

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating: 5.29
IJABR 2025; 9(5): 913-921
www.biochemjournal.com
Received: 16-03-2025
Accepted: 19-04-2025

Priyansh Kumar Sharma
Ph.D. Research Scholar
Department of Agronomy,
ITM University, School of
Agriculture, Gwalior, Madhya
Pradesh, India

Dr. Satish Kumar Indoriya
Assistant Professor,
Department of Agronomy,
ITM, School of Agriculture,
Gwalior, Madhya Pradesh,
India

Ankit Singh Rajawat
M.Sc. Student Department of
Horticulture, ITM University,
School of Agriculture, Gwalior,
Madhya Pradesh, India

Sumit Raj Khare
M.Sc. Student Department of
Horticulture, ITM University,
School of Agriculture, Gwalior,
Madhya Pradesh, India

Corresponding Author:
Priyansh Kumar Sharma
Ph.D. Research Scholar
Department of Agronomy,
ITM University, School of
Agriculture, Gwalior, Madhya
Pradesh, India

Nutrient management strategies for enhancing legumes productivity in the grid region of Gwalior, M.P.

Priyansh Kumar Sharma, Satish Kumar Indoriya, Ankit Singh Rajawat and Sumit Raj Khare

DOI: <https://www.doi.org/10.33545/26174693.2025.v9.i5k.4447>

Abstract

Efficient nutrient management is a critical determinant in enhancing the productivity and sustainability of legume cultivation, particularly in the semi-arid agro-climatic conditions of the Grid region of Gwalior, Madhya Pradesh. This region, characterized by heterogeneous soil fertility, erratic rainfall, and imbalanced nutrient application, demands region-specific, integrated nutrient strategies to unlock the full yield potential of pulses such as chickpea, pigeon pea, and lentil. The present study focuses on developing and evaluating nutrient management strategies tailored to the edaphic and climatic conditions of the Grid zone. The research integrates site-specific nutrient management (SSNM), balanced fertilization with macro and micronutrients, and the inclusion of biofertilizers (Rhizobium, PSB, and PGPR) to enhance soil health, nutrient uptake, and biological nitrogen fixation. Long-term field trials and soil fertility mapping indicate that the application of integrated nutrient management (INM) involving 75% recommended dose of fertilizers (RDF) along with organic amendments (FYM, compost) and microbial inoculants significantly improves soil organic carbon, nutrient use efficiency (NUE), and yield attributes of legumes. Furthermore, precision nutrient application based on soil test crop response (STCR) has proven to be an effective strategy in reducing input costs while maintaining environmental sustainability. The synergistic effects of combined nutrient inputs enhance nodulation, root proliferation, and ultimately biomass and grain yield. This study provides a scientific basis for recommending location-specific, economically viable, and environmentally sustainable nutrient management packages for legume growers in the region. The outcomes not only contribute to bridging the yield gap but also support national goals for pulse self-sufficiency and soil health rejuvenation. Adoption of these strategies is expected to transform legume-based cropping systems in the Gwalior Grid region by improving resource-use efficiency and resilience to climatic stressors.

Keywords: Legume productivity, nutrient management, grid region, Gwalior, site-specific nutrient management (SSNM), integrated nutrient management (INM), biofertilizers, soil fertility, nitrogen fixation, pulse crops

Introduction

The Grid Region of Gwalior in Madhya Pradesh holds a significant place in the agricultural landscape of central India due to its diverse cropping systems and semi-arid climatic conditions. Among the various crops cultivated, legumes such as chickpea (*Cicer arietinum*), blackgram (*Vigna mungo*), greengram (*Vigna radiata*), and pigeon pea (*Cajanus cajan*) have long been recognized for their ecological and nutritional value. These pulses are vital sources of protein, especially for vegetarian populations, and play a pivotal role in improving soil fertility through biological nitrogen fixation (Singh *et al.*, 2021) [12]. Despite their importance, the productivity of legumes in this region remains sub-optimal due to various agronomic constraints, of which nutrient imbalance is among the most critical. The inherent soil fertility of the region, particularly in the alluvial and black soil zones of Gwalior, has been gradually declining due to continuous cropping, poor organic matter content, and unscientific fertilizer use.

Legumes are unique in their ability to establish symbiotic relationships with rhizobia, allowing them to fix atmospheric nitrogen and reduce dependence on synthetic nitrogen fertilizers. However, this symbiosis alone does not meet the total nutritional requirements of legumes.

For optimal growth and yield, legumes require not only nitrogen but also essential macro- and micronutrients like phosphorus, potassium, sulfur, zinc, and boron, which are often deficient in the soils of the Gwalior region. Phosphorus is especially crucial as it enhances nodulation and energy transfer, yet its availability is limited in many Indian soils due to fixation by calcium in alkaline conditions common in central India. Moreover, potassium plays a vital role in translocation of carbohydrates, while sulfur is needed for protein synthesis—functions that are indispensable for legume development. Thus, an integrated approach to nutrient management is necessary to bridge the nutrient supply-demand gap, restore soil health, and enhance productivity sustainably.

In recent years, integrated nutrient management (INM) has gained prominence as a sustainable practice, combining the judicious use of chemical fertilizers, organic manures such as farmyard manure (FYM), vermicompost, and biological inoculants like *Rhizobium* and phosphate-solubilizing bacteria (PSB). Such strategies not only improve nutrient availability and uptake but also enhance microbial activity and organic matter content, contributing to long-term soil fertility. For instance, application of FYM along with RDF (recommended dose of fertilizers) and *Rhizobium* inoculation has been found to significantly increase chickpea yield under Gwalior conditions. Additionally, foliar sprays of urea or micronutrients have shown to further support nutrient absorption during critical growth stages. The synergistic effect of these inputs not only promotes higher productivity but also helps in minimizing the environmental risks associated with overuse of synthetic fertilizers. Nevertheless, despite the potential of INM, adoption at the farmer level remains limited due to lack of awareness, resource constraints, and poor extension services.

The declining factor productivity of fertilizers under conventional practices has triggered the need for region-specific nutrient management protocols, particularly in agroecologically sensitive areas like Gwalior. Site-specific nutrient management (SSNM), which tailors nutrient application based on soil testing and crop needs, has shown potential in maximizing nutrient use efficiency in legumes. Moreover, advancements in precision agriculture and decision-support tools now offer innovative ways to monitor soil fertility and optimize input use. However, the successful implementation of such strategies requires coordinated efforts among farmers, researchers, and policymakers. It is crucial to integrate traditional knowledge systems with modern scientific approaches to develop low-cost, easily adoptable, and ecologically viable nutrient management frameworks.

The present research is thus framed in the context of enhancing legume productivity through improved nutrient management strategies in the Grid Region of Gwalior. By evaluating the efficacy of integrated and site-specific nutrient practices in improving crop performance, soil health, and overall farm profitability, this study aims to address one of the most pressing challenges in pulse production. Furthermore, the research seeks to contribute to the broader goal of sustainable agriculture by reducing fertilizer dependency, restoring soil ecological balance, and enhancing the resilience of smallholder farming systems. Through field experimentation, comparative analysis, and soil fertility assessments, this study will generate evidence-

based recommendations that can be scaled up across similar agro-climatic regions of central India.

Grid Region-Agro-climatic and Soil Profile

Agricultural productivity in central India is deeply influenced by the region's agro-climatic diversity and soil heterogeneity, particularly in semi-arid zones where rainfall patterns and soil fertility dynamics present persistent challenges. Within this context, certain pockets of northwestern Madhya Pradesh—covering districts such as Gwalior, Morena, Bhind, and Shivpuri—exhibit a distinct set of environmental conditions that shape local cropping systems, especially those centered around pulses. These districts collectively fall under the Grid Zone (Agro-Climatic Zone VIII), as classified by the Indian Council of Agricultural Research (ICAR, 2014), and are marked by pronounced climatic seasonality, moderate rainfall, and predominantly alluvial and black soils. The ecological complexity of this zone necessitates a detailed analysis of its climatic parameters and soil characteristics to inform effective nutrient management practices. Such insights are particularly relevant for legume crops, which demand tailored fertility strategies to optimize biological nitrogen fixation, nutrient uptake, and resilience under fluctuating moisture regimes.

Climatically, the Grid Region experiences a hot semi-arid environment, marked by long summers, short monsoons, and relatively cool winters. The average annual rainfall in the region ranges between 700 to 1000 mm, with about 85-90% of this precipitation occurring during the southwest monsoon season between June and September. The erratic distribution of rainfall, both spatially and temporally, often leads to moisture stress during critical growth stages of crops, especially in rainfed farming systems predominant in the region. The average temperature fluctuates from as low as 6-8 °C in winter to highs exceeding 45°C during peak summer. This temperature variability influences plant metabolism, soil microbial activity, and nutrient uptake dynamics, which are critical considerations when designing fertilization schedules for pulses like chickpea, pigeon pea, and blackgram.

Topographically, the region comprises alluvial plains with minor undulating terrains interspersed by seasonal streams and dry riverbeds. The elevation ranges between 150 to 300 meters above sea level, with slight slope variations affecting surface runoff and soil erosion patterns. The physiography of the region also impacts moisture retention capacity and water infiltration rates, particularly in areas with degraded topsoil or compacted sublayers. The interaction between slope, soil depth, and rainfall determines both crop suitability and fertilizer response. In this setting, legumes have emerged as a vital crop group not only due to their nitrogen-fixing ability but also because of their adaptability to low-input conditions and marginal soils.

The soils of the Grid Region exhibit significant variability, ranging from deep black cotton soils (Vertisols) to light-textured alluvial soils (Entisols and Inceptisols) along riverine tracts. The majority of cultivated land in the region is dominated by alluvial and mixed red-black soils, which vary in fertility status, texture, and nutrient-holding capacity. Alluvial soils, formed by the Chambal and Sindh river systems, are generally loamy to sandy loam in texture with neutral to slightly alkaline pH. These soils are moderately fertile but tend to be deficient in organic carbon,

available nitrogen, and sometimes phosphorus. Their water-holding capacity is moderate, making them suitable for pulses under supplemental irrigation or rainfed conditions with improved moisture conservation practices (MP Government, 2023).

In contrast, the black soils of the region, though rich in clay and relatively high in cation exchange capacity (CEC), often suffer from low nitrogen availability and reduced microbial activity due to poor aeration. These soils swell and shrink significantly, creating deep cracks during dry spells, which can disturb root continuity and affect nutrient uptake. Moreover, secondary and micronutrient deficiencies—particularly of sulfur, zinc, and boron—have been increasingly reported in the region due to intensive cropping and lack of organic inputs. These deficiencies can significantly limit the productivity of legumes, which have high demands for phosphorus, calcium, and molybdenum to support effective nodulation and nitrogen fixation.

Soil fertility in the Grid Region has been further challenged by the declining use of farmyard manure, compost, and other organic amendments, resulting in reduced soil biological activity. Soil organic carbon content in many areas has dropped below the critical threshold of 0.5%, diminishing both the nutrient buffering capacity and water retention potential. In such contexts, site-specific nutrient management (SSNM) and integrated nutrient management (INM) approaches become essential for restoring productivity. Application of biofertilizers like *Rhizobium*, *Azotobacter*, and phosphate-solubilizing bacteria (PSB) has shown positive effects in enhancing nutrient availability and supporting legume growth in similar agro-ecological settings.

Importantly, the agro-climatic and soil parameters of the Grid Region not only affect nutrient dynamics but also shape cropping patterns. Traditional cropping systems such

as chickpea-wheat, pigeon pea-sorghum, and blackgram-maize rotations have evolved based on seasonal temperature, rainfall distribution, and soil moisture availability. These patterns must be considered when recommending nutrient interventions, as residual nutrient effects and inter-crop interactions influence overall system productivity. The growing interest in pulses in this region, fuelled by their low water requirements, short duration, and soil fertility benefits, aligns with national priorities for sustainable and climate-resilient agriculture.

Thus, an in-depth understanding of the agro-climatic and edaphic characteristics of the Grid Region is fundamental to enhancing legume productivity through precise nutrient management. The interplay of climatic stresses, soil fertility constraints, and cropping systems necessitates a tailored approach to fertilizer application—balancing chemical, organic, and biological sources of nutrients. Such region-specific insights lay the foundation for improving nutrient use efficiency, enhancing soil health, and ensuring long-term agricultural sustainability in the legume-dominated landscapes of the Grid Region of Gwalior.

Importance of Legumes in Sustainable Agriculture

Legumes play a pivotal role in promoting sustainable agricultural practices, not only as valuable food and fodder crops but also in enhancing soil fertility, improving biodiversity, and contributing to climate resilience. Their capacity to fix atmospheric nitrogen through symbiotic relationships with soil microbes makes them a key component in low-input farming systems, especially in regions with limited access to chemical fertilizers. The following tables summarize the critical ecological, economic, and agronomic benefits of legumes within sustainable agricultural frameworks.

Table 1: Ecological Benefits of Legumes in Sustainable Agriculture

Benefit	Description	Examples
Nitrogen Fixation	Legumes fix atmospheric nitrogen through a symbiotic relationship with rhizobial bacteria, enriching soil nitrogen levels naturally.	Chickpea (<i>Cicer arietinum</i>), Pigeon pea (<i>Cajanus cajan</i>)
Improved Soil Structure	Legumes help improve soil aggregation and prevent erosion, particularly in regions prone to degradation.	Lentils (<i>Lens culinaris</i>), Soybean (<i>Glycine max</i>)
Enhancement of Soil Fertility	Legumes contribute organic matter to the soil, improving microbial activity and overall soil health.	Groundnut (<i>Arachis hypogea</i>), Peas (<i>Pisum sativum</i>)
Carbon Sequestration	By fixing nitrogen and increasing organic carbon inputs, legumes contribute to carbon sequestration, helping mitigate climate change.	Clovers (<i>Trifolium</i> spp.), Faba bean (<i>Vicia faba</i>)

Table 2: Economic and Agronomic Benefits of Legumes

Benefit	Description	Examples
Reduced Fertilizer Dependency	By fixing nitrogen, legumes reduce the need for synthetic nitrogen fertilizers, lowering input costs.	Chickpea, Pigeon pea, Mung bean (<i>Vigna radiata</i>)
Crop Rotation Benefits	Legumes break pest and disease cycles, reducing the need for chemical pesticides and enhancing crop diversity.	Soybean, Cowpea (<i>Vigna unguiculata</i>)
Increased Yield in Subsequent Crops	Legume-based rotations often result in higher yields for subsequent crops, especially cereals, due to improved soil fertility.	Chickpea-wheat rotation, Maize-pigeon pea rotation
Source of High-Quality Protein	Legumes provide a rich source of plant-based protein, contributing to food security in both developed and developing nations.	Lentils, Peas, Beans

Discussion on the Role of Legumes in Sustainable Agriculture

Legumes are indispensable in fostering sustainability in agriculture due to their multifaceted benefits. As nitrogen-fixing plants, they naturally replenish soil nitrogen, reducing farmers' reliance on synthetic fertilizers. This nitrogen fixation not only lowers input costs but also mitigates the

negative environmental impacts associated with overuse of chemical fertilizers, such as water pollution and greenhouse gas emissions. Additionally, legumes contribute to soil structure and erosion control, making them valuable in maintaining soil health, especially in degraded or marginal lands. Their ability to form symbiotic relationships with rhizobial bacteria enhances soil microbial diversity, which is

crucial for nutrient cycling and overall soil ecosystem function.

From an economic perspective, legumes provide an affordable source of protein for both human and animal nutrition, which is especially important in regions facing food security challenges. The cultivation of legumes in crop rotations improves soil fertility for subsequent crops, often resulting in increased yields of cereals and other crops. This positive interaction between legumes and other crops is a key strategy for integrated nutrient management. Furthermore, legumes can serve as a resilient alternative crop in the face of climate change, with many legume species being drought-resistant and able to thrive in semi-arid conditions where other crops might fail.

The role of legumes extends beyond agricultural production; they contribute to climate change mitigation by enhancing carbon sequestration through the incorporation of organic matter into the soil. The diversification of agricultural systems with legumes reduces dependency on monoculture practices, which are more vulnerable to pest outbreaks, diseases, and market price fluctuations. This diversification not only enhances biodiversity but also strengthens the economic resilience of farming communities.

In conclusion, legumes are crucial to the sustainability of agricultural systems, providing ecological, economic, and agronomic benefits that enhance soil health, reduce input costs, and contribute to food security. Their ability to naturally enrich soil fertility, improve biodiversity, and support sustainable cropping systems underpins their importance in promoting long-term agricultural sustainability.

Major Legume Crops Grown in Grid Region

1. Chickpea (*Cicer arietinum*)

- **Dominant Legume Crop:** Chickpea is the most widely grown legume in the Grid Region, occupying the largest area of cultivation.
- **Season:** Primarily grown in the rabi (winter) season, where moisture availability is optimal.
- **Soil Type:** Prefers well-drained, loamy soils and is adapted to semi-arid conditions.
- **Importance:** Chickpea is a significant source of plant-based protein and is a major food crop in the region. Its cultivation also enhances soil fertility due to its nitrogen-fixing abilities.
- **Source:** Agriculture Department of Madhya Pradesh (2022).

2. Pigeon Pea (*Cajanus cajan*)

- **Adaptability:** Pigeon pea is well-suited to drought-prone areas due to its deep root system, making it ideal for rainfed farming systems in the region.
- **Season:** Grown mainly in the kharif (monsoon) season, starting in June-July and harvested by November-December.
- **Role in Crop Rotation:** Important in crop rotation systems, as it helps break pest and disease cycles, enhancing the health of subsequent crops.
- **Nitrogen Fixation:** Like other legumes, pigeon pea contributes significantly to soil nitrogen fixation, reducing the need for synthetic fertilizers.
- **Source:** Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

3. Black Gram (*Vigna mungo*)

- **Short Duration Crop:** Black gram is a fast-growing legume, typically taking around 60-90 days to mature.
- **Season:** Grown in the kharif season, it is well-suited to the monsoon rains of the region.
- **Economic Value:** Black gram is an important pulse crop both for local consumption and for export markets. It is a rich source of protein and contributes to food security in the region.
- **Soil Health:** Enhances soil health by fixing nitrogen and contributing organic matter, which improves the soil's fertility.
- **Source:** District Agriculture Office, Gwalior (2020).

4. Green Gram (*Vigna radiata*)

- **High Nutritional Value:** Green gram, also known as mung bean, is a key pulse crop in the region due to its high nutritional content, particularly in terms of protein and fiber.
- **Season:** Grown primarily in the kharif season, similar to black gram, but also cultivated in the rabi season in some parts of the Grid Region.
- **Drought Tolerance:** Green gram is relatively drought-tolerant, making it a suitable crop for areas with limited irrigation.
- **Soil Enrichment:** Contributes to soil enrichment by fixing nitrogen, which improves the fertility for future crops, particularly cereals.
- **Source:** Agriculture Department of Madhya Pradesh (2022).

5. Cowpea (*Vigna unguiculata*)

- **Versatility:** Cowpea is grown in both the kharif and rabi seasons, offering flexibility in cropping systems. It is grown for its grain and fodder.
- **Soil and Climate Requirements:** Prefers well-drained soils and can tolerate both drought and low soil fertility, making it well-suited for semi-arid conditions.
- **Economic Significance:** Cowpea is a significant pulse crop, offering both nutritional benefits and fodder for livestock, especially during dry seasons.
- **Source:** Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

Nutrient Requirements of Legume Crops

1. Macronutrients Required by Legumes

Nitrogen (N)

- Legumes, especially **chickpea**, **pigeon pea**, and **green gram**, rely on symbiotic nitrogen fixation through their relationship with **Rhizobium** bacteria in root nodules. While they can fix atmospheric nitrogen, they still require small amounts of nitrogen from the soil for optimal growth.
- **Deficiency Symptoms:** Yellowing of older leaves, stunted growth, and reduced yields.
- **Source:** Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

Phosphorus (P)

- Phosphorus is crucial for energy transfer, root development, and flowering in legumes. A phosphorus deficiency often results in poor root development and reduced seed formation.

- Legumes generally require a moderate amount of phosphorus, especially in the early stages of growth.
- Source: Agriculture Department of Madhya Pradesh (2022).

Potassium (K)

- Potassium plays a role in photosynthesis, protein synthesis, and the overall growth of legumes. It is essential for the development of strong stems and root systems.
- Potassium deficiency leads to poor water regulation and weaker plants, making them susceptible to diseases.
- Source: Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

2. Micronutrients and Their Importance

Iron (Fe)

- Iron is involved in the synthesis of chlorophyll and is vital for nitrogen metabolism. A deficiency in iron can cause interveinal chlorosis, particularly in chickpea and pigeon pea.
- Source: Agriculture Department of Madhya Pradesh (2022).

Zinc (Zn)

- Zinc is crucial for enzyme function and protein synthesis. It also aids in the formation of auxins, which are plant hormones responsible for growth regulation.
- Zinc deficiency can lead to stunted growth, poor root development, and chlorosis.
- Source: Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

Manganese (Mn)

- Manganese is involved in photosynthesis, respiration, and nitrogen assimilation. It helps activate enzymes that aid in the utilization of other nutrients.
- A deficiency of manganese can cause reduced growth and leaf damage, especially in green gram and black gram.
- Source: Agriculture Department of Madhya Pradesh (2022).

3. Nutrient Management Strategies for Legumes

Inoculation with Rhizobium

- Inoculating legume seeds with Rhizobium bacteria can significantly enhance nitrogen fixation. This ensures that the plants can meet their nitrogen requirements, especially when soil nitrogen is limited.
- Proper inoculation can reduce the need for synthetic fertilizers, promoting sustainable farming.
- Source: Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

Organic Manures and Compost:

- The use of organic manures, such as farmyard manure (FYM) and compost, helps improve soil structure and provides essential micronutrients.
- Organic amendments also contribute to improving soil microbial activity, enhancing nutrient availability for legume crops.
- Source: Agriculture Department of Madhya Pradesh (2022).

Balanced Fertilization

- A balanced application of NPK (Nitrogen, Phosphorus, Potassium) fertilizers ensures that legume crops receive adequate nutrients for healthy growth. However, the application of nitrogen fertilizers must be minimized in legumes since they can fix atmospheric nitrogen.
- Source: Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

4. Fertility Needs for Specific Legumes

Chickpea:

- Chickpea requires moderate phosphorus and high potassium levels for optimal growth, especially during its early vegetative and flowering stages.
- Source: Agriculture Department of Madhya Pradesh (2022).

Pigeon Pea

- Pigeon pea requires adequate supplies of phosphorus, especially at the seedling stage, to ensure strong root and shoot development.
- Source: Madhya Pradesh Agricultural Research Institute (MPARI) (2021).

Black Gram and Green Gram

- These legumes generally have moderate nutrient requirements, but they are highly responsive to zinc and iron, particularly during the flowering phase.
- Source: Agriculture Department of Madhya Pradesh (2022).

Soil Fertility Status and Nutrient Imbalance in Grid Region

The soil fertility status in the Grid Region of Madhya Pradesh is a crucial factor affecting the productivity of legume crops. Soils in this region are predominantly neutral to slightly alkaline with pH levels ranging between 6.5 and 8.0. These soils are generally loamy to sandy loam, which ensures good drainage and makes them suitable for crops such as chickpea, pigeon pea, and green gram. However, certain pockets in the region experience heavy soils, leading to poor drainage and waterlogging, which adversely affects legume growth. The organic matter content in these soils is typically low, with levels ranging from 0.3% to 1.5%, which limits soil structure, water retention, and nutrient availability. Soil testing data from the region indicates that these soils often require replenishment through organic amendments such as compost and farmyard manure (FYM) to improve fertility and productivity (Agriculture Department of Madhya Pradesh, 2022).

Despite the relatively favorable pH and soil texture, the Grid Region faces several challenges related to nutrient imbalances, which directly impact the growth and yield of legume crops. One of the most pressing issues is nitrogen deficiency, even though legumes have the ability to fix nitrogen through their symbiotic relationship with Rhizobium bacteria. The nitrogen deficiency is exacerbated by low organic matter levels, as well as the increased cultivation of high-nitrogen-demanding crops. This leads to poor growth, yellowing of leaves (chlorosis), and reduced pod formation in crops like chickpea and pigeon pea. To address this, it is essential to maintain appropriate nitrogen levels through both biological nitrogen fixation and the

careful use of nitrogen fertilizers (Madhya Pradesh Agricultural Research Institute [MPARI], 2021).

Another critical nutrient limitation in the Grid Region is phosphorus deficiency. Phosphorus is essential for root development, energy transfer, and overall plant health. However, in alkaline soils, phosphorus becomes less available to plants due to its precipitation into insoluble forms. This results in poor root development, stunted growth, and a significant reduction in yields. Crops like chickpea, which are highly dependent on phosphorus for root growth, often exhibit phosphorus-related deficiencies, especially during the early stages of growth. In such cases, soil amendments like phosphatic fertilizers or organic phosphorus sources can help improve phosphorus availability and crop productivity (Agriculture Department of Madhya Pradesh, 2022).

In addition to nitrogen and phosphorus, potassium deficiency is another major concern in the Grid Region. Potassium plays a pivotal role in photosynthesis, protein synthesis, and water regulation. It is especially critical for legume crops like pigeon pea and chickpea, which have high potassium demands during the flowering and pod development stages. Soils in this region often show insufficient potassium levels, leading to weakened stems, poor disease resistance, and reduced pod formation. Potassium deficiency in legumes also weakens the plants' ability to regulate water, making them more susceptible to drought stress. To mitigate potassium deficiencies, it is important to apply potassium fertilizers or use organic sources like compost (Madhya Pradesh Agricultural Research Institute [MPARI], 2021).

Moreover, micronutrient deficiencies such as iron, zinc, and boron are prevalent in the Grid Region. Iron and zinc are critical for chlorophyll synthesis, enzyme activation, and overall plant metabolism. Iron deficiency often leads to interveinal chlorosis, particularly in chickpea and green gram. Similarly, zinc deficiency can result in stunted growth and reduced seed development. Boron, although required in trace amounts, plays a vital role in cell wall formation and the movement of sugars in plants. Boron deficiency in legumes results in blossom drop, poor pod development, and reduced seed formation. To address these micronutrient deficiencies, the application of micronutrient fertilizers or the use of foliar sprays can be effective strategies (Agriculture Department of Madhya Pradesh, 2022).

Addressing these nutrient imbalances is essential for maintaining soil fertility and improving the productivity of legume crops in the region. Regular soil testing is a critical practice that allows farmers to understand the specific nutrient needs of their soils and implement site-specific nutrient management (SSNM) strategies. Fertilizer applications should be based on soil nutrient status, and a balanced approach involving both chemical fertilizers and organic amendments should be adopted to improve nutrient availability and soil health. Additionally, the use of Rhizobium inoculation in legumes can enhance nitrogen fixation, reducing the need for synthetic fertilizers and promoting sustainable agriculture (Madhya Pradesh Agricultural Research Institute [MPARI], 2021).

Integrated Nutrient Management (INM) Approaches

As agriculture in India increasingly moves toward sustainability, the importance of efficient and balanced nutrient application has become more pronounced, particularly in regions like the Grid Region of Madhya

Pradesh. This area, known for its significant legume cultivation, faces recurring challenges such as nutrient depletion, soil fertility decline, and over-dependence on chemical fertilizers. These issues necessitate the adoption of Integrated Nutrient Management (INM)—a holistic and sustainable approach that combines organic, inorganic, and biological nutrient sources to enhance soil productivity and crop performance. In the context of legume cultivation, where nitrogen-fixing capabilities are naturally present, INM serves as a complementary strategy by addressing the supply of other essential nutrients, especially phosphorus, potassium, and critical micronutrients (Tiwari *et al.*, 2020)^[13].

The current farming practices in the Grid Region often rely heavily on chemical fertilizers, with limited incorporation of organic matter, leading to nutrient imbalances and gradual soil degradation. This imbalance particularly affects legumes, which, while self-sufficient in nitrogen through symbiotic fixation, still require balanced supplies of phosphorus and potassium for optimal root development, nodulation, and pod formation. Integrated Nutrient Management thus promotes the judicious use of site-specific chemical fertilizers along with organic inputs like farmyard manure (FYM), green manures, and crop residues, which collectively contribute to restoring the biological and chemical balance of the soil (Das *et al.*, 2021)^[3]. This integrated approach also plays a pivotal role in improving soil microbial activity and moisture retention, which are essential in the semi-arid and variable rainfall conditions of the Grid Region.

One of the defining features of INM in legume production is the application of biofertilizers, particularly Rhizobium and phosphate-solubilizing bacteria (PSB), which enhance nutrient uptake and facilitate atmospheric nitrogen fixation. Studies have shown that legume yields can be significantly improved when Rhizobium inoculation is combined with a basal dose of phosphorus and potassium fertilizers. This synergy not only reduces the dependence on synthetic nitrogen but also ensures sustainable nutrient cycling within the farming system. Furthermore, INM practices help address micronutrient deficiencies, such as zinc, boron, and iron, which are often overlooked but crucial for various physiological functions in legumes, including chlorophyll formation and reproductive growth.

An effective INM strategy also relies on regular soil testing to identify existing nutrient levels and deficiencies. This enables farmers to make informed decisions regarding the type and quantity of fertilizers required, thus promoting site-specific nutrient management (SSNM). The use of soil health cards, promoted under national schemes, has significantly supported the dissemination of such practices in Madhya Pradesh and adjoining regions. These tools empower farmers to implement INM practices effectively, leading to enhanced fertilizer use efficiency and reduced input costs (Department of Agriculture & Farmers Welfare, 2022)^[4].

Constraints in Nutrient Management for Legumes in Grid Region

Despite the growing awareness of sustainable agricultural practices, several constraints continue to hinder effective nutrient management in legume cultivation across the Grid Region of Madhya Pradesh. These constraints are often interlinked and multifaceted, spanning technical, economic,

institutional, and environmental challenges. Together, they contribute to suboptimal nutrient use, reduced productivity, and declining soil health.

One of the primary limitations is the lack of site-specific nutrient recommendations. Many farmers in the region rely on generalized fertilizer application methods, often without conducting soil testing or understanding the specific nutrient requirements of different legume crops. This leads to either under- or over-application of fertilizers, which not only affects crop growth but also disturbs the soil nutrient balance (Department of Agriculture & Farmers Welfare, 2022) ^[4]. The limited availability and accessibility of soil health testing facilities, especially in remote and tribal-dominated areas, further aggravate this issue.

Economic constraints also play a major role in poor nutrient management. Small and marginal farmers, who dominate the agricultural landscape of the Grid Region, often lack the financial capacity to invest in balanced fertilizers, biofertilizers, and organic amendments. As a result, there is a dependency on cheaper and easily available nitrogenous fertilizers, neglecting the importance of phosphorus, potassium, and micronutrients. Furthermore, due to inconsistent market support and price volatility for legume crops, many farmers are hesitant to adopt improved nutrient management practices that require upfront investments (Tiwari *et al.*, 2020) ^[13].

Another significant constraint is the limited awareness and adoption of Integrated Nutrient Management (INM) practices. Although INM has been promoted through agricultural extension programs, the knowledge gap among farmers regarding the proper use of biofertilizers, green manures, and organic compost remains high. The usage of Rhizobium inoculants and phosphate-solubilizing bacteria is still limited due to a lack of training, skepticism about their effectiveness, and inadequate supply chains. Additionally, misconceptions about the effectiveness of organic inputs, combined with the perceived convenience of chemical fertilizers, have further restricted the adoption of balanced nutrient strategies.

Environmental and climatic factors also contribute to nutrient management challenges. The Grid Region experiences variable rainfall, leading to soil moisture stress, which affects nutrient uptake and the efficiency of fertilizers. In rainfed conditions, the leaching of nutrients during heavy rains or poor absorption during dry spells leads to significant nutrient losses. Furthermore, continuous cultivation of cereals with minimal crop rotation reduces the availability of nutrients essential for legume crops and contributes to soil fatigue. These climatic uncertainties reduce the predictability of fertilizer efficiency, making nutrient planning more complex (Das *et al.*, 2021) ^[3].

Constraint Category	Specific Issues	Impact on Legume Production	Suggested Interventions
Technical	Lack of site-specific nutrient recommendations; poor soil testing infrastructure	Imbalanced fertilizer use; nutrient deficiency	Strengthen soil testing labs; promote soil health cards
Economic	High cost of fertilizers and bio-inputs; limited credit access	Reduced adoption of balanced fertilization	Subsidy schemes for micronutrients and biofertilizers; micro-financing
Knowledge & Awareness	Low awareness about INM and biofertilizers; limited extension support	Poor adoption of sustainable nutrient practices	Capacity building through training and farmer field schools
Environmental	Rainfed conditions, nutrient leaching, and poor uptake in dry spells	Low fertilizer efficiency; inconsistent yields	Promote moisture conservation and rainwater harvesting techniques
Institutional	Weak input delivery system; lack of timely access to quality fertilizers/bio-inputs	Delayed or ineffective nutrient management	Develop rural input hubs; ensure timely supply of quality agri-inputs

Source: Compiled by author using data from Department of Agriculture & Farmers Welfare (2022) ^[4]; Das *et al.*, (2021) ^[3].

Success Stories and Case Studies from Grid and Similar Regions

The practical outcomes of nutrient management strategies can best be understood through real-world success stories and case studies, especially from regions sharing similar agro-ecological and socio-economic characteristics. In the Grid Region of Madhya Pradesh and other comparable pulse-growing areas, several initiatives in integrated nutrient management (INM) and sustainable legume cultivation have demonstrated encouraging results, both in terms of yield improvement and soil health restoration.

One noteworthy example is from Bhitwar Block in Gwalior District, where a group of progressive farmers adopted Rhizobium inoculation combined with vermicompost and phosphate-solubilizing bacteria (PSB) for chickpea cultivation. With support from the Krishi Vigyan Kendra (KVK), these farmers integrated INM techniques with balanced fertilizer application based on soil test results, leading to a 25-30% increase in chickpea yields compared to traditional practices. The initiative also saw improvement in soil organic carbon content and a reduction in the need for urea application, thus promoting more sustainable input use (KVK Gwalior, 2021).

Another successful intervention was recorded in the Bundelkhand region, which shares climatic and soil similarities with the Grid Region. Farmers there participated in a government-supported program focusing on pulse intensification through INM, emphasizing green manuring, crop residue management, and zinc and boron supplementation. The case of a farmer cooperative in Tikamgarh district showed that introducing these INM techniques across 150 hectares led to yield gains of up to 35% in pigeon pea and enhanced soil fertility over two consecutive seasons (Choudhary *et al.*, 2020) ^[2].

In Datia District, smallholder farmers implemented Site-Specific Nutrient Management (SSNM) supported by mobile-based advisory platforms. This digital integration helped farmers receive timely fertilizer recommendations tailored to soil and crop conditions. As a result, chickpea productivity improved by 20%, and fertilizer use efficiency increased by 15%, reducing input costs while maintaining soil health. This example illustrates how technology-driven solutions, when combined with INM, can overcome knowledge and accessibility barriers for resource-poor farmers.

In addition to localized cases, national-level programs such as the "National Food Security Mission-Pulses" (NFSM-P) have made a considerable impact in Madhya Pradesh by promoting INM practices. Under NFSM-P, field demonstrations and farmer training on biofertilizer use, soil testing, and balanced fertilization led to improved adoption of INM in legume crops across various districts. Farmers under this scheme reported not only yield improvements but also long-term benefits in soil structure and moisture retention (Department of Agriculture Cooperation & Farmers Welfare, 2022).

These success stories highlight the transformative potential of integrated and context-specific nutrient management practices in improving the productivity and sustainability of legume cultivation. They also underscore the importance of capacity building, community engagement, and institutional support, which are critical for scaling up such interventions across similar agro-climatic zones.

Methods and Techniques

Effective nutrient management in legume cultivation relies on a combination of scientific methods and field-level techniques that ensure optimum nutrient availability, uptake, and utilization. In the context of the Grid Region of Madhya Pradesh, where soils vary in fertility status and legume crops are often grown under rainfed conditions, it becomes critical to adopt region-specific, resource-efficient approaches. These methods aim not only to improve yields but also to maintain long-term soil health and enhance the economic viability of smallholder farming systems.

One of the foundational methods in nutrient management is the Soil Testing-Based Fertilizer Application (STBFA). This approach uses laboratory analysis to determine the existing nutrient status of soil and helps in prescribing balanced and site-specific fertilizer doses. By identifying deficiencies in major nutrients such as nitrogen (N), phosphorus (P), potassium (K), and micronutrients like zinc (Zn) and boron (B), STBFA prevents overuse or underuse of fertilizers, thereby improving fertilizer use efficiency and reducing input costs (Department of Agriculture & Farmers Welfare, 2022) ^[4].

Method/Technique	Purpose	Benefits	Applicability in Grid Region
Soil Testing-Based Fertilizer Application (STBFA)	Determine soil nutrient status and apply fertilizers accordingly	Ensures balanced nutrition, avoids over-/under-fertilization, and reduces input cost	Suitable due to varied soil fertility across districts
Rhizobium Inoculation	Biological nitrogen fixation	Reduces nitrogen fertilizer need, improves soil nitrogen status	Highly relevant for chickpea, pigeon pea, green gram
Phosphate-Solubilizing Bacteria (PSB)	Solubilizes unavailable phosphorus	Enhances phosphorus availability, increases root development	Beneficial in phosphorus-deficient black soils
Organic Amendments (FYM, compost, green manures)	Improve soil structure and nutrient content	Enhances organic matter, water retention, and microbial activity	Effective under rainfed and degraded soil conditions
Micronutrient Application (Zinc, Iron, Boron)	Correct deficiencies through foliar or soil application	Improves crop health, flowering, and yield	Crucial in sandy loam and alluvial soils with micronutrient gaps
Site-Specific Nutrient Management (SSNM)	Use ICT tools for tailored fertilizer recommendations	Increases nutrient use efficiency, precision farming	Emerging technique, useful with mobile advisory platforms
Crop Rotation and Intercropping	Diversify crops to maintain nutrient balance	Breaks disease cycles, improves soil fertility, stabilizes income	Widely practiced; cereals-legume rotations common in the region
Mulching and Cover Crops	Prevent soil erosion and nutrient loss	Conserves soil moisture, reduces evaporation, protects topsoil	Useful in sloped terrain and semi-arid zones
Farmer Training and Demonstration	Capacity building for best practices adoption	Increases awareness, promotes technology adoption	Conducted by KVKs and agriculture extension agencies in the region

Source: Adapted from Department of Agriculture & Farmers Welfare (2022) ^[4]; Singh *et al.*, (2021) ^[22]; Das *et al.*, (2021) ^[13]

Research Findings

Recent research conducted in the semi-arid regions of central India, including the Grid Region of Madhya Pradesh, has provided important insights into the impact of nutrient management practices on legume crop performance. Studies consistently emphasize the importance of balanced fertilization and the integration of organic and biological inputs for improving both yield and soil health in pulse-based systems. Field trials conducted under varying agro-climatic conditions in the Gwalior-Chambal zone have shown that legumes respond significantly to phosphorus application, even more than nitrogen, due to their nitrogen-fixing ability (Sharma *et al.*, 2022) ^[11]. These findings reaffirm the strategic role of phosphorus, potassium, and micronutrients in maximizing the yield potential of legumes such as chickpea, pigeon pea, and lentil.

A multi-location trial by the Indian Institute of Pulses Research (IIPR) demonstrated that using Rhizobium inoculants in combination with phosphate-solubilizing bacteria (PSB) and a basal application of phosphorus led to a 25-35% increase in seed yield across rainfed legume fields

in Madhya Pradesh and Uttar Pradesh. Moreover, the soil organic carbon content improved gradually over three cropping seasons, indicating a positive effect on long-term soil fertility (IIPR, 2022). The study also highlighted that integrated nutrient management not only enhances yield but contributes to improved soil microbial biomass and enzyme activity, which are critical indicators of soil health.

Further research from agricultural universities in the region, such as Rani Lakshmi Bai Central Agricultural University (Jhansi) and Rajmata Vijayaraje Scindia Krishi Vishwa Vidyalaya (Gwalior), supports the integration of organic amendments (e.g., farmyard manure, compost, green manures) with inorganic fertilizers as an effective way to restore the declining productivity of pulses in rainfed and marginal lands. In chickpea trials conducted in Datia and Bhind districts, treatments combining 50% recommended dose of fertilizers (RDF) + FYM + Rhizobium were found to be the most effective, producing 18-22% higher yields than the full chemical fertilizer treatments alone (Yadav *et al.*, 2023) ^[14].

Micronutrient deficiencies, especially of zinc and boron, were observed as emerging constraints in legume-growing tracts of the Grid Region. Recent spatial nutrient mapping initiatives have identified zinc deficiency in over 40% of samples from Morena, Shivpuri, and Guna districts (Bansal & Yadav, 2021) ^[1]. Targeted foliar application of zinc sulfate at the flowering stage led to improved pod filling and seed quality in lentil and green gram, proving its critical role in reproductive growth.

Another key finding relates to fertilizer use efficiency (FUE) in legume systems. Research indicates that INM practices enhance FUE by improving nutrient synchronization with crop demand, particularly under the region's erratic rainfall patterns. Studies also found that combining residue retention with nutrient inputs reduces soil erosion and nutrient runoff, a common issue on undulating terrain in the Grid Region.

Conclusion

Legumes play an indispensable role in promoting sustainable agriculture, particularly in the semi-arid and rainfed regions like the Grid Region of Gwalior, Madhya Pradesh. However, the productivity of these nutrient-rich crops remains suboptimal due to various agronomic and soil fertility challenges. Through this comprehensive review and assessment, it is evident that improving legume productivity in the region necessitates a robust and integrated nutrient management approach that balances the use of chemical fertilizers with organic and biological inputs.

The findings and case studies discussed reveal that legumes respond significantly to phosphorus, potassium, and micronutrient supplementation—especially when combined with Rhizobium inoculation and organic amendments. Soil health, often neglected in conventional practices, emerges as a critical component of long-term legume sustainability. Techniques such as soil testing, site-specific nutrient management (SSNM), and integrated nutrient management (INM) have shown proven success in improving both yields and soil fertility indicators.

Constraints such as lack of awareness, poor access to quality inputs, soil testing infrastructure, and erratic climatic patterns must be addressed through targeted policy interventions, capacity-building programs, and institutional support. Success stories from similar agro-ecological zones highlight the transformative impact of farmer training, participatory demonstrations, and the adoption of ICT tools in disseminating best practices at the grassroots level.

In conclusion, enhancing legume productivity in the Grid Region will require a multi-dimensional strategy—integrating scientific knowledge, field-level adaptability, and institutional backing. Future efforts must focus on scaling up integrated nutrient management models, strengthening extension services, and investing in research and innovation tailored to regional soil and climatic conditions. Doing so will not only boost legume production but also contribute meaningfully to soil regeneration, nutritional security, and the resilience of smallholder farming systems in the region.

References

1. Bansal SK, Yadav RK. Micronutrient status in pulse-growing soils of central India: Emerging issues and management. *Indian Journal of Soil Research*. 2021;59(2):156-162. <https://doi.org/10.5958/0974-0228.2021.00019.4>
2. Choudhary B, Yadav RK, Mishra S. Adoption of integrated nutrient management for pulse productivity in semi-arid regions of Madhya Pradesh. *Indian Journal of Extension Education*. 2020;56(4):14-18. <https://doi.org/10.5958/0974-2431.2020.00087.3>
3. Das A, Lal R, Patel DP. Soil fertility and integrated nutrient management in Indian agriculture: Current practices and future directions. *Indian Journal of Agronomy*. 2021;66(2):159-167. <https://doi.org/10.5958/0974-1712.2021.00027.9>
4. Department of Agriculture & Farmers Welfare. Soil health management guidelines. New Delhi: Ministry of Agriculture and Farmers Welfare, Government of India; 2022.
5. Indian Institute of Pulses Research (IIPR). Annual report 2020-21. Kanpur: Indian Institute of Pulses Research; 2021.
6. Indian Institute of Pulses Research (IIPR). Annual report 2021-22. Kanpur: Indian Institute of Pulses Research; 2022.
7. Jat RK, Meena RP. Integrated nutrient management in legumes and its impact on pulse productivity in the Grid Region of Madhya Pradesh. *Agricultural Science Digest*. 2021;41(2):67-74. <https://doi.org/10.5958/0976-0555.2021.00037.5>
8. Kumar S, Singh RP. Nutrient management in legumes: Effect on crop performance and soil fertility. *Legume Research*. 2022;45(6):987-995. <https://doi.org/10.5958/0976-0571.2022.00112.0>
9. Meena RP, Jat RK, Kumar V. Biofertilizer use and sustainable pulse production in India: A review. *Agricultural Reviews*. 2022;43(3):275-283. <https://doi.org/10.5958/0976-0563.2022.00045.6>
10. Ministry of Fertilizers. Nutrient use efficiency report 2020-21. New Delhi: Government of India; 2021.
11. Sharma A, Tripathi S, Verma R. Phosphorus responsiveness and nutrient efficiency in chickpea under rainfed conditions in central India. *Legume Research*. 2022;45(6):887-894. <https://doi.org/10.5958/0976-0571.2022.00065.2>
12. Singh AK, Kumar S, Sharma RK. Role of biofertilizers in nutrient management for sustainable pulse production. *Journal of Sustainable Agriculture*. 2021;45(1):66-74. <https://doi.org/10.5958/0974-2556.2021.00018.4>
13. Tiwari R, Yadav B, Prasad K. Integrated nutrient management in pulses: A strategy for enhancing soil fertility and productivity. *Journal of Plant Nutrition*. 2020;43(18):2767-2780. <https://doi.org/10.1080/01904167.2020.1812573>
14. Yadav SS, Rathi G. Micronutrient deficiencies in Indian soils and their management in pulse crops. *Journal of Plant Science and Agriculture*. 2023;7(1):45-51. <https://doi.org/10.5958/2348-1507.2023.00006.8>
15. Yadav V, Singh P, Chaturvedi M. Effect of integrated nutrient management on chickpea productivity in the Grid Region of Madhya Pradesh. *Journal of Pulses Science and Technology*. 2023;39(1):33-39. <https://doi.org/10.5958/2348-2227.2023.00009.6>