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Integrated Nutrient Management (INM): Concept, utility and importance in sustainable agriculture

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Abstract

Farmers have extensive experience using various organic material sources in an integrated and effective manner to maintain soil fertility and generate moderate crop yields through conventional farming methods. However, during the past 20 years, nutrient management has increasingly evolved to an excessive reliance on chemical fertilizers in order to attain food security with diminishing land and other resources. The long-term viability of the agricultural system is threatened by the increased prevalence of over-application of synthetic fertilizers in intensive agricultural areas, which results in low nutrient-use efficiency and environmental contamination. Achieving environmental benefits is a key component of INM which is fulfilled via combining the harmonious properties of both sources (organic, inorganic) and creating a combination that can be used for reducing the indiscriminate use of chemical fertilizers, maintaining a balance between fertilizer inputs and crop nutrient requirements, enhancing soil fertility, optimizing yield, maximizing profitability, and reducing pollution.

Keywords: Fertilizer, INM, Environment, Crop

Introduction

The vision of a world free of hunger and poverty, which is made more challenging by rising living standards in rural areas where the majority of the impoverished reside and their complete reliance on agriculture to meet their food needs, is the primary challenge facing agriculture planners and farming decision makers in the upcoming years. The key to eliminate the current suffering lies in the creation of a strategic plan that enhances prosperous farming and enables farmers themselves to achieve agricultural growth, reduce poverty, and sustain high returns. Therefore, the following question will be the primary problem in the approaching years. Can agriculture provide all of the world's population's anticipated food needs? (FAO, 2012) ^[1]. To meet the world's future food security and sustainability needs, food production must grow substantially while agriculture's environmental impact must decrease dramatically at the same time. Global food production must increase by 70% by 2050 to fulfil the increasing demand (Foley *et al.*, 2011) ^[2]. In order to meet this challenging target, an average annual increase in cereal production of 43 million metric tonnes per year is required. With the view of an increase in land scarcity and water shortage, most of the agriculture plans depend on the use of chemical fertilizers and the production of new high-yielding crop varieties. Yet, both components are much expensive and will lead to higher pressure and more responsibilities for the financial investments and consequently will lead to an increase in the total costs. Meanwhile, the price of fertilizers increases, year by year, due to the higher amount of fertilizers needed in the second and third seasons as compared with that in the first season to maintain the current yield production at economical level. Despite the increase in the quantity of fertilizer application, a part of applied fertilizers and soil native nutrients were already consumed by the current and previous crops, especially in the case of intensive agriculture, where two to three crops are annually cultivated. Moreover, application of inorganic fertilizers is not a pragmatic option for many poor farmers in different regions worldwide, because many poor farmers do not have enough money to pay the claim of fertilizer price, besides its scarcity and unavailability in times of need. Since ancient times, farmers have known that soil health can be restored by applying

organic manure; accordingly, they used to apply farmyard manure regularly and directly after crop harvest. Using organic manures post-harvest is linked to improved soil health and enhanced physical, chemical, and biological properties, especially in marginal soils with low organic matter and nutrient content (Selim, 2018) ^[3]. No single nutrient source chemical fertilizers, organic manures, crop residues, or bio-fertilizers can meet crop needs in intensive agriculture. Integrating these sources is key to boosting soil fertility and crop productivity. Integrated Nutrient Management (INM) safeguards soil health and reduces reliance on chemical fertilizers, offering economic benefits (Wang *et al.*, 2019; Song *et al.*, 2020) ^[4, 5]. Organic manures improve soil structure, and INM balances food security with environmental sustainability, impacting crop yield, soil quality, and greenhouse gas mitigation.

Need of Integrated Nutrient Management (INM)

- Prolonged use of chemical fertilizers, particularly those high in nitrogen, is degrading soil quality and exacerbating issues related to poor nitrogen use efficiency.
- Recent energy shortages, escalating fertilizer costs, and limited purchasing power among farmers necessitate a reassessment of alternative strategies.
- Excessive nitrogen application is leading to groundwater and environmental contamination, as well as contributing to ozone layer depletion through N₂O emissions.
- Soils dependent solely on chemical fertilizers for nutrients are experiencing diminishing productivity due to deficiencies in secondary and micronutrients.
- Organic manure and biofertilizers, available locally at lower costs, offer a solution by enhancing crop yields through improved soil structure, chemistry, and microbial activity.
- Although the supply of animal waste and crop residues is insufficient to meet demand, integrating organic waste with chemical and biofertilizers presents a promising alternative.

The concept of Integrated Nutrient Management (INM)

Integrated Nutrient Management (INM) combines traditional and modern methods to create a sustainable farming system that optimizes nutrient use from organic, inorganic, and biological sources. According to FAO (1998) ^[1], INM maintains or adjusts soil fertility to achieve a given level of crop production by leveraging all possible sources of plant nutrients. INM involves balancing inorganic, organic, and biological resources to sustain yields, preserve soil health, and provide environmentally friendly crop nutrition solutions. The goal is to utilize every available nutrient source wisely, synchronizing nutrient demand and release while minimizing losses. This approach reduces leaching, runoff, and emissions, achieving high nutrient-use efficiency (Zhang *et al.*, 2012) ^[6]. In order to increase agricultural output and reduce land degradation, it also seeks to optimize the physical, chemical, biological, and hydrological characteristics of the soil. More people are now aware that INM can simultaneously and nearly invisibly protect soil resources in addition to increasing crop output. In order to preserve available water and increase plant nutrients, its methods make use of farmyard manures, farm wastes, soil amendments, crop residues, natural and chemical fertilizers, green manures, cover crops, intercropping, crop rotations, fallows, conservation tillage, irrigation, and drainage. In order to reduce nutrient losses and enhance plant absorption, this strategy also incorporates novel methods such as deep fertilizer application and the use of urea coatings or inhibitors. Such practices encourage farmers to focus on long term planning and have greater consideration of

environmental impacts, rather than only focusing on yield-scaled profit. The main objective of integrated nutrient management is to maintain economic yield for a long time with minimal impact on native soil fertility and pollution, as well as to raise farmer awareness of eco-friendly techniques (organic farming system) for producing healthy, contaminant-free food while ensuring adequate financial returns. INM promotes soil biodiversity, improving ecosystem services and resilience. It also enhances crop quality and yield stability, supporting food security. By reducing chemical fertilizer use, INM mitigates environmental pollution and climate change impacts. Effective INM requires site-specific strategies, considering local soil, climate, and crop needs. Long-term INM adoption can restore degraded soils and improve agricultural sustainability

Principles of INM

Maximum use of organic inputs: The widespread use of organic inputs including compost, green manure, farmyard manure, and crop residues is a top priority for INM. These organic compounds enhance soil structure, water-holding capacity, and microbial activity in addition to supplying vital nutrients. Organic materials are essential for maintaining long-term agricultural output and lowering reliance on synthetic inputs by improving soil fertility naturally.

Minimizing loss of plant nutrients: A fundamental principle of INM is to reduce nutrient losses from the soil through practices that prevent leaching, volatilization, and erosion. This includes implementing conservation techniques such as mulching, cover cropping, and contour farming, which help retain nutrients within the soil profile. By minimizing nutrient losses, INM ensures that plants have continuous access to the essential elements required for growth, thereby improving nutrient use efficiency, and supporting sustainable crop production. Overall, these principles of INM focus on creating a balanced and resilient agricultural system that enhances soil health, promotes efficient nutrient management, and ensures sustainable productivity.

Judicious use of synthetic fertilizers: In order to supplement the nutrient supply from organic sources, INM promotes the cautious and balanced application of chemical fertilizers. By ensuring that crops receive the right nutrients in the right amounts at the right times, this method improves nutrient usage efficiency and avoids over application. INM seeks to maximize crop yields while reducing potential adverse environmental effects including nutrient runoff and soil deterioration by combining chemical fertilizers with organic amendments.

Components of INM

Organic manure: Well-decomposed organic manures, such as farmyard manure, digested cow dung, and compost (both urban and rural), were supplanted by chemical fertilizers as the most efficient source of plant nutrients with the advent of the Green Revolution. It is now essential to resume adding these manures. Organic manures include micronutrients, which are substances that both stimulate and impede growth, in addition to primary and secondary nutrients. However, some materials used to create urban waste compost, rural compost, and farmyard manure contain dangerous elements such as heavy metals like Ni, Cr, and Cd, which can have a detrimental effect on plant growth if they are present in sufficient amounts in organic manures. Furthermore, there are a number of industrial by-products and municipal trash that have a reasonable nutritious potential. These

nutrient-carriers, on the other hand, have not been thoroughly tested to determine their fertilizer equivalents. These sources must be integrated based on their availability in various crops and cropping systems. Industrial wastes such as spent-wash from distilleries, molasses, pressmud, and other sugar industry byproducts, as well as wastes from other food processing businesses, have a high manurial value (Das *et al.*, 2015) [7]. Organic manures release nutrients gradually, ensuring a continuous supply of nourishment for plants. They also enhance soil microbial activity, which plays an essential role in nutrient cycling and organic matter decomposition. Moreover, organic manures improve soil aeration, water retention, and root penetration, contributing to better crop growth and yield.

Table 1: Average nutrient content in some important organic manures (Yawalkar *et al.*, 1996) [8]

Organic manure	Product	N (%)	P ₂ O ₅ (%)	K ₂ O(%)
Bulky organic manure	FYM	1.6-1.8	1.0-1.2	1.2-1.8
	Compost	0.5	0.5	1.0
	Vermicompost	0.6-1.2	0.13-0.22	0.4-0.7
	Sesame cake	6.2	2.0	1.2
	Groundnut cake	7.3	1.5	1.3
Concentrated organic manure	Safflower cake	7.9	2.2	1.9
	Blood meal	10-12	1-2	0.6-0.8
	Fish meal	5-8	3-6	0.3-1.5
	Bone meal	3	20	-

Bio-fertilizers: Bio-fertilizers play a key role in Integrated Nutrient Management (INM), promoting sustainable agriculture. They add nutrients through nitrogen fixation, phosphorus solubilization, and growth-promoting biomolecules, making them an eco-friendly, low-cost technology. Bio-fertilizers conserve natural resources, maintain food safety, and support environmental quality. They include nitrogen-fixing bacteria, phosphate solubilizers, mycorrhizal fungi, and other microbes that enhance nutrient availability. Bio-fertilizers reduce chemical fertilizer use, minimizing environmental pollution. They're effective in diverse soils and climates, supporting crop productivity. Bio-fertilizers also produce beneficial compounds, boosting plant growth and resilience. Biofertilizers are the preparations containing microorganisms beneficial to agricultural production in terms of nutrient supply especially N and P. The bio-fertilizer is a carrier-based microbial inoculant that contains effective living microorganism cells. Biofertilizers have the ability to fix atmospheric nitrogen in ammonia form, mobilize nutrients, solubilize insoluble nutrients in the soil system, and release plant growth hormones that are essential for plant development and growth. The two main organic fertilizers for rice that can be used in place of chemical fertilizers are Azolla and blue-green algae (BGA). Particularly in rice soils with standing water, BGA can fix atmospheric nitrogen and release growth-promoting compounds. Biofertilizers are the products containing living cells of different types of microorganisms that have an ability to fix/mobilize nutrients from non-usable form through biological processes. These microorganisms are capable of mobilizing non-labile nutrients to plant roots. These also secrete some growth promoting substances. These micro-organisms are used for the treatment of seeds, seedlings and application to soil or in composting to increase soil fertility and help in crop growth and high yield. Vesicular Arbuscular Mycorrhizae (VAM) is the symbiotic

association of fungi with roots of vesicular plants with great potential in acquisition of P in P deficient soils and solubilization of unavailable P in the soil. The plant roots transmit substances to the fungi, and the fungi aid in transmitting nutrients and water to the plant roots. The mycorrhizal fungi carry out its functions by expanding surface area of plant root system by 10 to 1000 folds into the soil through their ramifying hyphae. The hyphae reach wetter soil areas and help plants to absorb nutrients, particularly the less available mineral nutrients like phosphorus, zinc, molybdenum and copper etc.

Table 2: Classification of Biofertilizers

Biofertilizers Group	Example
Nitrogen fixers	<i>Rhizobium</i> , <i>Frankia</i> , <i>Azotobacter</i> , <i>Azospirillum</i>
Phosphate solubilizers	<i>Bacillus megaterium</i> , <i>Pseudomonas striata</i> , <i>Penicillium</i> sp.
Phosphate mobilizers	<i>Amanita</i> sp., <i>Glomus</i> sp., <i>Gigaspora</i> sp., VAM
Silicate and Zinc Solubilizers	<i>Bacillus</i> sp.
Organic matter decomposer	<i>Trichoderma</i> , <i>Cytophaga</i> , <i>Polyporus</i> , <i>Agaricus</i> .

Green manure: Growing legumes as green manure to improve crop productivity and soil health is among the oldest practices. It gains more advantages, especially for light soils with sandy and loamy sand textures, as well as sandy loam soils or soils with a loam/silty loam texture. Although they may serve other purposes as well, green manures are crops planted particularly to improve and preserve the fertility and structure of the soil. In these circumstances, growing dhaincha (*Sesbania aculeata*) and burying it in the soil before the flowering stage at the time of transplanting rice has been found effective in raising the yield of both rice and wheat.

Table 3: Nitrogen fixing capacity of some green manure crops (Maheshwari *et al.*, 2020) [9]

Green manures crops	Botanical name	N fixing capacity (Kg ha ⁻¹)
Sun hemp	<i>Crotalaria Juncea</i>	134
Daincha	<i>Sesbania aculeate</i>	133
Manila agathi	<i>Sesbania rostrata</i>	96
Cluster bean	<i>Cyamopsis tetragonoloba</i>	91
Cowpea	<i>Vigna unguiculata</i>	74

Synthetic fertilizers: Synthetic fertilizers still the most significant component of INM. Because of the requirement to supply significant amounts of nutrients in intensive cropping with high productivity, fertilizer use has been steadily growing. Despite this, fertilizer consumption is not only insufficient but also unbalanced. The ratio of N:P₂O₅:K₂O is relatively large, although K, S, and micronutrients are frequently overlooked. Introduction of nutrient based subsidy (NBS) scheme during 2010 further distorted the fertilizer consumption ratio. Domestic fertilizer production is insufficient to fulfil demand, and the situation is unlikely to improve very soon. Constraints such as global price hikes in fertilizers and raw materials, on the other hand, would prevent large-scale fertilizer imports, resulting in a large disparity between supply and demand. While organics and bio-fertilizers are projected to fill some of the gap, fertilizer efficiency in closing the nutrient supply gap requires further attention.

Table 4: Percentage of nutrients in various synthetic fertilizers

Fertilizers	N (%)	P ₂ O ₅ (%)	K ₂ O(%)	Others
Urea	46	-	-	-
Ammonium sulphate	21	-	-	23-24% S
Single super phosphate	-	16	-	18-21% Ca, 12-14% S
Di-ammonium phosphate phosphate	18	46	-	-
Triple super phosphate	-	48	-	12-14% Ca
Muriate of potash	-	-	60	-
Sulphate of Potash	-	-	52	18% S
Gypsum	-	-	-	29% Ca, 23% S
Sodium borate (Borax)	-	-	-	11% B

Crop rotation / Intercropping: In order to maximize productivity while maintaining soil health, two crucial techniques in sustainable agriculture are crop rotation and intercropping. Crop rotation is the process of methodically switching around the kinds of crops that are planted in a certain

field over the course of several seasons. This method helps replenish soil nutrients while preventing the accumulation of pests and diseases unique to particular crops. Conversely, intercropping entails growing two or more crops on the same plot of land at the same time.

Table 5: Effect of Integrated nutrient management (INM) on different crop performance

Crop	Impact of INM	References
Rice	INM significantly increased boro rice yield and application of PSB and <i>Azotobacter</i> significantly increased available P & N in soil.	Garai <i>et al.</i> (2014) ^[13]
Rice	INM reduced N application AND boosted rice yield + soil nutrients	Jha <i>et al.</i> (2013) ^[14]
Cotton	INM significantly increased N, P, and K uptake and sustain soil fertility status.	Marimuthu <i>et al.</i> (2014) ^[15]
Legumes	A review paper of INM focused on principle, crop residue management, crop system, nutrient budget and soil C.	Parkinson (2013) ^[17]
Wheat	Manures/fertilizer application (farmyard manure, potassium and zinc fertilizers) produced significantly higher grain yield than the control plots. Leguminous crops significantly increased the yield of succeeding crops.	Nawab <i>et al.</i> (2011) ^[16]
Rice	INM produced significantly the highest grain (8.1 t ha ⁻¹) and straw yield (9.1 t ha ⁻¹) of hybrid rice, accompanying with high N, P and K uptake.	Kumar and Yadav (2009) ^[31]
Sorghum	INM resulted significantly in higher grain yield of sorghum	Srinivas <i>et al.</i> (2008) ^[18]
Potato	Inorganic manures worked wonders boosted soil organic C, available P, and K, and had a significant residual impact on sunflower's seed yield, growth, and phenology.	Thind <i>et al.</i> (2007) ^[19]
Rice	INM = more grain, more straw, more returns	Barik <i>et al.</i> (2006) ^[20]
Wheat	INM performed better as compared to sole treatment.	Chauhan <i>et al.</i> (2024) ^[10]
Chickpea	INM gave a solid boost to growth and yield in the field	Zala <i>et al.</i> (2024) ^[11]
Cumin	FYM + synthetic fertilizer = more branches and healthier plant population	Kumar <i>et al.</i> (2025) ^[12]
Rice/wheat	INM gave significantly higher mean grain yield of rice (3.2 t ha ⁻¹) and wheat (2.9 t ha ⁻¹) and yield of succeeding wheat increased by 43.1 to 48.9%. There was a build-up of available N, P, K and organic carbon in soil in all INM plots.	Singh <i>et al.</i> (2002) ^[33]
Chickpea	INM gave some great results - more pods per plant (66.4), seeds per pod (1.2), test weight (20.91 g), grain yield (2.4 t/ha), and haulm yield (3.2 t/ha)	Patil <i>et al.</i> (2013) ^[32]
Maize	Inoculants give plants a growth and yield boost while reducing N, P, and K buildup in soils	Adesemoye <i>et al.</i> (2008) ^[30]
Fenugreek	INM led to a significant jump in physiological traits and yield components, with seed yield up 71% and straw yield up 25% compared to the control	Dubey <i>et al.</i> (2011) ^[34]
Wheat	INM components combined gave a bigger boost to grain and straw yield than using single components alone	Kushwaha and Tripathi (2022) ^[21]
Mustard	Combining different nutrient sources turned out to be the top-performing treatment, boosting yield significantly	Dutta <i>et al.</i> (2022) ^[22]
Turmeric	The treatment combination of Vermicompost + NPK (100%) + Biofertilizer showed significantly better results for clump, primary, and secondary rhizome characteristics in turmeric	Mondal and Hore (2022) ^[23]

Integrated Nutrient Management (INM): Way towards long term sustainability

Improve soil properties: Due to an uneven use of mineral fertilizers, the majority of agricultural soil fertility is degrading day by day. According to many reports, the state of soil fertility has improved by the adoption of INM. The amount of mineralizable N in the soil is frequently proportional to the amount of SOC in the soil. Because soil physical characteristics and microbial biomass are intimately related to soil organic carbon and organic matter every soil management method that increases soil organic matter has a direct impact on soil physical properties and microbial biomass, for this a combination of organic and inorganic nutrient sources may be the best option,

primarily for improving soil physical health. Mandal *et al.* (2013) ^[24] found that the pigeonpea-wheat system's soil organic carbon and mineral N levels were enhanced by adding organic manures, particularly FYM, to the fertilization schedule. The addition of pigeonpea leaf litter through forced defoliation enhanced labile organic carbon percentages bigger than organic manures and boosted wheat production when applied to the suggested NPK or NPK + organics plots. Conversely, SPM proved to be a great source of nutrients for boosting output, but it had less of an impact on SOC fractions than FYM. Crops grow better under friable and well-aggregated soils with optimum soil bulk density as it greatly influencing crop root growth and nutrient uptake. Practicing long-term INM brings a favorable

difference in soil bulk density (Saha *et al.*, 2010) ^[26]. The main reason for decreasing bulk density under INM was aggregation of soil particles due to increasing organic matter as well as stability of aggregates which leads to an increase in the total pore space in the soil.

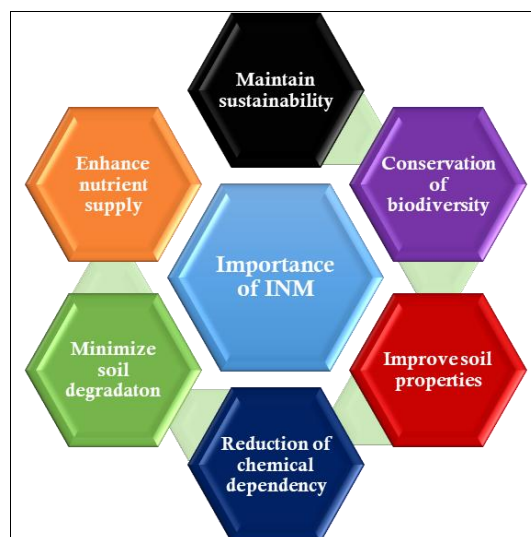
Eco-friendly practices: The massive change in ecosystem mostly attributable to the widespread use of synthetic fertilizers and pesticides, particularly in the intensive agriculture system (Peng *et al.*, 2010). As a result of their long-term use in some developing nations, chemical fertilizers, notably nitrogen, phosphorus, and potassium (NPK), are an important factor and primary source of environmental contamination and land erosion (Davidson *et al.*, 2014) ^[25]. INM technique that can minimize environmental degradation and continue to be the most effective way to achieve food security, enhance environmental quality, and fulfill ever increasing food demands without causing negative consequences. Integrated nutrient management is a simple system that can create a favorable soil condition and provide plants with a sufficient, efficient, and sustainable nutrient source. It is also a promising strategy that has made significant contributions to reducing negative environmental impact, increasing both the quantity and quality traits of global food supplies, and expanding land with a plan of sustainable and economical agricultural development.

Carbon sequestration: Enhancing carbon sequestration through integrated nutrient management can be achieved by exploring soil management practices, investigating the role of plant-soil-microbial interactions, exploring the integration of agroforestry practices, developing precision nutrient management techniques, and using modeling tools and decision support systems. Soil management practices that promote carbon sequestration include the use of organic amendments, cover crops, and crop rotations. These practices can help to increase soil organic matter, which is a major sink for atmospheric carbon. Beneficial soil microorganisms, such as mycorrhizal fungi, can help to improve nutrient uptake, promote root growth, and enhance soil aggregation.

Carbon sequestration: Soil organic matter is the most important indicator of soil fertility, quality and productivity and is usually estimated by determining soil organic carbon. It is generally believed that fertilizer application increases residues, including roots, returned to the soil, and as a result, can increase organic matter content and C sequestration. The INM through green manuring, crop residue incorporation and other animal-based manures has a profound influence on soil carbon stock. The direct application of organic manure to the soil, which encouraged the development and activity of microorganisms, as well as improved root growth, which led to increased biomass output, crop stubbles, and residues, are both associated with increasing the amount of organic carbon in the INM (Moharana *et al.*, 2012) ^[27].

Greenhouse Gas Emission (GHG): Worldwide, agriculture and related systems are thought to be a significant source of greenhouse gas emissions (Ravikumar *et al.*, 2021) ^[29]. Reducing excess nutrient application and applying nutrients in a balanced manner are the main ways to lessen its contribution. In most farmlands, ambiguous methods applying plant nutrients to increase crop yields has become a confusing procedure. Conversely, one of the main causes of anthropogenic greenhouse gas emissions in croplands is the uneven application of fertilizer.

Therefore, to keep these anthropogenic GHG emissions under control, devising, and practicing proper fertilizer management is essential (Carlson *et al.*, 2017) ^[28]. Of the several means of nutrient management, INM is proven better at minimizing GHG emissions. In INM, nutrient recycling and reuse strategies efficiently capture and recycle nutrients from various sources, such as agricultural residues, livestock manure, and wastewater. Practices like anaerobic digestion, composting, and biochar production can be used to convert these nutrient-rich materials into valuable organic amendments. Intercropping and crop rotation can also be made an integral part of INM systems that incorporate nitrogen-fixing crops can also reduce the need for synthetic nitrogen fertilizers and decrease nitrogen runoff.



Conclusion

Farmers have extensive experience using various organic material sources in an integrated and effective manner to maintain soil fertility and generate moderate crop yields through conventional farming methods. However, during the past 20 years, nutrient management has increasingly evolved to an excessive reliance on chemical fertilizers in order to attain food security with diminishing land and other resources. The long-term viability of the agricultural system is threatened by the increased prevalence of over-application of N in intensive agricultural areas, which results in low nutrient-use efficiency and environmental contamination. The practice of INM includes all possible sources of plant nutrients to optimize nutrient inputs, spatial and temporal matching of the soil nutrient supply with crop demand and reducing N losses while improving crop yield. Interaction of agricultural inputs leads to increases in crop productivity while substantially reducing N losses and GHG

emissions, judicious application of mineral and organic fertilization with higher resource-use efficiency, enhance the soil-plant-microbes-environmental sustainability.

References

1. FAO. FAOSTAT FAO database—statistics division food and agriculture organization of the United Nations, Rome. 2012. <http://faostat.fao.org/>
2. Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, *et al.* Solutions for a cultivated planet. *Nature*. 2011;478(7369):337-342.
3. Selim M. Potential role of cropping system and integrated nutrient management on nutrients uptake and utilization by maize grown in calcareous soil. *Egyptian J Agron*. 2018;40(3):297-312.
4. Wang H, Wang X, Bi L, Wang Y, Fan J, Zhang F, *et al.* Multi-objective optimization of water and fertilizer management for potato production in sandy areas of northern China based on TOPSIS. *Field Crops Res*. 2019;240:55-68.
5. Song F, Xu M, Duan Y, Cai Z, Wen S, Chen X, *et al.* Spatial variability of soil properties in red soil and its implications for site-specific fertilizer management. *J Integr Agric*. 2020;19:2313-2325.
6. Zhang F, Cui Z, Chen X, Ju X, Shen J, Chen Q, *et al.* Integrated nutrient management for food security and environmental quality in China. *Adv Agron*. 2012;116:1-40.
7. Das D, Dwivedi BS, Meena MC, Singh VK, Tiwari KN. Integrated nutrient management for improving soil health and crop productivity. *Indian J Fertil*. 2015;11(4):64-83.
8. Yawalkar KS, Agarwal JP, Bokde S. Manures and Fertilizers. 8th ed. Nagpur: Agri-Horticultural Publishing House; 1996.
9. Maheshwari NK, Singh RP, Manchanda G, Dubey RC, Maheshwari DK. Sunn hemp (*Crotalaria juncea*) nodulating bacteria capable for high antagonistic potential and plant growth promotion attributes: sun hemp nodulating rhizobia. *J Microbiol Biotechnol Food Sci*. 2020;10(3):385-389.
10. Chauhan J, Pandey S, Rawat A, Chauhan A, Bhatt P. Effect of INM on growth indices, yield attributes, yield and economics of wheat (*Triticum aestivum* L. emend. Fiori & Paol.). *J Exp Agric Int*. 2024;46(6):733-739.
11. Zala DA, Dadarwal RS, Jat RD, Prakash R, Asif M. Optimizing Integrated Nutrient Management (INM) for Enhanced Growth and Yield of Chickpea (*Cicer arietinum* L.) Under Irrigated Conditions. *J Exp Agric Int*. 2024;46(12):872-881.
12. Kumar C, Tatarwal AS, Dudi A, Ahirwar MK, Singh D. Impact of integrated nutrient management on growth and yield of cumin (*Cuminum cyminum* L.) in western Rajasthan. 2025.
13. Garai TK, Datta JK, Mondal NK. Evaluation of integrated nutrient management on boro rice in alluvial soil and its impacts upon growth, yield attributes, yield and soil nutrient status. *Arch Agron Soil Sci*. 2014;60(1):1-14.
14. Jha MN, Chaurasia SK, Bharti RC. Effect of integrated nutrient management on rice yield, soil nutrient profile, and cyanobacterial nitrogenase activity under rice-wheat cropping system. *Commun Soil Sci Plant Anal*. 2013;44(13):1961-1975.
15. Marimuthu S, Surendran U, Subbian P. Productivity, nutrient uptake and post-harvest soil fertility as influenced by cotton-based cropping system with integrated nutrient management practices in semi-arid tropics. *Arch Agron Soil Sci*. 2014;60(1):87-101.
16. Nawab K, Amanullah Shah P, Rab A, Arif M, Khan MA, Mateen A, *et al.* Impact of integrated nutrient management on growth and grain yield of wheat under irrigated cropping system. *Pak J Bot*. 2011;43:1943-1947.
17. Parkinson R. System Based Integrated Nutrient Management. By B. Gangwar & VK Singh (eds). New Delhi: New India Publishing Agency; 2012.
18. Srinivas M, Rao SV, Seetharama N. Effect of integrated nutrient management and different moisture conservation practices on yield and economics of rabi sorghum. 2008.
19. Thind SS, Sidhu AS, Sekhon NK, Hira GS. Integrated nutrient management for sustainable crop production in potato-sunflower sequence. *J Sustain Agric*. 2007;29(4):173-188.
20. Barik AK, Das A, Giri AK, Chattopadhyay GN. Effect of integrated plant nutrient management on growth, yield and production economics of wet season rice (*Oryza sativa*). *Indian J Agric Sci*. 2006;76(11).
21. Kushwaha A, Tripathi S. Response of chemical fertilizers and INM on productivity of wheat (*Triticum aestivum* L.) and properties of soil. *J Phytomorphol*. 2022;11(1):51-56.
22. Dutta PK, Deka CK, Deka P, Nath RK. INM for improving soil health and increasing the yield of Toria in Chirang district of Assam. *Pharma Innov J*. 2022;11(2):1796-1798.
23. Mondal R, Hore JK. Impact of INM on yield and economics of turmeric in Gangetic alluvial zone of West Bengal. *Indian J Ecol*. 2022;49(6):2125-2129.
24. Mandal N, Dwivedi BS, Meena MC, Singh D, Datta SP, Tomar RK, *et al.* Effect of induced defoliation in pigeonpea, farmyard manure and sulphitation pressmud on soil organic carbon fractions, mineral nitrogen and crop yields in a pigeonpea-wheat cropping system. *Field Crops Res*. 2013;154:178-187.
25. Davidson EA, Galloway JN, Millar N, Leach AM. N-related greenhouse gases in North America: innovations for a sustainable future. *Curr Opin Environ Sustain*. 2014;9:1-8.
26. Saha R, Mishra VK, Majumdar B, Laxminarayana K, Ghosh PK. Effect of integrated nutrient management on soil physical properties and crop productivity under a maize (*Zea mays*)-mustard (*Brassica campestris*) cropping sequence in acidic soils of Northeast India. *Commun Soil Sci Plant Anal*. 2010;41(18):2187-2200.
27. Moharana PC, Sharma BM, Biswas DR, Dwivedi BS, Singh RV. Long-term effect of nutrient management on soil fertility and soil organic carbon pools under a 6-year-old pearl millet-wheat cropping system in an Inceptisol of subtropical India. *Field Crops Res*. 2012;136:32-41.
28. Carlson KM, Gerber JS, Mueller ND, Herrero M, MacDonald GK, Brauman KA, *et al.* Greenhouse gas emissions intensity of global croplands. *Nat Clim Chang*. 2017;7(1):63-68.
29. Ravikumar C, Ravikumar M, Karthikeyan A, Senthilvalavan P, Manivannan R. Integrated nutrient management-promising way to reduce carbon dioxide and methane emission in flooded rice ecosystem: A review. *J Appl Nat Sci*. 2021;13(1).
30. Adesemoye AO, Kloepper JW. Plant-microbes interactions in enhanced fertilizer-use efficiency. *Appl Microbiol Biotechnol*. 2009;85(1):1-12.
31. Kumar J, Yadav MP. Effect of integrated nutrient management on yield, nutrient content and nutrient uptake in hybrid rice (*Oryza sativa* L.). *Res Crops*. 2009;10(2):199-

- 202.
32. Patil SV, Halikatti SI, Gurumurthy SB, Lokesh MS. Impact of weather on performance of chickpea (*Cicer arietinum* L.) with integrated organic nutrient management practices grown in vertisol of northern dry zone of Karnataka. *Res Crops*. 2013;14(1):777-785.
 33. Singh G, Kumar T, Kumar V, Singh RG, Sharma RB. Effect of integrated nutrient management on transplanted rice (*Oryza sativa*) and its residual effect on succeeding wheat (*Triticum aestivum*) crop in rainfed lowlands. *Indian J Agron*. 2002;47(3):311-317.
 34. Dubey PK, Pandey CS, Bhardwaj SB. Effect of integrated nutrient management on growth, yield attributes and yield of fenugreek (*Trigonella foenum-graecum* L.). *Int J Agric Stat Sci*. 2011;7(1):327-339.