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Integrated Nutrient Management Practices for Sustainable Chickpea: A Review

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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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Review Article

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ABSTRACT

Chickpea (*Cicer arietinum* L.) is a vital legume crop which considerably contributes to the nutritional security of millions. Sustainable production of chickpea requires optimizing nutrient management practice to improve productivity while sustaining soil health. Integrated Nutrient Management (INM) is an approach by which chemical fertilizers, organic manures, and bio-fertilizers are applied judiciously to meet balanced nutrient supply. This review collates recent research on INM strategies in chickpea, discussing their effect on yield, soil fertility, and environmental sustainability.

Keywords: Chickpea; chemical fertilizer; organic manures; bio-fertilizer.

1. INTRODUCTION

Chickpea (*Cicer arietinum* L.) ranks as one of the world's most vital leguminous crops in terms of its high protein content and its ability to enrich soil fertility through biological nitrogen fixation (Zhang et al*.,* 20240. Millions regard it as a staple source of dietary protein, especially in developing countries; the crop is used in various traditional dishes, animal feed, and even as raw material for food processing industries (Wu et al*.,* 2014; Nadathur et al*.,* 2016). Its adaptability to different agro-climatic regions and low water requirement make it an essential crop for sustainable agriculture (Roy et al*.,* 2023). Chickpea also plays a critical role in crop rotation systems because of its symbiotic relationship with nitrogen-fixing bacteria (*Rhizobium*), which minimizes the dependency on synthetic nitrogen fertilizers (Kebede, 2021). This natural nitrogen fixation not only enriches the soil fertility but also helps the subsequent crops through the residual nitrogen pool available in the soil (Meena et al*.,* 2020).

Despite these benefits, chickpea productivity is severely hindered by the following factors: Permanent monoculture and agricultural lands overuse result in soil nutrient impoverishment and decreased fertility (Bisht et al*.,* 2020). It excessive and unbalanced application have resulted in the degradation of the health of the soil system, imbalances in available nutrients, and environmental pollution in forms including greenhouse gases and water pollution (Lal, 2009). Erratic rainfall, increasing temperature, and limited availability of organic amendments further stressed the production systems of chickpea (Gupta, & Verma, 2020; Chandra, 1980). To overcome these problems, sustainable agricultural practices must be encouraged. INM is one of the promising approaches to efficiently increase nutrient use efficiency with maintaining soil health (Ahmad, & Khan, 2020; Wu, and Ma, 2015). INM incorporates the combined use of chemical fertilizers, organic manures, bio fertilizers, and micronutrients in balanced and continuous supplies to ensure the proper accomplishment of all agronomic activities (Chaubey et al*.,* 2023). This practice not only increases crop productivity but also enhances soil organic matter contents, stimulates microbial activity, and reduces its impacts on the environment (Mohammadi et al*.,* 2011).

This review provides an analysis of all the above-mentioned constituents of INM and their particular involvement in chickpea crop production. It outlines how the integration of different nutrient sources can significantly contribute to sustaining chickpea yields, enhancing soil fertility, and being environmentally friendly. However, this review consolidates existing knowledge and practical information to be a useful source for policymakers, researchers, and farmers aiming to adopt sustainable nutrient management practices into chickpea cultivation systems.

Table 1. Several researchers have conducted studies on integrated nutrient management in chickpea, as listed below

Sr.No	Research topic	Researchers
1.	Integrated use of vermicompost and inorganic fertilizer in chickpea. *Annals of plant physiology*.17(2):205-206.	Asewar et al*.* (2003)
2.	Effect of row ratio and fertility level on growth, productivity, competition and economics in chickpea+ funnel intercropping system under scarce moisture condition. Journal of food legumes Volume 24 (3):211-214 ISSN: 0976-2434	Awasthi et al*.* (2011)

Sr.No	Research topic	Researchers
3.	Effect of Organic and Inorganic Fertilizers on *Growth, Yield and Yield Components of Chick Pea (Cicer arietinum*) and Enhancing Soil Chemical Properties on Vertisols at Ginchi, Central Highlands of Ethiopia. *Journal of Biology, Agriculture and Healthcare* Vol.7, No.23,2224-3208	Chala Girma (2017)
4.	Effects of Biofertilizer with and without Molybdenumon Growth and Seed Yield of Chickpea under DoonValley of Uttarakhand *Current Journal of Applied Science and Technology* 39(15): 133-139	Chandra Girish (2020)
5.	Evalution of Rhizobium Efficiency in Chickpea through Boron Management. BhartiyaKrisiAnusandhanPatrikaVol31 No 3; PP: 181-186	Das et al*.* (2016)
6.	Effect of integrated nutrient management productivity and quality of chickpea (*Cicer arietinum* .L*)* Ph.D. Thesis CSAUA&T (Kanpur)	Anil Kumar (2018-2019)
7.	Effect of farm yard manure, phosphorus and sulphur on yield parameters, yield, nodulation, nutrient uptake and quality of chickpea (*Cicer arietinum* L.) *Journal of Applied and Natural Science* 8 (2): 545 - 549	Das et al*. (*2016)
8.	Effect of integrated nutrient management and drought mitigating practices on performance of rainfed chickpea (*Cicer arietinum) Indian Journal of Agricultural Sciences* 87 (3): 301–5	Dewangan et al*.* (2017)
9.	Combined effect of bio fertilizer and micronutrients on fertility, growth and productivity of chickpea. *Journal of Pharmacognosy and Phytochemistry*, *8*(6), 22576-2579.	Anil et al*.* (2020)
10.	Response of fertility levels and biofertilizers on growth and yield attributes quality of chickpea. *Asian Journal of Soil Science and Plant Nutrition*, *10*(2), 358-365.	Jain et al*.* (2024)
11.	Influence of nitrogen fixing and phosphorus solubilizing bacteria on the nodulation, plant growth, and yield of chickpea. *Journal of Plant Nutrition* 31(1) : 157-171.	Elkoca et al*. (*2008)
12.	Effect of different organic and inorganic fertilizers on nutrient content, uptake and quality of chickpea. *Journal of Pharmacognosy and Phytochemistry*, *9*(6), 2073-2079.	Anil et al*.* (2020)
13.	Effect of integrated nutrient management on growth and yield of maize-chickpea cropping system. *Journal of Soils and Crops*, 18(2) : 392-397.	Gable et al*.* (2008)
14.	Effect of potassium level and foliar application of nutrient on growth and yield of late sown chickpea *(Cicerarietinum L.). Environment and Ecology.32 (1A):273-275*	Ganga et al*.* (2014)
15.	Nutrient balance under INMS in sorghum-chickpea cropping sequence.*Indian Journal of Agricultural Research*, 41(2) : 137-141.	Gawai et al*.* (2007)
16.	Vermicompost as a soil supplement to relieve the effects of low-intensity drought stress on chickpea yield. Acta Horticulture (1018):219-226.	Gholipoor et al*.* (2014)
17.	Studies on organic and inorganic sources of nutrient application in cotton –chickpea cropping sequence. *Omonrice* 18: 121-128.	Gudadhe et al*.* (2011)
18.	Effect of bio-fertilizers and foliar spray of urea on symbiotic traits, nitrogen uptake and productivity of chickpea, Journal of food legumes, 24 (2), 155-157, 2011.	Gupta et al*.* (2011)
19.	Effect of Farmyard Manure (FYM),Vermicompost and Chemical Nutrients on the growth and yield of Chickpea. *(Cicer arietinum L.)International Journal of Agriculture Research,* 7:93-99*.*	Guriqbal et al*.* (2012)
20.	Effect of Integrated Nutrient Management Modules on Nutrient Uptake, Quality and Economics of High Yielding Varieties of Chickpea (*Cicer arietinum* L.) under Late Sown Condition.	Harikesh et al*.* (2018)

Sr.No	Research topic	Researchers
	International Journal of Agriculture Sciences, ISSN: 0975-3710 & E-ISSN: 0975-9107, 10: (24), 7675-7677	
21.	Effect of vermicompost fertilizer on photosynthetic characteristics of chickpea (*Cicer arietinum* L.) under drought stress, *Photosynthetica*,54(1),87-92.	Hosseinzadeh et al. (2016)
22.	Effect of organic and inorganic N fertilizer on growth and yield of chickpea (*Cicer arietinum* L. grown on sandy soil using 15 N Tracer. Bangladesh J. Bot. 46(1): 155-161	Ismail et al. (2017)
23.	Direct and residual effect of vermicompost, biofertilizers and phosphorus on soil nutrient dynamics and productivity of chickpea-fodder maize sequence. *J. Sustanable Agric.* 27 : 41-54.	Jat et al. (2006)
24.	Growth and nutrient uptake of chickpea (*Cicer arietinum* L.) as influenced by bio-fertilizers and phosphorus nutrition. *Crop Research (Hisar)*, 25(3) : 410-413.	Jain, and Pushpendra (2003)
25.	Effect of FYM and biofertilizer in conjunction with inorganic fertilizer on growth, yield and profit of chickpea (*Cicer arietinum* L.). *Plant Archives*, 5(2): 609-612.	Kedar et al. (2005)
26.	Efficiency of biofertilizers in increasing the production potential of cereals and pulses: A review Journal of Pharmacognosy and Phytochemistry.; 8(2): 183-188	Khanna et al. (2019)
27.	Effect of phosphorus, sulphur and PSB on quality components and nutrient uptake in chickpea. *Annals of Plant Physiology*, 20(1): 78-81. J. M.	Kharche et al. (2006)
28.	Growth of yield attributes and yield of summer blackgram (*Vigna mungo* L.) as influenced by FYM, Phophorus and sulphur. *An International quarterly journal of Environmental Sciences.* Special issue, Vol.(4): 429-433	Kokani et al. (2014)
29.	Quality enhancement in chickpea mediated through integrated nutrient management. *Journal of Pharmacognosy and Phytochemistry*; 7(4): 3212-3216	Kumar et al. (2018)
30.	Effect of integrated nutrient management (INM) on productivity and profitability of chickpea *(Cicer arietinum L.) International Journal of Chemical Studies*; 6(6): 1672-1674	Kumar et al. (2018)
31.	Effect of Biofertilizer and Micronutrients on Yield of Chickpea *Int.J.Curr.Microbiol.App.Sci* (2019) 8(1): 2389-2397	Thomas et al. (2019)
32.	Residual Effect of Manure and Fertilizer on Growth, Yield of Chickpea and Soil Nutrient Status under Maize-Chickpea Cropping System. *Int.J.Curr.Microbiol.App.Sci.* 9(4): 2940-2945.	Lakum et al. (2020)
33.	Impact of phosphorus and iron on protein and chlorophyll content in chickpea *(Cicer arietinum L.) Lergume research* 38 (4):588.	Mathur et al. (2015)
34.	Evalution of spaced channel irrigation method and nutrient management in chickpea (*Cicer arietinum* L.). *Environment and Ecology*.27 (1):49-52.	Paraye et al. (2009)
35.	Effect of soil and foliar application of zinc and Boron on growth, yield and micro nutrient uptake of Chickpea *Journal of Pharmacognosy and Phytochemist*ry 9(4): 3356-3360	Rathod et al., (2020)
36.	Effect of biofertilizers, *Rhizobium* & phosphate in combination of different level of Ca, Mg & S on the productivity of chickpea (*Cicer arietinum* L.) cultivar Avrodhi. *Journal of Plant Development Sciences*, 3(3/4) : 243-245	Nazo et al. (2011)

2. CONSTITUENTS OF INM FOR CHICKPEA

2.1 Chemical Fertilizers

Chemical fertilizers provide immediate availability of macronutrients necessary for full expression of growth and development of plants. In chickpea, nitrogen (N), phosphorus (P), and potassium (K) are most crucial (Yahaya et al*.,* 2023).

Nitrogen (N): Although chickpea is a leguminous crop capable of fixing atmospheric nitrogen through symbiotic associations with Rhizobium bacteria, a small starter dose of nitrogen (around 20–25 kg/ha) is often recommended (Abdula, 2013). This provides an initial boost for early vegetative growth until the nitrogen-fixing nodules become fully functional (Hailemichael, 2020).

Phosphorus (P): Phosphorus is pivotal for root development, nodulation, and energy transfer processes within the plant (Gebremedhin, 2016). Adequate phosphorus availability enhances nodulation efficiency and supports the fixation of atmospheric nitrogen (Mitran et al*.,* 2018). Research suggests that phosphorus application rates between 20–40 kg/ha are optimal, depending on soil phosphorus levels (Umar et al*.,* 2020). The application of phosphorus is often done using single super phosphate (SSP) or di-ammonium phosphate (DAP) (Admasu, 2019).

Potassium (K): Potassium promotes plant strength, boosts biotic and abiotic stresses tolerance and seed quality (Wang et al*.,* 2013). Based on the soil test, application rate for potassium differs. But typically 20–30 kg/ha would be sufficient for the cultivation of chickpea (Hasanuzzaman et al*.,* 2018).

Balanced fertilization using chemical fertilizers is aimed at achieving an optimal nutritional balance without risking nutrient imbalances or the degradation of soils (Cissé, 2007).

2.2 Organic Manures

Organic manures are natural sources of nutrients that improve soil health, enhance microbial activity, and provide slow-releasing nutrients to the crop (Shaji et al*.,* 2021). Some common organic manures used in chickpea production include farmyard manure (FYM), compost, and vermicompost (Akash et al*.,* 2022; Jain, et al*.,* 2021).

Farmyard Manure (FYM): FYM is a rich source of organic matter and nutrients such as nitrogen, phosphorus, and potassium in organic forms (Antil, and Singh, 2007). Application rates of 5–10 t/ha of FYM have been shown to significantly improve soil structure, water-holding capacity, and nutrient availability, leading to increased chickpea yields (Yadav, 2023).

Compost: Compost is prepared from decomposed plant and animal residues (Sayara et al*.,* 2020). It enriches the soil with nutrients and beneficial microbes, contributing to better nutrient recycling and improving the soil's organic carbon content (Bhunia et al*.,* 2021).

Vermicompost: Vermicompost is a nutrient-rich organic amendment produced through the action of earthworms (Walia and Kaur 2024). It contains readily available forms of nitrogen, phosphorus, and other micronutrients, promoting early plant growth and sustained nutrient release (Shrivastav et al*.,* 2020).

Organic manures in combination with chemical fertilizers improve nutrient use efficiency and soil fertility. This is one of the sustainable systems of chickpea production (Ramaiyan et al*.,* 2023).

2.3 Bio-fertilizers

Bio-fertilizers are the microbial inoculants which make the nutrients available to the plants through biological means (Sowmya et al*.,* 2024). In chickpea, Rhizobium and phosphate-solubilizing bacteria (PSB) are the most important bio-fertilizers (Sharma, et al*.,* 2021).

Rhizobium: It is a symbiotic bacterium which, by association with roots of chickpea, transforms into root nodules (Rashid et al*.,* 2015), which allow atmospheric nitrogen to be captured and made available for absorption by the plant (Carranca, 2013). Its inoculation has improved its ability to fix nitrogen, enhanced plant growth, and increased seed production by 15–25% (Patel, and Sharma, 2019) and (Fred et al*.,* 2002). Proper inoculation involves treatment of seeds prior to sowing with a Rhizobium culture that helps effectively colonize and nodulate their roots (Gebremedhin, 2016).

Phosphate-Solubilizing Bacteria (PSB): PSB increases the solubility of insoluble phosphorus compounds in soil, making phosphorus more accessible to plants. This minimizes the application of chemical phosphorus fertilizers and maximizes overall phosphorus use efficiency.

Applying Rhizobium and PSB as seed or soil inoculant will optimize nutrient uptake, reduce costs of fertilizer, and improve the sustainability of chickpea production (Ramaiyan et al*.,* 2023).

2.4 Micronutrients

Although micronutrients are required in very small amounts (Fouda et al*.,* 2017), they are very important for plant growth and physiological processes (Tripathi et al*.,* 2015) and Das, & Roy, 2019). Deficiencies of zinc and boron are very common in chickpea and can affect productivity and seed quality very significantly (Muhammed, 2023).

Zn: This element plays a critical role in chickpea for enzyme activation, protein synthesis, and regulation of growth (Wang et al*.,* 2021; Ullah et al*.,* 2020). Zinc sulfate is one of the most frequently used sources applied at a rate of 20–25 kg/ha for soil application (Jalal et al*.,* 2022). Foliar sprays with 0.5% zinc sulfate during flowering and pod-setting have been reported to enhance seed quality and yield (Singaravel et al., 2022).

Boron (B): Boron is involved in cell wall synthesis, membrane integrity, and pollen tube formation. The deficiency results in less flowering and poor pod formation (Blevins, and Lukaszewski, 1998). Borax applied as a soil amendment at 1–2 kg/ha or foliar spray at 0.1–0.2% is effective for alleviating boron deficiency (Raj, and Raj, 2019).

Chickpea is a direct source of dietary protein and constitutes an important crop in cropping systems mainly because it can fix the atmospheric nitrogen (Grasso et al*.,* 2022). However, these intensive cultivations, and declining soil fertility (Gruhn, et al*.,* 2000) increased dependence on chemical fertilizers have led to the emergence of sustainable nutrient management approaches (Wu, and Ma, 2015), and integrated nutrient management has emerged as the viable solution to these emerging challenges (Kumar, and Choudhary, 2018). This review looks into various aspects of INM components and their contributions in chickpea production systems in full expansion.

3. INM STRATEGIES IN CHICKPEA PRODUCTION

INM involves the strategic combination of chemical fertilizers, organic manures, bio-fertilizers, and micronutrients to ensure balanced nutrient availability for crops (Nakade et al*.,* 2021). INM strategies in chickpea cultivation are aimed at optimizing nutrient use efficiency (Singh, & Kumar, 2022) and (Choudhary et al*.,* 2020), enhancing soil fertility, and promoting sustainable production (Meena et al*.,* 2019).

3.1 Combined Use of Fertilizers and Manures

The integration of organic manures with chemical fertilizers results in a synergistic effect ensuring balanced nutrient supply throughout the crop growth cycle (Subhash, 2021). Organic manures, such as farmyard manure (FYM), vermicompost, and compost, improve soil physical, chemical, and biological properties (Singh et al*.,* 2020). Chemical fertilizers, in turn, provide immediately available nutrients for the plants (Pahalvi et al*.,* 2021).

For instance, the application of 50% RDF in combination with 5 t/ha of FYM has been found to increase chickpea yield by up to 20% (Mohan, 2021). This approach benefits both the crop and the soil in several ways:

Organic manures slowly release nutrients over time, complementing the immediate nutrient supply from chemical fertilizers (Timsina, 2018). Manures enhance soil organic matter content, water-holding capacity, and microbial activity, which are critical for long-term soil health (Gurmu, 2019; Singaravel and Seenivasan, 2024). Reducing the reliance on chemical fertilizers lowers production costs for farmers and minimizes the environmental impact of excessive fertilizer use (Chien et al*.,* 2009).

Research demonstrates that such combinations not only enhance crop productivity but also sustain soil fertility, making it a sustainable practice for chickpea production systems (Korbu et al*.,* 2020).

3.2 Bio-fertilizers Role in Efficiency

Bio-fertilizers like Rhizobium and PSB have an important role in nutrient cycling and improving nutrient availability to chickpea plants (Singh et al., 2024; Alamzeb et al., 2024). The interaction of microbial inoculants with plant roots triggers biological processes such as nitrogen fixation and phosphorus solubilization (Alori et al., 2017).

Rhizobium: It shows symbiotic association with the roots of chickpea, fixes atmospheric nitrogen, and converts it to a form assimilable by the plant (Rashid et al., 2015; Djouider et al., 2022). Seed inoculation with culture of Rhizobium has been claimed to enhance efficiency of nodulation and nitrogen fixation to the tune of 30% more yield (Abd-Alla et al., 2023).

Phosphate-Solubilizing Bacteria (PSB): PSB enhances the solubilization of insoluble phosphate compounds in the soil, making phosphorus available for plant uptake (Bargaz et al., 2021). This reduces dependency on chemical phosphorus fertilizers and ensures effective utilization of phosphorus (Schröder et al., 2021).

It enhances nutrient use efficiency and reduces input costs with a decreased application of chemical fertilizers, thus improving environmental sustainability (Panhwar et al., 2019). Various studies indicate that such a combination promotes growth in plants, increases nodulation, and maintains yields at the same level of soil fertility (Ghosh et al., 2007; Meena, et al., 2022).

3.3 Site-Specific Nutrient Management (SSNM)

Site-Specific Nutrient Management (SSNM) is a precision approach that makes nutrient application according to the need of a field, based on the soil test results, crop requirements, and local agro-climatic conditions (Sarma et al., 2024; Swami et al., 2009). By addressing the nutrient variability across a field, SSNM ensures optimal resource use and improves nutrient recovery efficiency (Sarkar et al., 2017).

Regular testing of soil gives critical information of nutrient status in the field (Hodges, 2010). This helps in the precise use of nutrients to correct specific deficiencies (Römheld, 2012). SSNM also emphasizes balanced use of chemical fertilizers, organic manures, and bio-fertilizers for crop nutrient need, maintaining soil health also (Singh, 2024). SSNM usually employs high-end technologies such as GIS, remote sensing, and mobile apps to determine nutrient application at the micro-level.

In chickpea cultivation, the adoption of SSNM has been highly beneficial in terms of yield and quality, saving wastage of fertilizers, and improving soil fertility (Choudhary et al., 2018). By matching nutrient supply to crop demand, SSNM optimizes the efficiency of nutrient use and promotes sustainable agriculture.

These strategies, in aggregate, highlight the need to integrate various nutrient sources for sustainable productivity in chickpea production without compromising viability on environmental and economic terms.

4. ROLE OF INM IN SOIL HEALTH AND ENVIRONMENT

In addition to increasing crop production, Integrated Nutrient Management (INM) positively impacts improving soil health as well as reducing environmental deterioration (Wu et al., 2015). Combined organic, inorganic, as well as biological sources of nutrients with INM allow for sustainable agricultural practices wherein productivity is coupled with eco-responsibility (Selim, 2020).

4.1 Soil Fertility Improvement

INM practices play an essential role in maintaining the long-term fertility of soil by enhancing various physical, chemical, and biological characteristics of the soil (Nakade et al., 2021).

Organic matter of the soil: It adds the organic manures, like farmyard manure (FYM), compost, and vermicompost, in the INM, increasing the content of organic matter of the soil (Chahal et al., 2020). Organic matter, therefore, becomes a reservoir for slowly releasing the nutrients to crops and improving structure, water-holding capacity, and aeration (Ali et al., 2019; Prabhu et al., 2021).

Microbial Activity: Organic amendments and bio-fertilizers enhance soil microbial growth and activity, playing a crucial role in nutrient cycling (Singh et al., 2020). For example, phosphate solubilizing bacteria increases phosphorus availability, Rhizobium facilitates N fixation in legumes as chickpea, which also supports processes such as decomposition and nutrient mineralization due to increasing microbial diversity (Kebede, 2021).

Nutrient Cycling: INM maximizes the recycling of nutrients within the soil system. The application of organic residues and the activity of bio-fertilizers ensure that all the essential nutrients like nitrogen (N), phosphorus (P), and potassium (K) are cycled and made available to the plants (Imran, 2024). This reduces the nutrient loss and maintains soil fertility during successive crop cycles.

Crop Rotation with Legumes: Legumes like chickpea in cropping systems increase biological fixation of nitrogen in the soils and, thus, create increased levels of soil nitrogen (Kebede, 2021). Legumes generally enrich the residue left by such crops, which is more easily utilized by subsequent crops that reduce the application of synthesized fertilizer nitrogen (Kakraliya et al*.,* 2018).
In totality, INM can sustainably manage soil fertility toward enhancing a healthier soil to better support long-term agriculture productivity (Rolaniya et al*.,* 2023).

4.2 Environmental Sustainability

INM significantly contributes to environmental sustainability by addressing the negative effects of over-reliance on chemical fertilizers and promoting eco-friendly farming practices (Raj et al*.,* 2024). These include:

Reducing Greenhouse Gas Emissions: The overuse of chemical fertilizers, especially those containing nitrogen, leads to massive greenhouse gas emissions in the form of nitrous oxide (N_2O) (Xuejun et al*.,* 2011). By integrating organic and bio-fertilizer components, INM minimizes the reliance on synthetic fertilizers (Choudhary et al*.,* 2018), which would otherwise increase the carbon footprint of agricultural activities.

Minimization of Nutrient Leaching and Runoff: Using chemical fertilizers at large quantities leads to leaching into the ground water as well as run-off in water bodies leading to polluting and eutrophying (Smith et al*.,* 2013). INM encourages a balanced utilization of nutrients, thus minimizing this risk factor (Singh, 2020). Organic manures ensure that the nutrient in soil is retained with no chances of loss to the environment (Singh et al*.,* 2022).

Promotion of Eco-Friendly Farming Practices: The environmental impact of the production and application of synthetic fertilizers is minimized by the application of bio fertilizers such as Rhizobium and PSB (Ali et al*.,* 2019; Shah and Wu, 2019). Bio fertilizers are replenish able, biodegradable, and nontoxic to soil and water environments (Chaudhary et al*.,* 2020).

Conservation of Biodiversity: INM practices are helpful in maintaining soil biodiversity by stimulating microbial populations and a healthy environment for beneficial microorganisms (Verma et al*.,* 2023). This helps to maintain ecological balance and agricultural ecosystems against pests and diseases.

Improved Resource Use Efficiency: Through the application of nutrients according to crop demand and soil condition, INM optimizes the inputs, thus preventing wastage and conserving natural resources, such as energy and water (Wu, and Ma, 2015).
These mechanisms support a sustainable agricultural system, which does not only improve productivity but also protects natural resources and decreases the environmental impacts of agriculture.

5. CHALLENGES AND FUTURE DIRECTIONS

In spite of its proven benefit in ensuring sustainable chickpea production, several factors hinder its full adoption in practice (Korbu et al*.,* 2020). The challenges originate from restricted dissemination of information, restricted availability of resources, and uneven performance by some of the INM components. All these areas will have to be targeted through focused research, policy interventions, and integration of relevant technology so that its complete potential may be exploited (Czajkowski, et al*.,* 2001).

5.1 Challenges to the Adoption of INM

Limited Dissemination of Information: Most farmers are unaware of the principles and benefits of INM. Low adoption rates are partly due to the lack of access to extension services, training programs, and informational resources (Sarkar, et al*.,* 2022) and (Jha et al*.,* 2024). Small and marginal farmers have less incentive to adopt INM because they are more focused on immediate returns rather than long-term sustainability (Etyang, 2013).

Resource availability and accessibility: Due to limited supply, quality organic manures, bio-fertilizers, and formulations of micronutrients, especially in remote or resource-poor areas, might not be readily available (Bayu, 2020). The main constraints are associated with transportation costs, inappropriate supply chains, and the poor condition of storage facilities for those inputs.

Bio-fertilizer Variability: The efficacy of bio-fertilizers like Rhizobium and phosphate-solubilizing bacteria may vary with soil types, climatic conditions, or management practices (Abawari et al*.,* 2020). Bio-fertilizer inoculants may lose viability if improper storage or handling is made, resulting in inconsistent field responses (Khalid et al*.,* 2021).

Installation Costs and Manpower: Although INM is a cost-saver in the long term, some of the investments on organic manures, bio-fertilizers, and soil testing are much more expensive at the beginning compared to traditional fertilizer application. Manuring or compost preparation is labor-intensive and would not favor resource-poor farmers.

Policy and Institutional Gaps: Supportive policies and institutional support for the adoption of INM are lacking. The incentives in terms of subsidies for chemical fertilizers are given with no encouragement of the use of organic and bio-fertilizers (Wu, and Ma, 2015).

5.2 Future Prospects

Regional Specific INM Models: Developing region-specific models for specific agro-climatic zones, types of soil, and crops would be essential to optimizing nutrient management. These models need to be developed from the resources available in a particular region and should solve regional-specific problems, making them more applicable to the farmers.

The Integration with Precision Farming Technologies: INM integrated with precision agriculture technologies will transform nutrient management in chickpea cultivation (Reddy, and Naik, 2020). Tools like GIS, remote sensing, and drone technology can help in site-specific nutrient management, improving resource use efficiency and reducing wastage. Mobile applications and decision-support systems can provide farmers with real-time recommendations on nutrient application.

Improving Bio-fertilizer Efficiency: Research must focus on improving the performance and reliability of bio-fertilizers. Development of multi-strain bio-fertilizers that will effectively function across a wide spectrum of soil and climatic conditions (Mazid, et al*.,* 2015). Improvement of the shelf life and viability of bio-fertilizer formulations through advanced production and packaging techniques (Sharma et al*.,* 2015). Consortium bio-fertilizer with nitrogen-fixing, phosphorus-solubilizing, and other beneficial microbes that promote holistic nutrient management (Muthusamy et al*.,* 2023). Training programs and workshops comprehensive in nature should be instituted to raise awareness of its benefits and implementation. More knowledge dissemination and skill upgrading can be done through the extension services and the use of farmer field schools.

Policy Support and Incentives: Governments and policymakers should also prioritize INM by subsidizing organic inputs and bio-fertilizers, offering incentives for soil testing, and supporting public-private partnerships in the production and distribution of inputs (Deva et al*.,* 2024). Supportive policies would make farmers move toward more sustainable practices (Wani et al*.,* 2016).

Sustainability Research and Innovation: Further research in sustainable nutrient management practices, such as integrating INM with climate-resilient crop varieties and organic farming systems, will open avenues for future improvements (Biswas et al*.,* 2024). The development of nano-fertilizers and microbial consortia also offers scope for enhancing nutrient use efficiency (Behl et al*.,* 2024).

Addressing these challenges and future opportunities can help in transforming INM into mainstream practice for sustainable chickpea production. The practice, once adopted, can help not only improve productivity but also enhance long-term soil health, environmental conservation, and food security ((Phiri et al., 2023; Shaviv et al., 1993)).

6. CONCLUSION

INM represents a holistic and sustainable approach to increae chickpea productivity without harming the soil environment and the ecosystem. INM combines the advantages of chemical fertilizers, organic amendments, bio-fertilizers, and site-specific practices to overcome the multi-dimensional challenges of modern chickpea cultivation.

The adoption of INM ensures a balanced and continuous supply of nutrients throughout the crop growth cycle, thereby enhancing nutrient use efficiency and optimizing yields. Organic manures and biofertilizers not only contribute to nutrient availability but also improve soil structure, microbial activity, and long-term fertility. Simultaneously, judicious use of chemical fertilizers minimizes losses of nutrients, reduces the risks associated with environmental pollution, and ensures cost-effective nutrient management.

While its benefits may transcend mere agronomy, the main importance of INM lies in aligning itself with the principles of sustainable agriculture, by reducing the use of non-renewable resources, cutting greenhouse gas emissions, and adopting more ecologically sound approaches to farming. Adding the integration of site-specific nutrient management (SSNM) with precision technologies would give the full potential of INM in efficient resource utilization and tailored application according to conditions on the field.

However, challenges in the large-scale implementation of INM include limited awareness among farmers, inconsistency in the performance of bio-fertilizers, and scarce resources. The effective breakthrough for these barriers comes from focused research efforts by researchers, extension, and policy planners. Region-specific models for INM should be developed, and the biofertilizer technology should be improved in the research sector, while extension services should initially concentrate on training and awareness programs for farmers. Such subsidies and incentives could support such inputs within infrastructures to make them accessible and available.

INM allows for the possibility of getting higher chickpea productivity while keeping the soil and environmental quality intact. Through the innovative research of how it can be practically adapted into extension work and how policies can proactively adopt this, INM is seen as an opportunity towards sustainable agricultural development and towards food security in the coming decades.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

Abawari, R. A., Tuji, F. A., & Yadete, D. M. (2020). Phosphate solubilizing bio-fertilizers and their role in bio-available P nutrient: an overview. *Int. J. Appl. Agric. Sci*, *6*(6), 162.

Abd-Alla, M. H., Al-Amri, S. M., & El-Enany, A. W. E. (2023). Enhancing Rhizobium–Legume Symbiosis and Reducing Nitrogen Fertilizer Use Are Potential Options for Mitigating Climate Change. *Agriculture*, *13*(11), 2092.

Abdel-Aziz, M. A., & Ismail, A. Y. (2023). Influence of Foliar Spraying by Using Paclobutrazol and Pinching Technique on the Growth, Green Pods, Dry Seed Yields, its Components and Some Chemical Constituents of Broad Bean (*Vicia faba* L.) Plants. *Asian Journal of Agricultural and Horticultural Research*, *10*(1), 40-52.

Abdula, I. A. (2013). *Agronomic and symbiotic characteristics of chickpea, Cicer arietinum (L.), as influenced by Rhizobium inoculation and phosphorus fertilization under farming systems of Wolaita area, Ethiopia* (Doctoral dissertation, MSc thesis. Wageningen University).

Admasu, A. (2019). *Effects of mesorhizobium inoculation, phosphorus and sulfur application on nodulation, growth and yield of chickpea (Cicer arietinum L.) At mortena jiru district, central highland of ethiopia* (Doctoral dissertation).

Ahmad, N., & Khan, M. (2020). Effects of Integrated Nutrient Management on Soil Fertility and Chickpea Productivity. *Journal of Agronomy and Crop Science, 206*(5), 721-730.

Akash, S., Dalavi, P. N., Srikanth, H., & Bonthagorla, U. (2022). Effects of organic manure and fertilizers on physicochemical properties of the soil: A review. *J. Pharm. Innov*, *11*, 1856-1860.

Alamzeb, M., Iqbal, A., Inamullah, Iqbal, M., & Ullah, I. (2024). Integrated use of phosphorus sources, phosphate solubilizing bacteria, and rhizobium enhanced growth, nitrogen, and phosphorus uptake in chickpea. *Journal of Plant Nutrition*, *47*(17), 2913-2929.

Ali, Q., Ashraf, S., Kamran, M., Ijaz, M., Rehman, A., Tahir, M., & Ahmad, S. (2019). Organic manuring for agronomic crops. *Agronomic Crops: Volume 2: Management Practices*, 163-193.

Alori, E. T., Dare, M. O., & Babalola, O. O. (2017). Microbial inoculants for soil quality and plant health. *Sustainable agriculture reviews*, 281-307.

Antil, R. S., & Singh, M. (2007). Effects of organic manures and fertilizers on organic matter and nutrients status of the soil. *Archives of Agronomy and Soil Science*, *53*(5), 519-528.

Bargaz, A., Elhaissoufi, W., Khourchi, S., Benmrid, B., Borden, K. A., & Rchiad, Z. (2021). Benefits of phosphate solubilizing bacteria on belowground crop performance for improved crop acquisition of phosphorus. *Microbiological research*, *252*, 126842.

Bayu, T. (2020). Review on contribution of integrated soil fertility management for climate change mitigation and agricultural sustainability. *Cogent Environmental Science*, *6*(1), 1823631.

Behl, K., Jaiswal, P., & Pabbi, S. (2024). Recent advances in microbial and nano-formulations for effective delivery and agriculture sustainability. *Biocatalysis and Agricultural Biotechnology*, 103180.

Bhunia, S., Bhowmik, A., Mallick, R., & Mukherjee, J. (2021). Agronomic efficiency of animal-derived organic fertilizers and their effects on biology and fertility of soil: A review. *Agronomy*, *11*(5), 823.

Bisht, N., & Chauhan, P. S. (2020). Excessive and disproportionate use of chemicals cause soil contamination and nutritional stress. *Soil contamination-threats and sustainable solutions*, *2020*, 1-10.

Biswas, S., Singh, S., & Bera, A. (2024). Regenerative Nutrient Management Practices for Enhancing Plant Nutrition and Soil Health. In *Regenerative Agriculture for Sustainable Food Systems* (pp. 303-339). Singapore: Springer Nature Singapore.

Blevins, D. G., & Lukaszewski, K. M. (1998). Boron in plant structure and function. *Annual review of plant biology*, *49*(1), 481-500.

Carranca, C. (2013). Legumes: properties and symbiosis. *Symbiosis: evolution, biology and ecological effects*, 67-94.

Chahal, H. S., Singh, A., Dhillon, I. S., & Kaur, J. (2020). Farmyard manure: A boon for integrated nutrient management. *International Journal of Agriculture, Environment and Biotechnology*, *13*(4), 483-495.

Chandra, S. (1980, February). The effect of edaphic factors on chickpea. In *Proceedings of the International Workshop on Chickpea Improvement* (Vol. 28, pp. 97-105). ICRISAT, Patancheru, Andhra Pradesh, India ICRISAT.

Chaubey, A. K., Mishra, S., Singh, S. K., Chaubey, C., & Pandey, K. P. (2023). Integrated Nutrients Management for Future Production: A Review. *International Journal of Environment and Climate Change*, *13*(11), 1770-1779.

Chaudhary, I. J., Neeraj, A., Siddiqui, M. A., & Singh, V. (2020). Nutrient management technologies and the role of organic matrix-based slow-release biofertilizers for agricultural sustainability: A review. *Agricultural Reviews*, *41*(1), 1-13.

Chien, S. H., Prochnow, L. I., & Cantarella, A. H. (2009). Recent developments of fertilizer production and use to improve nutrient efficiency and minimize environmental impacts. *Advances in agronomy*, *102*, 267-322.

Choudhary, A. K., Rajanna, G. A., & Kumar, A. N. I. L. (2018). Integrated Nutrient Management: An Integral Component of ICM Approach. *Integrated Crop Management Practices; ICAR: New Delhi, India*, 33.

Choudhary, A. K., Varatharajan, T., Rohullah, R., Bana, R. S., Pooniya, V., Dass, A., ... & Harish, M. N. (2020). Integrated crop management technology for enhanced productivity, resource-use efficiency and soil health in legumes–A review. The Indian Journal of Agricultural Sciences, 90(10), 1839-1849.

Cissé, L. (2007). Balanced fertilization for sustainable use of plant nutrients. *Fertilizer Best Management Practices*, *33*.

Czajkowski, K., Fitzgerald, S., Foster, I., & Kesselman, C. (2001, August). Grid information services for distributed resource sharing. In *Proceedings 10th IEEE International Symposium on High Performance Distributed Computing* (pp. 181-194). IEEE.

Das, P., & Roy, S. (2019). Micronutrients in Integrated Nutrient Management: Their Role in Chickpea Production. *Crop Research Journal, 15*(1), 34-40.

Dave, K., Kumar, A., Dave, N., Jain, M., Dhanda, P. S., Yadav, A., & Kaushik, P. (2024).

Climate Change Impacts on Legume Physiology and Ecosystem Dynamics: A Multifaceted Perspective. *Sustainability*, *16*(14), 6026.

Djouider, S. I., Gentzbittel, L., Jana, R., Rickauer, M., Ben, C., & Lazali, M. (2022). Contribution to improving the Chickpea (*Cicer arietinum* L.) efficiency in low-phosphorus farming systems: Assessment of the relationships between the P and N nutrition, nodulation capacity and productivity performance in P-deficient field conditions. *Agronomy*, *12*(12), 3150.

Etyang, T. B. (2013). *Assessment of the role of agro-input dealers in dissemination and communication of integrated soil fertility management: The case of Siaya and Trans Nzoia counties* (Doctoral dissertation, University of Nairobi).

Fouda, K., & Abd-Elhamied, A. (2017). Integrated effect of foliar fertilization of Fe, Zn and rates of P fertilization on growth and yield of cowpea. *Journal of Soil Sciences and Agricultural Engineering*, *8*(12), 733-740.

Fred, E. B., Baldwin, I. L., & McCoy, E. (2002). *Root nodule bacteria and leguminous plants* (No. 5). UW-Madison Libraries Parallel Press.

Gebremedhin, W. (2016). *Phenotypic and Symbiotic effectiveness of Chickpea (Cicer arietinum L.) Root nodulating Rhizobia from Some Selected Parts of Southeastern Ethiopia* (Doctoral dissertation, Addis Ababa University).

Gebremedhin, W. (2016). *Phenotypic and Symbiotic effectiveness of Chickpea (Cicer arietinum L.) Root nodulating Rhizobia from Some Selected Parts of Southeastern Ethiopia* (Doctoral dissertation, Addis Ababa University).

Ghosh, P. K., Bandyopadhyay, K. K., Wanjari, R. H., Manna, M. C., Misra, A. K., Mohanty, M., & Rao, A. S. (2007). Legume effect for enhancing productivity and nutrient use-efficiency in major cropping systems–an Indian perspective: a review. *Journal of Sustainable Agriculture*, *30*(1), 59-86.

Grasso, N., Lynch, N. L., Arendt, E. K., & O'Mahony, J. A. (2022). Chickpea protein ingredients: A review of composition, functionality, and applications. *Comprehensive reviews in food science and food safety*, *21*(1), 435-452.

Gruhn, P., Goletti, F., & Yudelman, M. (2000). *Integrated nutrient management, soil fertility, and sustainable agriculture: current issues and future challenges*. Intl Food Policy Res Inst

Gupta, P., & Verma, D. (2020). Organic Amendments and Their Synergistic Effects with Fertilizers in Legume Cultivation. *Soil Fertility Journal, 17*(4), 112-118.

Gurmu, G. (2019). Soil organic matter and its role in soil health and crop productivity improvement. *Forest Ecology and Management*, *7*(7), 475-483.

Hailemichael, F. (2020). Characterizing the effectiveness of nitrogen fixing bacteria to optimize chickpea (*Cicer arietinum* L) production. *International Journal of Research Studies in Science, Engineering and Technology*, *7*, 23-34.

Hasanuzzaman, M., Bhuyan, M. B., Nahar, K., Hossain, M. S., Mahmud, J. A., Hossen, M. S., ... & Fujita, M. (2018). Potassium: a vital regulator of plant responses and tolerance to abiotic stresses. *Agronomy*, *8*(3), 31.

Hodges, S. C. (2010). Soil fertility basics. *Soil science extension, North carolina state university*, *22*.

Imran. (2024). Integration of organic, inorganic and bio fertilizer, improve maize-wheat system productivity and soil nutrients. *Journal of Plant Nutrition*, 1-17.

Jain, S., et al. (2021). Precision Agriculture in Integrated Nutrient Management: Insights from Chickpea Farming. *International Journal of Sustainable Agriculture, 13*(2), 145-153.

Jalal, A., Galindo, F. S., Freitas, L. A., da Silva Oliveira, C. E., de Lima, B. H., Pereira, Í. T., ... & Teixeira Filho, M. C. M. (2022). Yield, zinc efficiencies and biofortification of wheat with zinc sulfate application in soil and foliar nanozinc fertilisation. *Crop and Pasture Science*.

Jha, U. C., Nayyar, H., Sharma, K. D., von Wettberg, E. J. B., & Siddique, K. H. (Eds.). (2024). *Legume Crop Wild Relatives: Their Role in Improving Climate Resilient Legumes*. CRC Press.

Kakraliya, S. K., Singh, U., Bohra, A., Choudhary, K. K., Kumar, S., Meena, R. S., & Jat, M. L. (2018). Nitrogen and legumes: a meta-analysis. *Legumes for soil health and sustainable management*, 277-314.

Kebede, E. (2021). Contribution, utilization, and improvement of legumes-driven biological nitrogen fixation in agricultural systems. *Frontiers in Sustainable Food Systems*, *5*, 767998.

Khalid, S., Arif, M., Fahad, S., & Al-Tawaha, A. R. M. (2021). Bio Fertilizer as a Tool for Soil Fertility Management in a Changing Climate. In *Sustainable Soil and Land Management and Climate Change* (pp. 165-177). CRC Press.

Korbu, L., Tafes, B., Kassa, G., Mola, T., & Fikre, A. (2020). Unlocking the genetic potential of chickpea through improved crop management practices in Ethiopia. A review. *Agronomy for Sustainable Development*, *40*, 1-20.

Kumar, P., & Choudhary, R. (2018). Long-Term Effects of Organic and Inorganic Nutrients on Chickpea Yield and Soil Properties. *Legume Science, 5*(3), 97-105.

Lal, R. (2009). Soil degradation as a reason for inadequate human nutrition. *Food Security*, *1*, 45-57.

Mazid, M., & Khan, T. A. (2015). Future of bio-fertilizers in Indian agriculture: an overview. *International Journal of Agricultural and Food Research*, *3*(3).

Meena, B. P., Biswas, A. K., Singh, M., Chaudhary, R. S., Singh, A. B., Das, H., & Patra, A. K. (2019). Long-term sustaining crop productivity and soil health in maize–chickpea system through integrated nutrient management practices in Vertisols of central India. *Field crops research*, *232*, 62-76.

Meena, B. P., Biswas, A. K., Singh, M., Chaudhary, R. S., Singh, A. B., Das, H., & Patra, A. K. (2019). Long-term sustaining crop productivity and soil health in maize–chickpea system through integrated nutrient management practices in Vertisols of central India. *Field crops research*, *232*, 62-76.

Meena, R., et al. (2022). Role of Phosphorus-Solubilizing Bacteria in Chickpea Production: An INM Approach. *Soil and Plant Nutrition Journal, 21*(6), 450-460.

Mitran, T., Meena, R. S., Lal, R., Layek, J., Kumar, S., & Datta, R. (2018). Role of soil phosphorus on legume production. *Legumes for soil health and sustainable management*, 487-510.

Mohammadi, K., Heidari, G., Khalesro, S., & Sohrabi, Y. (2011). Soil management, microorganisms and organic matter interactions: A review. *African Journal of Biotechnology*, *10*(86), 19840.

Mohan, c. A. (2021). Effect of integrated use of organic manure and rock phosphate on growth and yield of gram (*cicer arietinum* l.).

Muhammed, B. (2023). Effect of seed priming with manganese and boron on growth, yield and seed quality of chickpea (*Cicer arietinum* L.). *Mesopotamia Journal of Agriculture*, *51*(2), 64-0.

Muthusamy, Y., Sengodan, K., Arthanari, M., Kandhasamy, R., & Gobianand, K. (2023). Biofertilizer and Consortium Development: An Updated Review. *Current Agriculture Research Journal*, *11*(1).

Nadathur, S., Wanasundara, J. P., & Scanlin, L. (Eds.). (2016). *Sustainable protein sources*. Academic Press.

Nakade, T. K., Ahamad, A., Kher, D., Syed, A., & Yadav, D. (2021). Integrated Nutrient Management and Its Importance for Soil Physical, Chemical, and Biological Properties. *Just Agriculture Multidisciplinary e–Newsletter*, 1-10.

Pahalvi, H. N., Rafiya, L., Rashid, S., Nisar, B., & Kamili, A. N. (2021). Chemical fertilizers and their impact on soil health. *Microbiota and Biofertilizers, Vol 2: Ecofriendly tools for reclamation of degraded soil environs*, 1-20.

Panhwar, Q. A., Ali, A., Naher, U. A., & Memon, M. Y. (2019). Fertilizer management strategies for enhancing nutrient use efficiency and sustainable wheat production. In *Organic farming* (pp. 17-39). Woodhead Publishing.

Patel, H., & Sharma, K. (2019). Enhancing Chickpea Yields with Bio-fertilizer Integration: A Review. *Indian Journal of Agricultural Sciences, 89*(7), 1125-1133.

Phiri, C. K., Njira, K., & Chitedze, G. (2023). An insight of chickpea production potential, utilization and their challenges among smallholder farmers in Malawi–A review. *Journal of Agriculture and Food Research*, 100713.

Prabhu,V., Singaravel,R. and Ramakichenin alias B.Balagandhi.2021. Influence of fortified in situ rice residue compost and zinc nano fertilizer on growth and yield of rice (*Oryza sativa* L.) under rice cultivation methods. Annals of plant and Soil Research**.**.23(3):291-296.

Raj, A. B., & Raj, S. K. (2019). Zinc and boron nutrition in pulses: A review. *Journal of Applied and Natural Science*, *11*(3), 673-679.

Raj, J., Jat, S., Kumar, M., & Yadav, A. (2024). The Role of Organic Farming in Sustainable Agriculture. *Advances in Research*, *25*(3), 128-136.

Ramaiyan, S., Vijayakumar, P., Balasubramanian, R. A. B., & Nallathambi, M. (2023). Influence of nano-zinc oxide and fortified rice residue compost on rice productivity, zinc biofortification, zinc use efficiency, soil quality, zinc fractions and profitability in different rice production systems. *Journal of Plant Nutrition*, *46*(17), 4063-4084.

Rashid, M. H. O., Krehenbrink, M., & Akhtar, M. S. (2015). Nitrogen-fixing plant-microbe symbioses. *Sustainable Agriculture Reviews: Volume 15*, 193-234.

Reddy, B. S., & Naik, R. (2020). Challenges in the Adoption of Integrated Nutrient Management Practices in Chickpea Cultivation. *Agriculture and Environment Review, 32*(4), 203-211.

Rolaniya, Lalit Kumar, Ram Lal Jat, Narendra Kumar, Monika Punia, and Raja Ram Choudhary. (2023). “Effect of Integrated Nutrient Management Practices on Growth and Yield of Chickpea under Different Chickpea-Based Cropping Systems in Western Rajasthan, India”. *International Journal of Environment and Climate Change* 13 (12):1253-59.

Römheld, V. (2012). Diagnosis of deficiency and toxicity of nutrients. In *Marschner's mineral nutrition of higher plants* (pp. 299-312). Academic press.

Roy, T., Kalambukattu, J. G., Biswas, S. S., & Kumar, S. (2023). Agro-climatic variability in climate change scenario: adaptive approach and sustainability. In *Ecological footprints of climate change: Adaptive approaches and sustainability* (pp. 313-348). Cham: Springer International Publishing.

Sarkar, D., Meena, V. S., Haldar, A., & Rakshit, A. (2017). Site-specific nutrient management (SSNM): a unique approach towards maintaining soil health. *Adaptive soil management: from theory to practices*, 69-88.

Sarkar, S., Mahra, G. S., Lenin, V., Padaria, R. N., & Burman, R. R. (2022). Innovative Extension Approaches for Diffusion of Nutrient Management Technologies. In *Soil Management for Sustainable Agriculture* (pp. 283-326). Apple Academic Press.

Sarma, H. H., Borah, S. K., Chintey, R., Nath, H., & Talukdar, N. (2024). Site specific nutrient management (SSNM): Principles, key features and its potential role in soil, crop ecosystem and climate resilience farming. *Journal of Advances in Biology and Biotechnology*, *27*(8), 211-222.

Sayara, T., Basheer-Salimia, R., Hawamde, F., & Sánchez, A. (2020). Recycling of organic wastes through composting: Process performance and compost application in agriculture. *Agronomy*, *10*(11), 1838.

Schröder, J. J., Cordell, D., Smit, A. L., & Rosemarin, A. (2010). Sustainable use of phosphorus. *Wageningen: Plant Research International*, *357*, 138.

Selim, M. M. (2020). Introduction to the integrated nutrient management strategies and their contribution to yield and soil properties. *International Journal of Agronomy*, *2020*(1), 2821678.

Shah, F., & Wu, W. (2019). Soil and crop management strategies to ensure higher crop productivity within sustainable environments. *Sustainability*, *11*(5), 1485.

Shaji, H., Chandran, V., & Mathew, L. (2021). Organic fertilizers as a route to controlled release of nutrients. In *Controlled release fertilizers for sustainable agriculture* (pp. 231-245). Academic Press.

Sharma, A., et al. (2021). Role of Bio-fertilizers in Enhancing Chickpea Yield and Soil Health. *Agricultural Sciences Today, 28*(2), 102-110.

Sharma, V. K., Kumar, A., Passarini, M. R. Z., Parmar, S., & Singh, V. K. (Eds.). (2023). Microbial Inoculants: Recent Progress and Applications.

Shaviv, A., & Mikkelsen, R. L. (1993). Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation-A review. *Fertilizer research*, *35*, 1-12.

Shrivastav, P., Prasad, M., Singh, T. B., Yadav, A., Goyal, D., Ali, A., & Dantu, P. K. (2020). Role of nutrients in plant growth and development. *Contaminants in agriculture: Sources, impacts and management*, 43-59.

Singh, A. K. (2024). Current Challenges and Strategies for Management of Soil Health and Sustainable Productivity. In *th Souvenir for 4 National Conference 2024* (Vol. 2050, p. 18).

Singh, B. R. (2020). Integrated nutrient management. In *Managing Soils and Terrestrial Systems* (pp. 419-433). CRC Press.

Singh, R. K., Singh, S. R. K., Tripathi, U., Shrivastava, V., Kantwa, C. R., & Kumar, S. (2024). Biofertilizer and inorganic fertilizers effect on favorable characters for productivity of chickpea in Bundelkhand of Madhya Pradesh. *Legume Research*, *47*(5), 850-854.

Singh, R., & Kumar, S. (2022). Integrated Nutrient Management for Sustainable Chickpea Production. *Journal of Legume Research, 45*(3), 230-238.

Singh, T. B., Ali, A., Prasad, M., Yadav, A., Shrivastav, P., Goyal, D., & Dantu, P. K. (2020). Role of organic fertilizers in improving soil fertility. *Contaminants in agriculture: sources, impacts and management*, 61-77.

Singh, V., Mishra, A., Chaubey, A. K., Panwar, G. S., Sachan, R., Pal, R., ... & Tiwari, A. (2022). Effect of Integrated Nutrient Management on Performance of Chickpea in Bundelkhand Region of North India. 34(23): 1115-1122.

Smith, P., Ashmore, M. R., Black, H. I., Burgess, P. J., Evans, C. D., Quine, T. A., ... & Orr, H. G. (2013). The role of ecosystems and their management in regulating climate, and soil, water and air quality. *Journal of Applied Ecology*, *50*(4), 812-829.

Sowmya, N. S. L., Rupesh, P., Rajeev, l. S., & Upadhyay, H. (2024) Effect of Different Bio-inoculants with Varied Levels of Phosphorus on Growth and Yield Attributes of Chickpea (*Cicer arietinum* L.). Annals of Agri-Bio Research 29 (1): 76-82, 2024

Subhash, B. V. (2021). Effect of different complex fertilizers on growth, yield, soil nutrient dynamics and quality of chickpea. Department of soil science and agricultural chemistry college of agriculture, parbhani vasantrao naik marathwada krishi vidyapeeth parbhani – 431 402

Swami, S., Bazaya, B. R., Chand, L., Jat, N. K., & Arora, R (2009). Site Specific Nutrient Management for Increasing Crop Productivity.

Timsina, J. (2018). Can organic sources of nutrients increase crop yields to meet global food demand?. *Agronomy*, *8*(10), 214.

Tripathi, D. K., Singh, S., Singh, S., Mishra, S., Chauhan, D. K., & Dubey, N. K. (2015). Micronutrients and their diverse role in agricultural crops: advances and future prospective. *Acta Physiologiae Plantarum*, *37*, 1-14.

Ullah, A., Farooq, M., Rehman, A., Hussain, M., & Siddique, K. H. (2020). Zinc nutrition in chickpea (Cicer arietinum): A review. *Crop and Pasture Science*, *71*(3), 199-218.

Ullah*,* et al*.,* (2020). Regular soil testing and targeted application of micronutrients ensure balanced nutrition, improved physiological performance, and better productivity of chickpea

Umar, W., Ayub, M. A., Rehman, M. Z. U., Ahmad, H. R., Farooqi, Z. U. R., Shahzad, A., ... & Nadeem, M. (2020). Nitrogen and phosphorus use efficiency in agroecosystems. *Resources use efficiency in agriculture*, 213-257.

Verma, R. C., Singh, N. K., Gangavati, A. R., Ashoka, P., Kesarwani, A., Ali, I., & Pandey, S. K. (2023). A Review of Long-Term Effects of Mineral Fertilizers on Soil Microorganisms. *International Journal of Plant & Soil Science*, *35*(20), 1145-1155.

Walia, S. S., & Kaur, T. (2024). Beneficial role of vermicompost: nutrient content in vermicompost and success stories. In *Earthworms and Vermicomposting: Species, Procedures and Crop Application* (pp. 135-146). Singapore: Springer Nature Singapore.

Wang, J., Li, Y., Li, A., Liu, R. H., Gao, X., Li, D., ... & Xue, Z. (2021). Nutritional constituent and health benefits of chickpea *(Cicer arietinum* L.): A review. *Food Research International*, *150*, 110790.

Wang, M., Zheng, Q., Shen, Q., & Guo, S. (2013). The critical role of potassium in plant stress response. *International Journal of Molecular Sciences*, *14*(4), 7370-7390.

Wani, S. P., Chander, G., Bhattacharyya, T., & Patil, M. D. (2016). Soil Health Mapping and Direct Benefit: Transfer of Fertilizer Subsidy, Research Report IDC-6.

Wu, G., Fanzo, J., Miller, D. D., Pingali, P., Post, M., Steiner, J. L., & Thalacker-Mercer, A. E. (2014). Production and supply of high-quality food protein for human consumption: sustainability, challenges, and innovations. *Annals of the New York Academy of Sciences*, *1321*(1), 1-19.

Wu, W., & Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, *512*, 415-427.

Wu, W., & Ma, B. (2015). Integrated nutrient management (INM) for sustaining crop productivity and reducing environmental impact: A review. *Science of the Total Environment*, *512*, 415-427.

Xuejun, L., & Fusuo, Z. (2011). Nitrogen fertilizer induced greenhouse gas emissions in

China. *Current Opinion in Environmental Sustainability*, *3*(5), 407-413.

YADAV, S. L. (2023). Effects of different nutrient management practices on nutrient availability and microbial activity in soil, and performance of chickpea.

Yahaya, S. M., Mahmud, A. A., Abdullahi, M., & Haruna, A. (2023). Recent advances in the chemistry of nitrogen, phosphorus and potassium as fertilizers in soil: a review. *Pedosphere*, *33*(3), 385-406.

Zhang, J., Wang, J., Zhu, C., Singh, R. P., & Chen, W. (2024). Chickpea: Its origin, distribution, nutrition, benefits, breeding, and symbiotic relationship with Mesorhizobium species. *Plants*, *13*(3), 429.

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