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Organic Farming vs. Integrated Nutrient Management: A Comparative Review of Agricultural Productivity and Sustainability

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

In an era where sustainable agriculture is crucial for global food security and environmental preservation, organic farming and Integrated Nutrient Management (INM) have emerged as leading practices. This review paper offers a comprehensive comparison of these two approaches, focusing on their impact on agricultural productivity and sustainability. Organic farming, with its emphasis on reducing the use of chemical fertilizers, pesticides, growth hormones, and feed additives, aligns closely with the principles of sustainability. It enhances food quality, promotes soil health, and mitigates adverse environmental effects by encouraging natural recovery cycles. However, organic farming's limitations, such as lower yields and a more labour-intensive approach have prompted interest in innovative solutions that blend organic practices with modern technologies. Integrated

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Nutrient Management (INM) presents a compelling alternative. By combining organic, inorganic, and biological nutrient sources, INM seeks to optimize nutrient use efficiency and maintain soil health. This approach offers a flexible nutrient management strategy, balancing organic and inorganic inputs to maintain crop productivity while reducing environmental impact. Studies have shown that INM can improve soil properties, such as bulk density, porosity, and water-holding capacity, leading to enhanced crop yields and lower greenhouse gas emissions. The paper explores how INM's integrated approach not only stabilizes crop production but also supports the growth of soil microbes, providing a source of energy and organic carbon. By using a combination of specific microorganisms, organic matter, and minimal doses of inorganic fertilizers, INM can achieve a harmonious balance that reduces environmental pollution and ensures long-term soil fertility. Ultimately, this review underscores the potential of combining organic and INM practices to create a sustainable and productive agricultural system. Through a comparative analysis, the paper aims to guide researchers, policymakers, and farmers towards adopting strategies that foster agricultural sustainability without compromising productivity.

Keywords: Bulk density; porosity; Organic farming; productivity; sustainability; water-holding capacity.

1. INTRODUCTION

Agriculture faces significant challenges in the coming years due to a growing global population and dwindling natural resources. As hunger and poverty become more acute, the need for strategic planning in agriculture becomes more critical to ensure food security and poverty alleviation. The key question is whether agriculture can meet the increasing food demands as the global population surpasses 7.5 billion [1]. With land and water resources becoming scarcer, many agricultural plans emphasize the use of chemical fertilizers and high-yielding crop varieties, leading to increased costs and pressures on farmers [2]. Additionally, many farmers in impoverished regions find inorganic fertilizers economically unviable. In this context, Integrated Nutrient Management [3] (INM) emerges as a viable approach to achieving sustainable agricultural practices. INM seeks to combine organic, inorganic, and bioorganic resources to create a balanced nutrient mix, promoting soil health, increasing productivity, and reducing the risk of pollution. Organic manures and farmyard composting have long been known to restore soil health and improve soil structure, which is essential in regions with marginal or low-fertility soils [4].

One of the key benefits of INM is its capacity to reduce the reliance on inorganic fertilizers, thereby lowering costs for farmers while maintaining or increasing crop yields [5]. Organic practices also provide health benefits, which appeal to a growing segment of consumers willing to pay higher prices for organic produce. Unlike inorganic fertilizers that can leach into groundwater, organic fertilizers have a longer-lasting impact on soil and plant health [6]. Adopting INM principles allows farmers to utilize natural resources more efficiently, recycle organic waste, and reduce environmental pollution. This integrated approach creates a more sustainable framework for agricultural practices, aligning with environmental goals while offering farmers cost-effective solutions. However, successful implementation of INM requires collaboration among researchers, extension specialists, government agencies, and NGOs to develop suitable strategies that meet farmers' needs and budgets. Training programs and capacity-building initiatives can support farmers in understanding plant nutrient requirements, compatible nutrient combinations, and techniques to maximize nutrient-use efficiency [7].

Conventional farming has been the predominant agricultural system for decades, driven by the Green Revolution's focus on high-yield crops, synthetic fertilizers, and chemical pesticides [2,8]. This approach has substantially increased food production to meet the demands of a growing global population. However, conventional farming relies heavily on inorganic fertilizers and chemical pesticides, which can have significant environmental and health implications. The intensive use of synthetic fertilizers in conventional farming can lead to nutrient runoff into waterways, causing eutrophication and harming aquatic ecosystems [9]. Additionally, the excessive use of chemical pesticides can lead to pesticide resistance, threatening both crop production and biodiversity. Over time, these practices may degrade soil health, leading to reduced fertility and increased dependency on synthetic inputs to maintain yields.

Conventional farming often prioritizes short-term productivity over long-term sustainability, with little regard for the environmental impact of farming practices [4]. The emphasis on monocultures, which simplifies planting and harvesting, can lead to decreased biodiversity and greater vulnerability to pests and diseases [10]. While conventional farming has succeeded in boosting crop yields, it faces growing criticism for its environmental impact and its contribution to unsustainable agricultural practices. Conventional farming has played a pivotal role in increasing agricultural productivity, particularly during the Green Revolution. The introduction of high-yielding crop varieties, synthetic fertilizers, and advanced irrigation techniques has significantly boosted crop production [11]. This has been crucial in addressing food security and meeting the dietary needs of an expanding global population.

Despite these achievements, the long-term sustainability of conventional farming is increasingly questioned. The heavy reliance on chemical fertilizers and pesticides raises concerns about soil degradation, groundwater contamination, and adverse effects on non-target organisms, including beneficial insects like bees [12]. Furthermore, the carbon footprint associated with synthetic fertilizer production contributes to climate change, adding to the environmental challenges faced by conventional agriculture. As the agricultural sector seeks to balance productivity with sustainability, there is a growing interest in alternative farming practices, such as organic farming and integrated nutrient management [13] (INM), which aim to reduce environmental impact while maintaining or improving crop yields [8-10]. These approaches offer a potential pathway to more sustainable agriculture by promoting soil health, biodiversity, and reduced chemical dependency, highlighting the need for a comparative review of agricultural practices.

2. NITROGEN USE EFFICIENCY IN SUSTAINABLE CROP PRODUCTION SYSTEMS

Nitrogen use efficiency (NUE) is a critical metric for assessing crop production systems, as it encompasses both productivity enhancement and environmental sustainability. The primary aim of NUE is to increase crop productivity through optimal crop nutrition while reducing nitrogen (N) losses from the field [14]. The use of intensive cropping practices, which began with the green revolution, has addressed some challenges related to poor agricultural production. However, a declining response to additional inputs has emerged as a significant

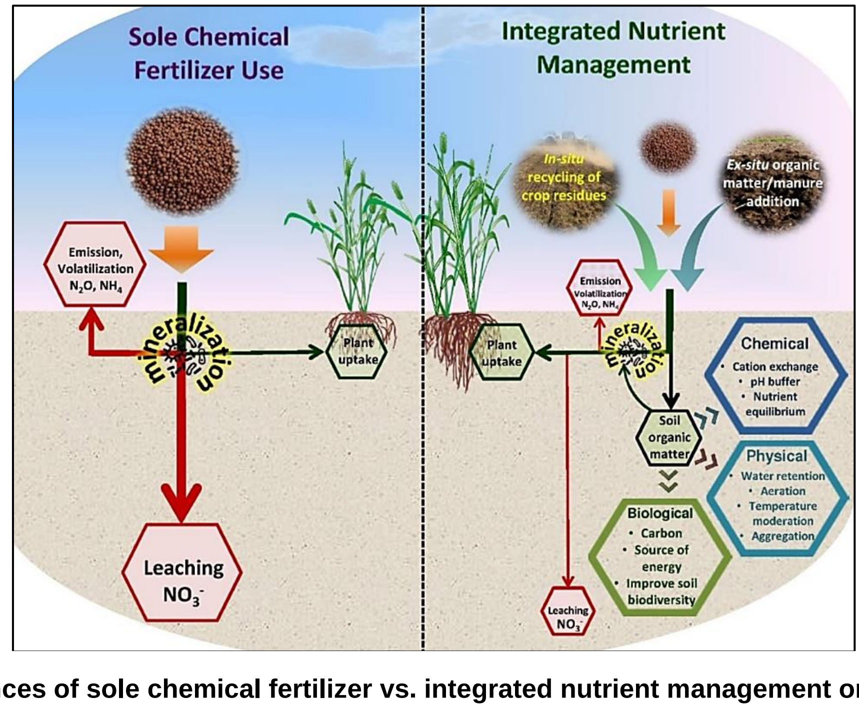

Fig. 1. Influences of sole chemical fertilizer vs. integrated nutrient management on the nitrogen pools, mineralization, leaching, and volatilization fluxes. Source: Bhardwaj et al. [15]

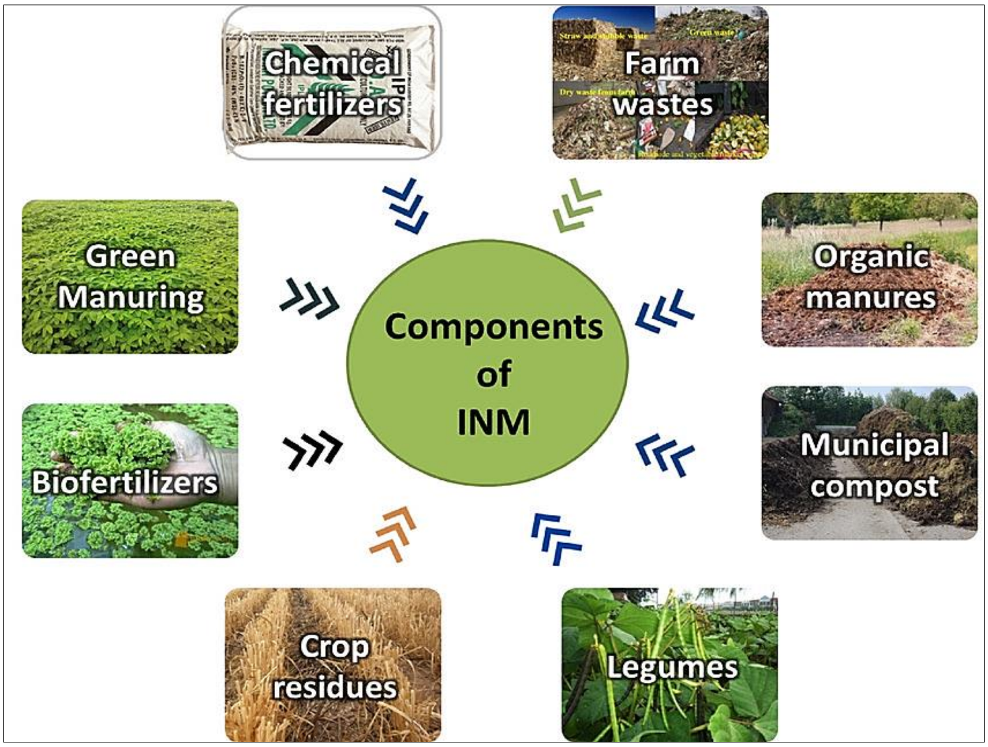

Fig. 2. Various components used in integrated nutrient management (INM) [15]

concern, particularly in rice-wheat cropping systems. The rice-wheat cropping system poses unique challenges due to contrasting management practices. This management variability creates difficulties in conserving and efficiently utilizing soil nitrogen. The flooding of rice fields can lead to ammonia (NH_3) volatilization, while nitrate (NO_3-N) leaching is a primary source of nitrogen loss during aerobic conditions [16]. An effective strategy to enhance nitrogen efficiency is the integrated use of organic manures and chemical fertilizers. Integrated Nutrient Management (INM) aims to improve soil fertility, maintain crop productivity, and promote soil health through the balanced use of chemical fertilizers, organic manures, and waste crop residues [17]. Key practices under INM include the application of manures, compost, mulching, crop residues, diversified cropping systems, and cover crops.

INM is recognized as a sustainable approach for restoring soil health, improving soil organic carbon, and sustaining overall system productivity (Fig. 1). The approach envisions substituting some chemical fertilizers with organic nutrient sources, without negatively impacting yields. Organic options for the rice-wheat system may include farmyard manure, composted crop residues, and other organic sources of nutrients [18]. By adopting INM practices, farmers can address both the productivity and sustainability challenges inherent in intensive cropping systems. This integrated approach not only improves nitrogen use efficiency but also contributes to long-term environmental sustainability.

3. THE CONCEPT OF INTEGRATED NUTRIENT MANAGEMENT (INM)

Fertilizers are generally classified into two categories based on their source: organic (natural) and inorganic (mineral, synthetic, or man-made). Integrated Nutrient Management (INM) is an agricultural practice that combines the advantages of both organic and inorganic sources to reduce chemical fertilizer usage and achieve a balance between nutrient inputs and crop nutrient requirements (Fig. 2). The goal of INM is to maintain soil fertility, restore soil health, and ensure a continuous nutrient supply to plants to optimize yield [2,19]. This approach integrates traditional and modern fertilizer and nutrient management techniques to encourage sustainable agricultural practices. It also aims to reduce environmental impact by minimizing the overuse of chemical fertilizers while utilizing organic sources to improve soil quality [20]. Key aspects of INM include raising awareness among farmers about sustainable practices, promoting the use of organic waste as compost, and reducing reliance on synthetic fertilizers. By focusing on long-term sustainability and food safety, INM contributes to both environmental health and increased profitability for farmers. The broader adoption of INM can lead to improved crop yields, reduced pollution, and healthier food production [21].

Integrated Nutrient Management (INM) is influenced by several factors, including crop nutrient requirements, the nutrient content of the soil, and the types of materials that can be used safely to enhance nutrient-use efficiency [20]. INM also provides a way to safely dispose of organic waste by recycling it into high-quality compost. Key components of the INM concept include educating farmers about the benefits of INM practices, discouraging excessive use of chemical fertilizers, and promoting long-term sustainability in agriculture 12-15]. The focus should shift from short-term profit to a balanced approach that considers environmental impacts and the production of safe food. This approach aligns with the growing consumer preference for food safety, a factor that can ultimately increase a farmer's profitability. The primary goal of INM is to sustain economic yields over the long term with minimal damage to soil fertility and reduced pollution. It also seeks to promote environmentally friendly practices, such as organic farming, to produce healthy, contaminant-free food while ensuring farmers achieve reasonable financial returns [11]. This approach encourages farmers to adopt sustainable practices that benefit both the environment and their business.

3.1 Advantages of Integrated Nutrient Management (INM)

Optimizing soil conditions for maximum productivity is a multifaceted endeavour, necessitating a harmonious interplay of various factors [4]. Soil nutrient content stands as a cornerstone, requiring precise calibration to ensure availability in forms readily absorbable by plants at critical growth stages [22]. Effective nutrient management strategies, as advocated by several studies, emerge as indispensable tools in achieving robust crop development and yield across diverse agro-ecological contexts. Such strategies offer a range of benefits, including enhancement of soil fertility, improved fertilizer solubility and availability, and alignment of nutrient supply with crop demands (Fig. 3) [6-8].

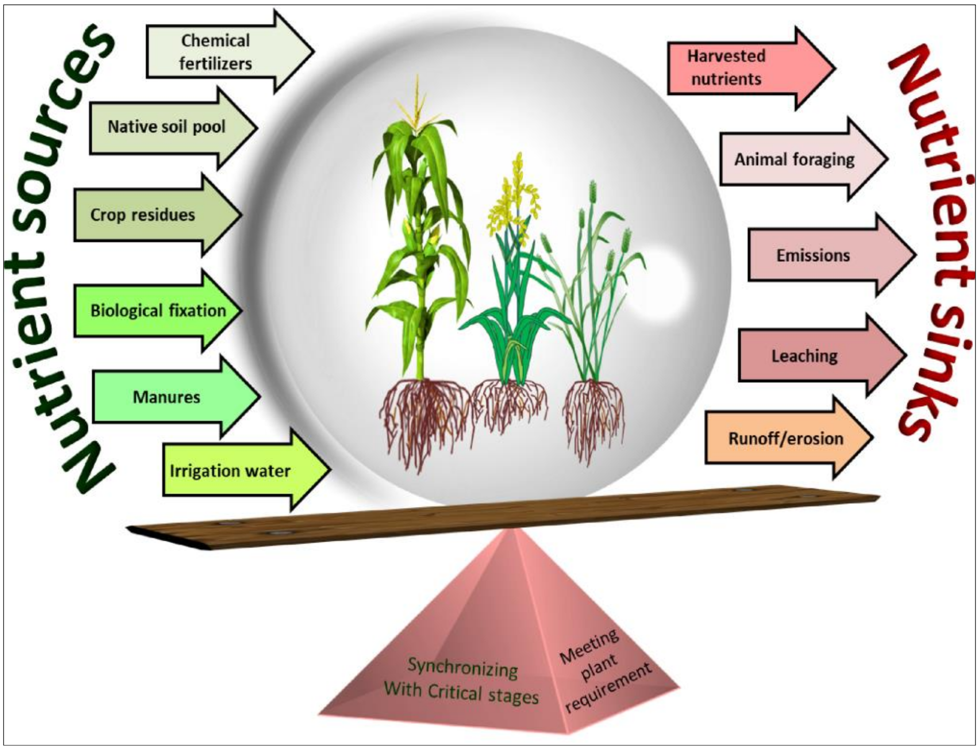

Fig. 3. Balancing the nutrient for meeting plant requirement and availability in INM [15]

Furthermore, they play a pivotal role in bolstering soil physiochemical and biological functions while mitigating soil degradation, water pollution, and ecosystem disruption [23]. By fostering carbon sequestration and minimizing nutrient runoff, these practices contribute to environmental sustainability. Economically, they prove advantageous by reducing production costs and enhancing profitability for farmers. Moreover, nutrient management strategies bolster crop resilience to both biotic and abiotic stresses [24], ensuring food security in regions grappling with rapid population growth [25]. Thus, they represent a holistic approach to farming that not only fosters food safety but also addresses pressing soil and environmental concerns.

3.2 Impact of Integrated Nutrient Management on Soil Fertility and Productivity

Research on Integrated Nutrient Management (INM) highlights the crucial role of applying macronutrients such as nitrogen, phosphorus, and potassium (NPK) in appropriate amounts [26]. These studies focus on the optimal rate and timing of fertilizer application, crop variety responses, and the effects of integrating NPK with other agronomic practices [18,20]. Findings suggest that applying the recommended levels of inorganic fertilizers is crucial for maintaining productive yields, especially in soils with low fertility. However, while inorganic fertilizers can be beneficial, their prolonged and unbalanced use might extend the growing season, delay flowering, and push back physiological maturity by one to two weeks, leading to reduced yield quantity and quality. Additionally, consistent overuse of inorganic fertilizers may lead to micronutrient deficiencies, compromising soil productivity and sustainability [27].

Given these challenges, INM emerges as a vital practice, offering a way to reduce nutrient losses and mitigate the environmental impacts associated with conventional fertilizer use, while maintaining higher crop yields and profitability. INM focuses on combining different nutrient sources in a way that meets plant requirements at the right intervals, enhancing nutrient-use efficiency [28]. This approach not only helps avoid nutrient deficiencies but is also crucial for addressing socioeconomic issues, particularly for small-scale farmers with limited resources for soil fertility management. By integrating INM, farmers can achieve more sustainable and productive agricultural systems.

4. ADOPTION AND NEED OF ORGANIC FARMING IN INDIA

India is a predominantly agricultural nation, with over 58% of its population relying on farming for their livelihood. Until the 1960s, organic farming was the norm, with farmers using natural methods to cultivate crops. However, a combination of rapid population growth and frequent droughts prompted the Indian government to collaborate with the United States, leading to the introduction of chemical fertilizers and pesticides to boost agricultural productivity [29,30]. This transition, part of the "Green Revolution," temporarily addressed food security issues but had long-term adverse effects on the environment and soil health. By the 1990s, the productivity gains from conventional farming had begun to diminish, with increased costs, soil degradation, and adverse impacts on human health. The intensive use of synthetic fertilizers and pesticides led to a host of problems, including high water consumption, the proliferation of diseases and weeds, and uncontrollable environmental pollution [31]. The high doses of pesticides, which increased from 24.32 thousand tonnes in 1970-75 to 75 thousand tonnes in 1990-91, contributed to these issues, with significant consequences for aquatic life, plants, and animals. Conventional farming, once seen as a solution, became unsustainable and unfavourable for many Indian farmers [29-32].

The detrimental effects of conventional farming have raised serious concerns about environmental degradation and the need for sustainable agricultural practices. In response, there has been a renewed interest in organic farming, which focuses on sustainable resource management and minimizing chemical use [33]. Organic farming promotes the use of natural materials such as crop residues, farmyard manure, compost, green manure, oil cakes, bio-fertilizers, and bio-pesticides to enhance soil fertility and reduce the harmful impacts of conventional farming practices [34]. Despite its benefits, organic farming in India occupies just 0.03% of the total cultivated area, a stark contrast to global figures, where organic farming ranges from 3.7% to 11.3% of cropland. One reason for the slow adoption of organic farming in India is the lack of governmental support and the three-year transition period required before a farmer can label their produce as "organic." During this time, farmers must continue to invest in organic practices without the financial benefits of the organic label.

To promote organic farming and encourage the transition from conventional methods, there is a need for more comprehensive policies and government support. The only policy related to organic farming in India is the National Standards of Organic Production (2000), which lacks the depth and support required to make organic farming a viable alternative [35]. Governments must develop policies that support farmers during the transition period and establish stronger linkages between farmers and markets to ensure the success of organic farming. By reintroducing organic farming practices and expanding their use, India can achieve a more sustainable agricultural system. Organic farming has the potential to solve food shortages, reduce environmental degradation, and improve the economic viability of farming [36]. With appropriate government support and increased awareness, India can make significant strides towards a more sustainable agricultural future while maintaining food security for its population.

5. INTEGRATED NUTRIENT MANAGEMENT (INM) OVER ORGANIC FARMING

In synthesizing a review paper exploring the drawbacks of organic farming and the rationale for choosing Integrated Nutrient Management (INM) over organic farming, it's imperative to delve into the complexities and nuances of both agricultural practices [14]. Organic farming, while celebrated for its emphasis on natural inputs and environmental sustainability, is not without its limitations. One significant drawback of organic farming is its lower productivity compared to conventional methods. Organic practices often result in lower yields due to limitations in nutrient availability, pest and disease management, and weed control [34]. Additionally, organic farming requires larger land areas to achieve comparable yields, which can be economically unfeasible for farmers with limited resources. Moreover, organic farming faces challenges in terms of nutrient management. While organic fertilizers such as compost and manure are utilized, their nutrient content can be variable and may not always meet crop requirements. This inconsistency in nutrient availability can lead to imbalances and deficiencies, affecting crop growth and yield. Furthermore, organic farming may struggle to meet the demands of a growing global population. With increasing pressure on food production, there are concerns about the ability of organic methods to sustainably feed the world.

In contrast, Integrated Nutrient Management (INM) offers a holistic approach that combines organic and inorganic inputs to optimize nutrient availability while minimizing environmental impacts [4]. INM integrates the use of organic materials, such as compost and crop residues, with judicious applications of synthetic fertilizers. This approach allows for precise nutrient management, ensuring that crops receive the necessary nutrients in the right quantities and at the right time. Additionally, INM offers flexibility and adaptability to diverse agroecological contexts, making it suitable for smallholder farmers as well as large-scale agricultural operations. By harnessing the benefits of both organic and inorganic inputs, INM can enhance soil fertility, improve crop yields, and promote sustainable agriculture practices [7-9]. Ultimately, while organic farming has its merits, it's essential to acknowledge its limitations and explore alternative approaches like INM that offer a balanced and pragmatic solution to the challenges of modern agriculture [28,31]. Through rigorous research and evidence-based decision-making, we can work towards sustainable agricultural systems that prioritize both environmental stewardship and food security.

6. ADVANTAGES OF INTEGRATED NUTRIENT MANAGEMENT OVER ORGANIC FARMING

Integrated Nutrient Management (INM) offers several advantages over organic farming, particularly in terms of balancing productivity with environmental sustainability [8]. While organic farming strictly relies on natural inputs, INM combines both organic and inorganic sources to optimize nutrient availability and enhance crop yields. This flexibility allows INM to adapt to different soil conditions and nutrient requirements, providing a more comprehensive approach to soil fertility and plant nutrition. One key advantage of INM is its potential to increase crop productivity compared to organic farming [11]. Organic farming, due to its reliance on slower-releasing organic nutrients, can sometimes struggle to meet the immediate nutrient demands of high-yielding crops [16,17]. INM, however, utilizes a balanced mix of organic and inorganic fertilizers, ensuring that crops receive a steady supply of nutrients throughout their growth cycle. This balanced approach helps maintain soil fertility while supporting high levels of productivity, making it a more suitable option for large-scale agricultural systems where yield is a critical factor.

Another benefit of INM is its role in reducing the environmental impact of conventional agriculture. INM promotes the judicious use of chemical fertilizers, reducing the risk of nutrient runoff and environmental contamination. By integrating organic manures, compost, and other natural materials into the nutrient management plan, INM improves soil structure, enhances microbial activity, and reduces the need for chemical inputs [33,34]. This approach not only mitigates the harmful effects of synthetic fertilizers but also supports sustainable agricultural practices by promoting soil health and biodiversity. Overall, INM offers a balanced solution that combines the best of both organic and conventional farming practices. It provides a pathway to sustainable agriculture by optimizing nutrient use, supporting high crop productivity, and minimizing environmental impact. While organic farming has its own merits, particularly in terms of environmental stewardship, INM can be more adaptable and productive, making it a valuable approach for modern agriculture [36].

Integrated Nutrient Management (INM) has distinct advantages over organic farming when considering growth parameters, yield parameters, and soil properties. While organic farming focuses on natural inputs, INM integrates both organic and inorganic sources to meet the comprehensive nutrient needs of crops, allowing for greater flexibility and productivity.

6. 1 Growth Parameters

INM often leads to better growth parameters compared to organic farming [34]. The balanced use of organic manures and inorganic fertilizers ensures that crops receive a consistent supply of essential nutrients throughout their growth cycle. This leads to healthier plants with improved shoot and root development. The use of inorganic fertilizers in moderation can quickly address nutrient deficiencies, promoting rapid and robust growth. In contrast, organic farming relies solely on organic sources, which may release nutrients more slowly, potentially leading to delayed plant growth in high-yielding crops.

6.2 Yield Parameters

In terms of yield parameters, INM tends to offer higher crop yields compared to organic farming. The integration of inorganic fertilizers with organic amendments allows for optimal nutrient availability, boosting plant growth and productivity [52]. This approach is particularly beneficial in high-intensity farming systems where consistent and high yields are necessary. Organic farming, while environmentally sustainable, might not always achieve the same level of productivity due to the slower nutrient release from organic sources. By combining both organic and inorganic sources, INM maximizes crop yield while minimizing nutrient losses to the environment. Yield is a key focus in agricultural production systems, and a well-managed nutrient strategy is crucial for achieving optimal yields. The effect of integrated nutrient management (INM) on rice equivalent yield has been analyzed by comparing the yields from INM-treated plots with those from conventional nutrient management across various crops and cropping systems. The results are summarized in Table 1 [51].

6.3 Soil Properties

INM has a positive impact on soil properties, promoting soil health while maintaining productivity. The incorporation of organic manures and compost in INM improves soil structure, increases organic matter content, and fosters a thriving soil microbiome [53]. These factors contribute to enhanced soil fertility and water retention [54]. Additionally, the controlled use of inorganic fertilizers in INM reduces the risk of soil degradation and contamination, a concern often associated with conventional farming. Organic farming also supports soil health, but INM's balanced approach provides a broader range of nutrients, supporting both immediate crop needs and long-term soil sustainability.

Table 1. Comparison of grain yield in conventional and integrated nutrient management system

Crop/cropping system	Nutrient management system	equivalent yield	% change from conventional system	References
Maize	Conventional	8.2	39.9	[37,38]
	INM	13.7		
Maize	Conventional	7.7	1.2	[39]
	INM	7.7		
Maize	Conventional	5.1	29.7	[40]
	INM	7.3		
Maize	Conventional	1.5	1.3	[41]
	INM	1.5		
Maize	Conventional	9.2	−4.4	[41]
	INM	8.8		
Wheat	Conventional	3.4	32.9	[42]
	INM	5.1		
Wheat	Conventional	3.4	32.9	[42]
	INM	5.1		
Wheat	Conventional	5.3	14.5	[43]
	INM	6.2		
Wheat	Conventional	2.1	54.1	[43]
	INM	4.5		
Wheat	Conventional	1.3	66.5	[42]
	INM	3.8		
Wheat	Conventional	6	7.7	[44]
	INM	6.5		
Wheat	Conventional	4.3	8.4	[45]
	INM	4.7		
Wheat	Conventional	7.2	8.1	[41]
	INM	7.8		
Rice	Conventional	5.9	16.2	[46]
	INM	7		
Rice	Conventional	5.4	8.0	[47]
	INM	5.9		
Rice	Conventional	8.6	21.6	[34]
	INM	11		
Rice	Conventional	5.4	8.0	[48]
	INM	5.9		
Rice	Conventional	3.9	23.1	[49]
	INM	5		
Rice	Conventional	4.5	38.6	[49]
	INM	7.3		
Rice-wheat	Conventional	7.7	54.6	[41,46]
	INM	16.9		
Soybean	Conventional	3	3.4	[50]
	INM	3.1		
Soybean	Conventional	2.1	44.9	[50]
	INM	3.8		
Soybean	Conventional	4.5	26.6	[50]
	INM	6.1		
Soybean	Conventional	6.5	20.2	[50]
	INM	8.1		

Source: Paramesh et al. (2023) [51]

7. FUTURE PERSPECTIVES OF ORGANIC FARMING VS. INTEGRATED NUTRIENT MANAGEMENT

The future of agriculture relies heavily on the adoption of sustainable practices that address food security, environmental health, and resource conservation [36,51]. Organic farming and Integrated Nutrient Management (INM) represent two key approaches to achieving these goals, each with its own strengths and limitations. Understanding their future trajectories can guide policymakers, farmers, and researchers toward more sustainable agricultural systems. Organic farming focuses on eliminating synthetic chemicals and relying solely on organic inputs. Its future is tied to increasing consumer demand for organic products and a growing awareness of environmental sustainability [55]. As people become more conscious of the health and environmental risks associated with conventional farming, the demand for organic produce is likely to increase. This shift in consumer preferences could lead to an expansion of organic farming practices.

However, organic farming faces challenges related to productivity and scalability. Since organic farming relies on slower nutrient release from organic sources, it can struggle to meet the immediate nutrient needs of high-yielding crops [56]. This may limit its adoption in large-scale, high-intensity farming systems where consistent productivity is crucial. To address this, future developments in organic farming must focus on improving soil health, optimizing organic nutrient cycles, and finding innovative methods to enhance crop yields without compromising organic principles. INM offers a balanced approach by combining organic and inorganic inputs to meet crop nutrient requirements. Its future is promising due to its flexibility and adaptability to various agricultural contexts. As sustainability becomes a central focus in agriculture, INM provides a pathway to reduce the environmental impact of farming while maintaining high productivity [57].

The future perspectives for INM include a greater emphasis on resource efficiency, soil health, and reduced chemical dependency. By integrating organic manures, compost, and crop residues with judicious use of inorganic fertilizers, INM can promote soil fertility, reduce nutrient runoff, and minimize environmental contamination [37,58]. Additionally, the adoption of precision agriculture technologies can further enhance nutrient-use efficiency, allowing farmers to apply nutrients more effectively and reduce waste. Looking ahead, there is a possibility for convergence between organic farming and INM. Both approaches aim to reduce environmental impact and promote sustainable agriculture, albeit with different methods. The synergy between organic farming's focus on natural inputs and INM's balanced approach can lead to innovative practices that combine the best of both worlds. This convergence could result in agricultural systems that are both productive and environmentally sustainable. Ultimately, the future of agriculture will require a combination of these approaches, with organic farming providing a foundation for sustainability and INM offering a flexible, adaptive model for maintaining productivity. By exploring the strengths and challenges of each, agricultural stakeholders can develop more holistic strategies to ensure food security, environmental health, and economic viability in the years to come.

8. CONCLUSION

The comparative review of organic farming and Integrated Nutrient Management (INM) underscores the need for sustainable agricultural practices that balance productivity with environmental stewardship. Organic farming, with its focus on natural inputs and strict avoidance of synthetic chemicals, provides an environmentally friendly approach to agriculture. However, it may face challenges in meeting the nutrient demands of high-yielding crops and achieving large-scale productivity. INM, on the other hand, offers a flexible solution by integrating both organic and inorganic sources of nutrients. This balanced approach supports high crop productivity while minimizing environmental impact. By promoting soil health, reducing nutrient runoff, and enhancing resource efficiency, INM emerges as a robust model for sustainable agriculture. The future of agriculture likely lies in a combination of these approaches, with organic farming providing a foundational framework and INM offering the flexibility and adaptability needed for modern agricultural systems. The convergence of organic farming's principles with INM's balanced methodology can lead to innovative practices that address both environmental and productivity concerns. By focusing on integrated approaches that combine the strengths of organic farming and INM, agriculture can move toward a more sustainable, productive, and environmentally conscious future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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