soil fertility, environmental sustainability, productivity, and farm economics

| Dimension                                           | Key effects of INM                                                                                                                                                                                                                    | Representative citations                                                                                                                                                                                           |
|-----------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Soil fertility and soil health                      | Increases soil organic carbon, available N, P and K; improves soil structure, aggregation, porosity and water-holding capacity; enhances microbial biomass and enzymatic activity, thereby strengthening long-term soil productivity. | (Paramesh <i>et al.</i> , 2023; Selim, 2020; Sharma <i>et al.</i> , 2022; Urmi <i>et al.</i> , 2022; Kumari <i>et al.</i> , 2025; Choudhary <i>et al.</i> , 2025; Saini <i>et al.</i> , 2025) [12, 43, 49, 54, 69] |
| Environmental sustainability and climate mitigation | Reduces nitrogen leaching and nutrient runoff losses; lowers emissions of NH <sub>3</sub> , N <sub>2</sub> O and CH <sub>4</sub> ; improves nutrient recycling and reduces overall carbon footprint of cropping systems.              | (Wu & Baoluo, 2015; Panta & Parajulee, 2021; Urmi <i>et al.</i> , 2022; Paramesh <i>et al.</i> , 2023) [42, 43, 69]                                                                                                |
| Crop productivity and farm economics                | Enhances crop yield (often 8-150%), improves nutrient-use efficiency (NUE), reduces dependence on chemical fertilizers and input costs, and increases net returns and benefit-cost ratio in diversified cropping systems.             | (Wu & Baoluo, 2015; Sharma <i>et al.</i> , 2022; Urmi <i>et al.</i> , 2022; Paramesh <i>et al.</i> , 2023; Sharma <i>et al.</i> , 2025; Kumari <i>et al.</i> , 2025; Saini <i>et al.</i> , 2025) [43, 49, 69]      |

## Conclusion

Integrated Nutrient Management represents a scientifically validated and economically viable strategy for achieving sustainable crop production, improved soil health, and enhanced farmer profitability. By combining organic, inorganic, and biological nutrient sources, INM improves nutrient-use efficiency, stabilizes yields, reduces environmental pollution, and strengthens the resilience of cropping systems. Although constraints related to input availability, labour requirements, technical knowledge, and policy support continue to limit its widespread adoption, emerging technologies such as precision nutrient management, nano-inputs, and digital soil mapping provide new opportunities for advancing INM implementation. Future efforts should therefore focus on system-based nutrient strategies, strengthened extension services, and supportive policy frameworks to ensure long-term agricultural sustainability and food security.

## References

1. Ali A, Niu G, Masabni J, Ferrante A, Cocetta G. Integrated nutrient management of fruits, vegetables, and crops through the use of biostimulants, soilless cultivation, and traditional and modern approaches A mini review. *Agriculture*. 2024. DOI:10.3390/agriculture14081330
2. Al-Shammary A, Al-Shihmani L, Fernández-Gálvez J, Caballero-Calvo A. Optimizing sustainable agriculture: A comprehensive review of agronomic practices and their impacts on soil attributes. *J Environ Manage*. 2024;364:121487. DOI:10.1016/j.jenvman.2024.121487
3. Al-Suhaibani N, Selim M, Alderfasi A, El-Hendawy S. Comparative performance of integrated nutrient management between composted agricultural wastes, chemical fertilizers, and biofertilizers. *Agronomy*. 2020;10(10). DOI:10.3390/agronomy10101503
4. Antil R, Raj D. Integrated nutrient management for sustainable crop production and improving soil health. In: *Nutrient Dynamics for Sustainable Crop Production*. 2019. DOI:10.1007/978-981-13-8660-2\_3
5. Begizew G. Role of integrated nutrient management for enhancing nitrogen use efficiency in crop. *Open J Plant Sci*. 2020. DOI:10.17352/ojps.000017
6. Bhardwaj A, Malik K, Chejara S, Rajwar D, Narjary B, Chandra P. Integration of organics in nutrient management for rice-wheat system improves nitrogen use efficiency. *Front Plant Sci*. 2023;13. DOI:10.3389/fpls.2022.1075011
7. Bindu D, Mamatha B, Gayathri B, Anand S, Subbarayappa C, Rohitha D. Influence of integrated nutrient management on soil properties in quinoa. *Asian J Soil Sci Plant Nutr*. 2024. DOI:10.9734/ajsspn/2024/v10i3358
8. Bisht N, Chauhan P. Excessive and disproportionate use of chemicals cause soil contamination and nutritional stress. In: *Soil Contamination*. 2020. DOI:10.5772/intechopen.94593
9. Chauhan J, Bhatt M. Nitrogen, phosphorus, and potassium uptake in wheat as influenced by integrated nutrient management. *J Adv Biol Biotechnol*. 2025. DOI:10.9734/jabb/2025/v28i103041
10. Chejara S, Malik K, Rani M, Bhardwaj A. Integrated nutrient management: Concept, constraints, and advantages for sustainable agriculture. *J Nat Resour Conserv Manag*. 2021;2(2):85-94.
11. Chivenge P, Saito K, Bunquin M, Sharma S, Dobermann A. Co-benefits of nutrient management tailored to smallholder agriculture. *Glob Food Secur*. 2021;30. DOI:10.1016/j.gfs.2021.100570
12. Choudhary H, Devi N, Rinwa V, Singh A, Roy A, Rana N, *et al*. Impact of integrated nutrient management on soil health and yield of mungbean: A review. *Indian J Agric Res*. 2025. DOI:10.18805/ijare.a-6260
13. Congreves K, Otchere O, Ferland D, Farzadfar S, Williams S, Arcand M. Nitrogen use efficiency definitions of today and tomorrow. *Front Plant Sci*. 2021;12. DOI:10.3389/fpls.2021.637108
14. Darjee S, Shrivastava M, Langyan S, Singh G, Pandey R, Sharma A, *et al*. Integrated nutrient management reduced nutrient losses and increased wheat yield. *Arch Agron Soil Sci*. 2022;69:1298-1309. DOI:10.1080/03650340.2022.2084535
15. Das A, Purakayastha T, Ahmed N, Biswas S, Chakraborty D, Yeasin M, *et al*. Soil organic carbon accrual under integrated organic management. *Soil Use Manag*. 2025;41. DOI:10.1111/sum.70111
16. Dhaliwal S, Sharma S, Sharma V, Shukla A, Walia S, Alhomrani M, *et al*. Long-term integrated nutrient management in maize-wheat system. *Agronomy*. 2021;11. DOI:10.3390/agronomy11112258
17. Dobermann A, Bruulsema T, Cakmak I, Gérard B, Majumdar K, McLaughlin M, *et al*. Responsible plant nutrition: A new paradigm. *Glob Food Secur*. 2022. DOI:10.1016/j.gfs.2022.100636
18. Fayyaz F, Anwar A, Yousaf G. On-farm crop productivity and economic assessment under integrated nutrient management. *J Agric Sci Sri Lanka*. 2024. DOI:10.4038/jas.v19i2.9988
19. Gholkar M, Thombare P, Koli U, Kumbhar N. Techno-economic assessment of land remediation through nutrient management. *Environ Chall*. 2022. DOI:10.1016/j.envc.2022.100492
20. Gupta K, Bordoloi N. Integrated nutrient management effect on soil properties and crop yield. *Agric Sci Dig*. 2024. DOI:10.18805/ag.d-6159
21. Gyanwali P, Singh K, Pathak R, Bhattarai B. Effect of integrated nutrient management on cauliflower growth and yield. *Nepal Hortic*. 2022. DOI:10.3126/nh.v16i1.44967
22. Jastrzębska M. Integrated management and efficient use of nutrients in crop systems. *Agriculture*. 2025. DOI:10.3390/agriculture15101098
23. Jat R, Jain N, Yadav R, Reddy K, Choudhary R, Zala P, *et al*. System-based integrated nutrient management improves productivity and soil quality. *Sustainability*. 2023. DOI:10.3390/su15021361
24. Kamboj D, Choudhary R, Diwakar A, Maurya S. Integrated nutrient management for improving soil sustainability and crop productivity. *J Adv Biol Biotechnol*. 2024. DOI:10.9734/jabb/2024/v27i111690
25. Khambalkar P, Agrawal S, Dhaliwal S, Yadav S, Sadawarti M, Singh A, *et al*. Sustainable nutrient management balancing soil health and food security. *Appl Food Res*. 2025. DOI:10.1016/j.afres.2025.101087.
26. Kumar A, Menon S. A review on integrated nutrient management: An approach to sustainability. *Int J Chem Stud*. 2020. DOI:10.22271/chemi.2020.v8.i6y.11023
27. Kumari R, Ranjan S, Saha R, Das S, Paswan S, Kumari P. Enhancing crop productivity and soil health through integrated nutrient management in cash crop systems. *AATCC Rev*. 2025;13(2). DOI:10.21276/aatccreview.2025.13.02.73
28. Kumawat A, Kumar D, Shivay YS, Sangwan S, Yadav D,

- Pooniya V, *et al.* Optimal combinations of green manures and composts for improving soil properties and rice yield. *Int J Plant Prod.* 2025;19:99-116. DOI:10.1007/s42106-024-00322-2
29. Kurmi P, Rai H, Upadhyaya A, Mandloi S. Effect of long-term nutrient management practices on soil physical properties under rice-wheat system. *Indian J Soil Conserv.* 2025.
  30. Kushwah N, Billore V, Sharma O, Singh D, Chauhan A. Integrated nutrient management for optimal plant health and crop yield. *Plant Sci Arch.* 2023. DOI:10.51470/psa.2023.8.2.10
  31. Madhurya P, Latha M, Rao CC, Sree S. Effect of integrated nutrient management on soil physico-chemical properties. *Int J Plant Soil Sci.* 2022. DOI:10.9734/ijpss/2022/v34i242733
  32. Mallikarjun M, Maity S. Effect of integrated nutrient management on soil biological properties in rice. *Int J Curr Microbiol Appl Sci.* 2018. DOI:10.20546/ijcmas.2018.711.176
  33. Mangaraj S, Paikaray R, Maitra S, Pradhan S, Garnayak L, Satapathy M, *et al.* Integrated nutrient management improves growth and yield in rice-greengram system. *Plants.* 2022;11. DOI:10.3390/plants11010142
  34. Manohar B, Sanjay K, Rakesh K, Mainak G, Shweta S, Srivastava J. Impact of integrated nutrient management on wheat productivity under long-term system. *Plant Sci Today.* 2025. DOI:10.14719/pst.7721
  35. Marzouk S, Kwaslema D, Omar M, Mohamed S. Soil microbes and integrated nutrient management for sustainable rice production: A review. *Heliyon.* 2024;11. DOI:10.1016/j.heliyon.2024.e41158
  36. Meena S, Swaroop N, Dawson J. Effect of integrated nutrient management on soil properties. *Agric Sci Dig.* 2016;36:56-59. DOI:10.18805/asd.v35i1.9312
  37. Midya A, Saren B, Dey J, Maitra S, Praharaj S, Gaikwad D, *et al.* Integrated nutrient management improves nutrient uptake and soil health in rice. *Agronomy.* 2021. DOI:10.3390/agronomy11091894
  38. Nath C, Dutta A, Hazra K, Praharaj C, Kumar N, Singh S, *et al.* Long-term impact of organic amendments on soil properties. *Sci Rep.* 2023;13. DOI:10.1038/s41598-023-33255-3
  39. Ondrašek G, Al-Tawaha A, Bell RW. Integrated nutrient management for sustainable crop production and food security. *Front Plant Sci.* 2023;14. DOI:10.3389/fpls.2023.1288030
  40. Pahalvi H, Rafiya L, Rashid S, Nisar B, Kamili A. Chemical fertilizers and their impact on soil health. 2021. DOI:10.1007/978-3-030-61010-4\_1
  41. Pant KS, Prakash P, Chand K, Bhatia AK. Soil responses to integrated nutrient management in lentil-based systems. *Int J Environ Clim Change.* 2024;14(11):765-784.
  42. Panta S, Parajulee D. Integrated nutrient management in soil and sustainable agriculture. *Int J Appl Sci Biotechnol.* 2021. DOI:10.3126/ijasbt.v9i3.39275
  43. Paramesh V, Kumar M, Rajanna G, Gowda S, Nath A, Madival Y, *et al.* Integrated nutrient management for improving crop yields and reducing greenhouse gas emissions. *Front Sustain Food Syst.* 2023;7. DOI:10.3389/fsufs.2023.1173258
  44. Paramesh V, Kumar P, Bhagat T, Nath A, Manohara K, Das B, *et al.* Integrated nutrient management enhances yield and soil quality in rice systems. *Agronomy.* 2023. DOI:10.3390/agronomy13061557
  45. Purohit S, Mishra G, Mohapatra K. Review on integrated nutrient management in sweet corn. *Int J Curr Microbiol Appl Sci.* 2020;9:2213-2219. DOI:10.22271/phyto.2020.v9.i3aj.11647
  46. Ramteke P, Gabhane V. Nutrient use efficiency under nutrient management practices in intercropping systems. *Environ Conserv J.* 2023. DOI:10.36953/ecj.13512395
  47. Ren Z, Zhang H, Li H, Wu Q, Huang Y, Ye Y, *et al.* Improving wheat yield and fertilizer use efficiency through nutrient management. *Sustainability.* 2025. DOI:10.3390/su17083481
  48. Saha S, Saha B, Seth T, Dasgupta S, Ray M, Pal B, *et al.* Micronutrient availability under long-term integrated nutrient management. *J Soil Sci Plant Nutr.* 2019. DOI:10.1007/s42729-019-00071-6
  49. Saini N, Yadav H, Saini S, Sharma A. Advances in integrated nutrient management practices for cereal crops. *Int J Plant Soil Sci.* 2025. DOI:10.9734/ijpss/2025/v37i15279
  50. Sande T, Tindwa H, Alovizi A, Shitindi M, Semoka J. Enhancing sustainable crop production through integrated nutrient management. *Front Agron.* 2024. DOI:10.3389/fagro.2024.1422876
  51. Sandhu P, Walia S, Gill R, Dheri G. Long-term integrated nutrient management effects on soil properties. *Commun Soil Sci Plant Anal.* 2020;51:1641-1657. DOI:10.1080/00103624.2020.1791156
  52. Sarvade S, Agrawal S, Bajpai R, Thakur R, Shrivastava A. Integrated nutrient management in agroforestry. *Int J Bio-resource Stress Manag.* 2025. DOI:10.23910/1.2025.5870a
  53. Sarwar N, Abbas N, Farooq O, Akram M, Hassan M, Mubeen K, *et al.* Biochar integrated nutrient application improves crop productivity. *Sustainability.* 2023. DOI:10.3390/su15032232
  54. Selim M. Introduction to integrated nutrient management strategies and their contribution to yield and soil properties. *Int J Agron.* 2020. DOI:10.1155/2020/2821678
  55. Selim M. Integrated nutrient management strategies and their contribution to yield and soil properties. *J Plant Sci.* 2021;9:139. DOI:10.11648/j.jps.20210904.13
  56. Shah F, Wu W. Soil and crop management strategies for sustainable productivity. *Sustainability.* 2019. DOI:10.3390/su11051485
  57. Shah J, Kumar K, Vaishnav P. Advanced technologies and sustainable practices for soil health management. *Plant Arch.* 2025. DOI:10.51470/plantarchives.2025.sp.ictpairs-062
  58. Shahid M. Integrated nutrient management to maintain maize productivity. *Cornous Biol.* 2024.
  59. Sharma A, Rana N, Pandey R. Integrated nutrient management strategies for sustainable rice production. *Int J Res Agron.* 2025. DOI:10.33545/2618060x.2025.v8.i4f.2807
  60. Sharma S, Padbhushan R, Kumar U. Integrated nutrient management in rice-wheat system: Evidence from meta-analysis. *Agronomy.* 2019. DOI:10.3390/agronomy9020071
  61. Sharma T, Arya V, Sharma V, Sharma J, Gulshan T, Bera A, *et al.* Integrated nutrient management: A long-term approach towards sustainability. *Int J Plant Soil Sci.* 2022. DOI:10.9734/ijpss/2022/v34i2031171
  62. Singh A, Pandey A, Singh U. Effect of integrated nutrient management on soil chemical properties: A review. *Int J Chem Stud.* 2020;8:3438-3441.

DOI:10.22271/chemi.2020.v8.i4aq.10186

63. Singh S, Patel C. Integrated nutrient management: An effective approach for sustainable agriculture. *Int J Curr Microbiol Appl Sci*. 2020.  
DOI:10.20546/ijcmas.2020.905.186
64. Singh V, Shahi U, Singh O, Chaubey C. Integrated nutrient strategies for enhancing soil health and phosphorus management. *J Innov Solut Eco Environ Sustain*. 2025.  
DOI:10.46991/jisees.2025.si1.169
65. Suchitha N, Tripathy S, Mohapatra B, Narendar G, Prameela G. Impact of integrated nutrient management on rice productivity. *AATCC Rev*. 2025.  
DOI:10.21276/aatccreview.2025.13.03.221
66. Surve V, Patel P, Patel T, Jinjala H. Integrated nutrient management for enhancing cereal crop production: A review. *Annu Res Rev Biol*. 2024.  
DOI:10.9734/arrb/2024/v39i42069
67. Tomar A, Saikia J. Effect of integrated nutrient management on soil properties under dolichos bean cultivation. *Int J Plant Soil Sci*. 2022.  
DOI:10.9734/ijpss/2022/v34i1230966
68. Tyagi J, Ahmad S, Malik M. Nitrogenous fertilizers: Environmental impact and mitigation strategies. *Int J Environ Sci Technol*. 2022;19:11649-11672.  
DOI:10.1007/s13762-022-04027-9
69. Urmi T, Rahman M, Islam M, Jahan N, Mia M, Akhter S, *et al*. Integrated nutrient management for rice yield and soil fertility. *Plants*. 2022;11. DOI:10.3390/plants11010138
70. Wu W, Xia B. Integrated nutrient management for sustaining crop productivity and reducing environmental impact. *Sci Total Environ*. 2015;512-513:415-427.  
DOI:10.1016/j.scitotenv.2014.12.101
71. Yadav K, Singh A, Chaturvedi S, Singh S, Kumar V, Gupta P, *et al*. Integrated nutrient management in sustainable agriculture: Advances and challenges. *Int J Plant Soil Sci*. 2025. DOI:10.9734/ijpss/2025/v37i95710

**Author Affiliation****Aakash Kumar Saini**

Ph.D. Scholar, Division of Soil Science, ICAR-Indian Institute of Soil Science, Bhopal, Madhya Pradesh, India

**Jyoti Kahar**

Ph.D. Scholar, Department of Agronomy, Mahatma Gandhi Chitrakoot Gramodaya Vishwavidyalaya, Chitrakoot, Madhya Pradesh, India

**Lalit Krishna Yadav**

Assistant Professor, Department of Soil Science and Agricultural Chemistry, Shri Vishwanath P.G. College, Kalan, Sultanpur, Uttar Pradesh, India

**Pradeep Chouhan**

Ph.D. Scholar, Department of Agronomy, Medicaps University, Indore, Madhya Pradesh, India

**Priya Niva Kujur**

Ph.D. Scholar, Department of Soil Science, Birsa Agricultural University, Ranchi, Jharkhand, India

**Rohitash Meena**

Ph.D. Scholar, Division of Agronomy, ICAR-National Dairy Research Institute, Karnal, Haryana, India

**Sidharth Sankar Acharya**

Instructor (Agricultural Science), Agro Polytechnic Centre, Keonjhar, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, India

**Shikha Goswami**

Assistant Professor, Department of Information Technology, College of Technology, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India

**Nikhil Yadav**

M.Sc. Student, Department of Soil Science and Agricultural Chemistry, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh, India

**Urmila Choudhary**

Ph.D. Scholar, Department of Soil Science and Agricultural Chemistry, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan, India