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Integrated nutrient management in vegetable crops: A review

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Abstract
INM is an approach to optimize nutrient availability and utilization in vegetable crops. It involves the amalgamation of various sources of nutrients, such as natural, chemical and microbial fertilizers, to preserve soil fertility and improve plant productivity. Vegetable crops have high nutrient requirements for their growth and development. However, excessive or imbalanced utilize of element guide to nutrient imbalances, soil deprivation, and environmental pollution. Integrated nutrient management provides a sustainable solution to address these issues. FYM, manure as well as green manure are example of organic manures which are rich sources of vital nutrients and natural matter. They improve loam arrangement, WHC, and microbial activity as well as enhanced nutrient availability to plants. In addition to organic manures, inorganic fertilizers can be used judiciously based on soil testing and crop nutrient requirements. Balanced fertilization ensures that all essential nutrients are supplied in appropriate amounts, avoiding deficiencies or excesses. This approach not only optimizes crop growth but also minimizes nutrient losses, thus reducing environmental pollution. Nitrogen-fixing bacteria, phosphate-solubilizing bacteria as well as *mycorrhizal* fungi are expel of biofertilizers which can be used for enhance nutrient availability and uptake by vegetable crops. These beneficial microorganisms establish symbiotic relationships with plants, facilitating nutrient acquisition from the soil. By promoting nutrient cycling and improving soil health, biofertilizers contribute to sustainable vegetable crop production.

Keywords: INM, manure, fertilizers, biofertilizers, compost, soil health

Introduction
Vegetable is an indispensable part of the nation's agricultural system having both food value and export earnings. Vegetables are lavish in vitamins, minerals, dietary fibers, CHO and proteins. Demands of vegetable crops increased days by days due to its antioxidant properties (Singh and Kalloo, 2000) [47].
INM is an approach that aims to optimize nutrient use efficiency in vegetable crops by integrating various sources of nutrients. This approach combines the use of natural and unnatural fertilizers, along with other management practices, for ensure sustainable as well as environmentally friendly crop production. In recent years, INM has gained significant attention and has become an essential component of vegetable crop management (Khan *et al.*, 2008) [19].

Objectives of INM
One of the primary objectives of INM is to optimize nutrient availability for vegetable crops. By combining natural and non-living sources of nutrients, INM provide balanced supply of essential elements required for optimal plant growth. This approach ensures that crops receive the necessary nutrients in the right proportions, leading to healthier and more productive plants. Another objective of INM is to improve soil fertility and structure. By incorporating natural material into the soil, INM helps enhance soil health and structure. Organic matter improves soil moisture retention, nutrient-holding capacity, and microbial activity, ultimately creating a favorable environment for vegetable crops to thrive. INM also focuses on minimizing nutrient losses and environmental pollution. Through precise nutrient application techniques, such as split application and site-specific fertilization, INM aims to reduce nutrient runoff and leaching. This helps prevent the contamination of water bodies and protects the surrounding ecosystem. Furthermore, INM promotes sustainable agriculture by reducing dependence on chemical fertilizers. By incorporating organic sources of nutrients, farmers can gradually reduce the use of synthetic fertilizers, thereby minimizing the potential negative impacts on soil health and ecosystem balance. This objective aligns with the principles of

organic farming and sustainable agriculture practices. Lastly, INM aims to improve overall farm profitability and economic sustainability. By optimizing nutrient management, farmers can achieve higher crop yields and quality, leading to increased market value and profitability. Additionally, by minimizing input costs associated with synthetic fertilizers, INM can contribute to reducing production expenses and improving the economic viability of vegetable productions (Arslan, 2023) [5].

Components of INM

1. Organic Manure

It is natural fertilizer, which are alternative for chemical fertilizers that are utilized for improve nutrient status of soil as well as promote healthy vegetable development. It is derivative as of natural source such as mammal waste, crop materials, and compost. (Aruna *et al.*, 2020) [6].

A. Farm yard manure: It is also known as FYM, is a valuable organic fertilizer that is commonly used in agriculture. It is made up of decomposed animal waste, such as cow dung, along with straw and other organic materials. NPK contain in FYM is noted in Table 1. (Vinay *et al.*, 2020) [51].

B. Compost: Organic compost is a valuable resource for gardeners and farmers alike. It is a natural fertilizer that is made from decomposed organic matter, such as food scraps, yard waste, and manure. It is a simple with cost-effective method to reprocess these materials and turn them into nutrient-rich soil. (Agnew and Leonard, 2003) [3].

C. Vermicompost: vermicompost, also known as worm compost, is a natural and sustainable method for reprocess natural material. This process involves the use of earthworms to break down organic materials such as food scraps, yard waste, and paper into a dark, crumbly substance called vermicompost. (Jorge *et al*., 2019) [18].

Table 1: Composition of different organic manure

Manure	N (%)	P (%)	K (%)
FYM	0.5	0.2	0.5
Compost	0.5	0.5	0.5
Town compost	1.4	1.0	1.4
Vermicompost	3	1	1.5

D. Green manure: Some crops are twisted into soil while still they are green for restore fertility and productivity it is recognized as green manuring. Leguminosae group crops are generally used for green manuring. These crops being capable of nitrogen fixing, add nitrogen in the soil (Satya *et al*., 2016) [38]. Some of the important green manure crops and their N fixation capacity are given billow:

Sr. No.	Green manure crops	Botanical name	'N' fixation capacity per ha.	Reference
1	Sunhemp	*Crotalaria juncea*	134 kg	Kumar *et al*., 2020 [21].
2	Daincha	*Sesbania aculeate*	133 kg	Reddy and Kumar, 2022 [35].
3	Manila Agathi	*Sesbania rostrata*	96 kg	
4	Cluster bean	*Cyamopsis tetragonoloba*	91 kg	
5	Cow pea	*Vigna unguiculata*	74 kg	

Benefits of Organic Manure

Benefits of organic manure are displayed in below:

1. **Improved Soil Structure:** Organic manure helps improve soil structure by enhancing its water-holding capacity and reducing erosion. It promotes the formation of aggregates, allowing for better aeration and root penetration. This results in healthier and more productive soil.
2. **Nutrient Enrichment:** Organic manure provides a slow and steady release of nutrients to plants, ensuring a continuous supply throughout their growth cycle. This gradual nutrient release minimizes the risk of nutrient leaching and runoff, reducing environmental pollution.
3. **Enhanced Soil Fertility:** The organic matter present in organic manure acts as a reservoir for nutrients, making them readily available to plants.
4. **Environmental Sustainability:** The utilization of natural compost reduces reliance on inorganic fertilizers, which often have harmful sound effects on the atmosphere. It helps to preserve biodiversity, protect water quality, and reduce greenhouse gas emissions.

Methods of Application

Organic manure applied in soil by various methods. Some common methods include (Gana, 2011) [16]:

1. **Broadcasting:** This involves spreading the organic manure evenly over the soil surface. It is suitable for large-scale applications, especially in open fields.
2. **Top Dressing:** In this method, organic manure is applied around the base of plants or crops. It is particularly useful for providing supplemental nutrition during the growing season.
3. **Mulching:** Organic manure can be utilized as mulch to wrap the upper surface around plants. This helps retain moisture, suppress weeds, and gradually release nutrients as the mulch decomposes.

2. Biofertilizers

Biofertilizers are substances that contain living microbes, such as bacteria, fungi, and algae, which improve nutrient accessibility to the plants. Unlike chemical fertilizers, which provide nutrients directly to plants, biofertilizers work by improving soil health and promoting the growth of beneficial microorganisms. These microorganisms, in turn, help in the decomposition of organic matter, fix atmospheric nitrogen, solubilize phosphorus, and enhance nutrient absorption by plants (Chaudhari and Barot, 2023) [12].

Classes of biofertilizers

In vegetable crops many types of biofertilizers are use, each with its specific benefits. Some common types include:

1. Nitrogen-Fixing Biofertilizers

These biofertilizers contain nitrogen-fixing bacteria, such as *Rhizobium* and *Azotobacter*, which convert atmospheric nitrogen into a form that plants can utilize. This helps in reducing the dependence on synthetic nitrogen fertilizers, which are energy-intensive to produce and can cause environmental pollution.

2. Phosphate-Solubilizing Biofertilizers

These biofertilizers contain phosphate-solubilizing bacteria, such as *Bacillus* and *Pseudomonas*, which release bound phosphorus from the soil, making it available for plant uptake. This is particularly beneficial in soils with low phosphorus availability, reducing the need for phosphorus-based chemical fertilizers.

3. Potash-Mobilizing Biofertilizers

These biofertilizers contain potash-mobilizing bacteria, such as *Bacillus* and *Pseudomonas*, which enhance the availability of potassium in the soil. Potassium is an essential nutrient for vegetable crops, promoting overall growth, yield, and disease resistance.

Benefits of Biofertilizers in Vegetable Crop:

The use of biofertilizers in vegetable crops offers numerous advantages, both agronomically and environmentally. Some key benefits include (Chaudhari and Barot, 2023) [12].

1. **Improved Soil Health:** Biofertilizers enhance soil fertility and structure by promoting the growth of beneficial microorganisms. This improves WHC of soil, minerals accessibility as well as overall crop health.
2. **Reduced Chemical Fertilizer Dependency:** Biofertilizers reduce the reliance on synthetic chemical fertilizers, which can be expensive and harmful to the environment. This reduces the risk of nutrient imbalances and pollution of water bodies.
3. **Sustainable Agriculture:** Biofertilizers align with the principles of sustainable agriculture by promoting natural processes and minimizing the use of synthetic inputs. They contribute to the conservation of soil biodiversity and reduce the carbon footprint of farming practices.
4. **Enhanced Crop Yield and Quality:** The application of biofertilizers raises productivity as well as improves nutritional quality of vegetables. This is due to the improved nutrient uptake, disease resistance, and overall plant vigor provided by biofertilizers.

3. Inorganic fertilizers

It is an inorganic matter which artificially produces. It is very quick in releasing the nutrients and help in early establishment and development of plants. There are mainly three types of fertilizers (Bafoev *et al*., 2022) [10].

- Nitrogenous fertilizers: Such types of fertilizers contain only nitrogen. Nitrogen found in form of nitrate (NO_3) or ammonical form (NO_4). *e.g*., Urea, Ammonium Sulphate, Ammonium nitrate.
- Phosphatic fertilizers: Such fertilizers contain only phosphorus. *e.g*., SSP, DSP, TSP.
- Potassic fertilizers: Potash is required in relatively larger amount than any other nutrients excepting nitrogen. Potash is supplied to the plants using potassic fertilizers. *e.g*., Potassium Chloride (MOP), Potassium Sulphate (SOP).

Advantages

Following are the advantages of chemical fertilizers in vegetable productions (Pahalvi *et al*., 2021) [29]:

1. **Nutrient Availability:** Inorganic fertilizers are formulated to provide essential nutrients, such as nitrogen, phosphorus, and potassium, in a readily available form for plants. This ensures that crops receive the necessary nutrients for healthy growth and higher yields.
2. **Quick Release:** Inorganic fertilizers are designed to release nutrients rapidly, allowing plants to absorb them immediately. This quick-release characteristic is beneficial when immediate nutrient supplementation is required to correct deficiencies or boost growth.
3. **Customizable Formulations:** Inorganic fertilizers can be tailored to specific crop requirements by adjusting the nutrient ratios. This flexibility allows farmers to address specific nutrient deficiencies in their soil, promoting optimal plant growth and yield.
4. **Increased Crop Productivity:** Inorganic fertilizers have been instrumental in increasing agricultural productivity and meeting the demands of a growing population. By providing essential nutrients in easily absorbable forms, they help plants grow faster and produce higher yields.
5. **Ease of Application:** Synthetic fertilizers are easy to handle and apply. They come in various forms like granules, powders, or liquids, making them convenient to use and distribute evenly across fields. This ease of application saves time and labor compared to organic alternatives.

Disadvantages

Following are the disadvantages of chemical fertilizers in vegetable productions (Pahalvi *et al*., 2021) [29]:

1. **Environmental Pollution:** One of the significant drawbacks of inorganic fertilizers is their potential to cause environmental pollution. Excessive or improper use of synthetic fertilizers can lead to nutrient runoff, contaminating water bodies and causing eutrophication. This pollution can harm aquatic life and disrupt ecosystems.
2. **Soil Degradation:** Over-reliance on inorganic fertilizers can lead to soil degradation and reduced fertility. Continuous use of these fertilizers without proper soil management practices can result in nutrient imbalances, soil acidification, and reduced microbial activity, negatively impacting long-term soil health.
3. **Health Risks:** Inorganic fertilizers contain chemicals that can be harmful to human health. Prolonged exposure to these chemicals can lead to respiratory problems, skin irritations, and other health issues. Additionally, the consumption of crops grown with excessive synthetic fertilizer use may contain higher levels of nitrates, which can be harmful if ingested in large quantities.
4. **Cost:** Inorganic fertilizers can be expensive, especially for small-scale farmers. The production and distribution costs associated with synthetic fertilizers contribute to their higher price compared to organic alternatives. This cost factor can limit accessibility and affordability for farmers in developing regions.
5. **Dependency:** Continuous use of inorganic fertilizers can create a dependency on external inputs, as they do not contribute to long-term soil fertility. This reliance on synthetic fertilizers can lead to a cycle of increased application rates and diminishing returns, making it challenging to transition to more sustainable farming

practices.

Advantages of INM

1. Improved Nutrient Use Efficiency
One of the significant advantages of INM is the improved nutrient use efficiency in vegetable crops. Traditional methods of nutrient application often result in nutrient losses through leaching, volatilization, and runoff, leading to inefficiency and environmental pollution. However, with INM utilization of natural martial such as manure and dung which helps in improve soil and nutrient availability. Additionally, sensible apply of inorganic element based on soil testing and crop nutrient requirements which ensures that nutrients are supplied in the proper amount and growing stage which result in minimizing losses and maximizing crop uptake.

2. Enhanced Soil Health
INM practices contribute to the improvement of soil health in vegetable crops. Organic fertilizers like manure and green compost, enrich the soil with natural substance, which improve loam arrangement and WHC. By adopting INM, farmers can maintain the long-term productivity and sustainability of their vegetable crop fields (Aulakh, 2010) [8].

3. Reduced Environmental Pollution
Another significant advantage of INM is the reduction of environmental pollution associated with nutrient management in vegetable crops. Extreme utilization of inorganic elements leads to nutrient imbalances, water contamination, and greenhouse gas emissions. However, by integrating organic fertilizers, farmers can reduce their reliance on synthetic fertilizers, thereby minimizing the risk of nutrient pollution. Organic fertilizers release nutrients slowly, providing a sustained supply to the crops and reducing the risk of nutrient leaching into groundwater. By adopting INM, farmers can contribute to a cleaner and healthier environment (Zhang *et al.*, 2012) [54].

4. Improved Crop Quality and Nutrition
Organic fertilizers like compost, contain a wide range of micronutrients and beneficial compounds that promote plant growth and enhance crop quality. By adopting INM, farmers can meet consumer demands for healthier and more nutritious vegetable crops (Wu and Ma, 2015) [52].

Constraints of INM
Following are constrains of INM (Selim, 2020) [39]:

1. **Lack of Awareness and Knowledge:** One of the major constraints of INM is the limited awareness and knowledge among farmers and agricultural extension workers. Many farmers are not aware of the concept of INM or its potential benefits. They often rely on traditional practices and are resistant to change. Similarly, agricultural extension workers may not have sufficient knowledge or training to promote and implement INM practices effectively. This lack of awareness and knowledge hampers the adoption of INM and limits its potential impact on agricultural productivity and sustainability.
2. **Limited Availability of Inputs:** Another constraint of INM is the limited availability of inputs required for its implementation. Organic manures, such as farmyard manure and compost, play a crucial role in INM. However, their availability is often limited, especially in regions where livestock rearing is not prevalent. Similarly, biofertilizers, such as nitrogen-fixing bacteria and mycorrhizal fungi, may not be readily available or affordable for small-scale farmers. The limited availability of these inputs restricts the adoption of INM and undermines its effectiveness.
3. **Cost and Affordability: The** cost of implementing INM practices can be a significant constraint for farmers, especially those with limited financial resources. INM often involves the use of multiple inputs, including organic manures, mineral fertilizers, and biofertilizers. The purchase and application of these inputs can be expensive, particularly for small-scale farmers. Moreover, the cost of transporting and storing these inputs adds to the overall financial burden. The high cost and affordability issues associated with INM hinder its widespread adoption and limit its potential benefits for farmers.
4. **Lack of Infrastructure and Technology:** The successful implementation of INM requires adequate infrastructure and technology support. This includes facilities for composting organic waste, storage and transportation systems for inputs, and testing laboratories for soil and nutrient analysis. However, in many regions, such infrastructure and technology are lacking or inadequate. Farmers may not have access to proper storage facilities for organic manures, leading to nutrient losses and inefficiencies. Similarly, the absence of testing laboratories makes it difficult to determine the nutrient requirements of crops accurately. The lack of infrastructure and technology hampers the effective implementation of INM and reduces its potential benefits.

Effect of INM in vegetable crops

Solanaceous Vegetables
Chopra *et al.* (2017) [14] observed maximum plant height, root length, dry weight, chlorophyll content, LAI, number of flowers per plant, fruits per plant, crop yield per plant, and biochemical ingredient like crude protein, dietary fiber, total carbohydrates and total sugar of tomato was recorded with 50% RDF + 5 t ha^{-1}ARV (Agro Residue Vermicompost). Singh *et al.* (2015) [44] revealed that the plants treated with 50% RDF + 10 t ha^{-1} FYM + 5 t ha^{-1} poultry manure + biofertilizer showed maximum number of leaves per plant, fruits per plant, fruit length, mean fruit weight, yield per plant, yield per plot and ascorbic acid content in tomato. Application of FYM 15 t ha^{-1} along with 75 per cent RDF (NPK) + B + Zn proved to be the best treatment combination in terms of number of primary branches per plant, average number of fruits per plant, fruit yield (per plant, per plot and per hectare), net returns and B: C ratio in tomato cv. Rocky which studied by Manohar *et al.* (2013) [26]. Sepat *et al*. (2012) [40] noted that application of 50% NPK + FYM + *Azotobacter* gave values of $plant^{-1}$ height, branches, clusters of fruit, fruits $cluster^{-1}$, fruit size, weight of fruit $^{-1}$, fruit yield $plant^{-1}$in tomato. The soil application of 25% chemical fertilizers + 25% vermicompost + 25% cow dung + 25% vermi-tea noted greater fruit yield per plant, yield per plot and total yield in chilli which experimented by Aslam *et al.* (2022) [7]. Gokul *et al*. (2020) [17] in chilli revealed that the application of 75% recommended dose of fertilizers + poultry manure @ 5 t ha-1 + biofertilizers + 2% $MgSO_4$ registered the maximum plant

height, leaf area index, number of branches plant^{-1} and chlorophyll content. Shabir *et al.* (2017) [41] showed that applications of RFD (75%) + FYM (50%) + Sheep manure + (50%) + Poultry manure (50%) + Vermicompost (50%) + Biofertilizer (100%) in chilli recorded significantly higher values for fruit length, fruit girth, number of fruits per plant, average fruit weight, fruit yield per plant, fruit yield per plot, red ripe fruit yield per hectare, dry fruit yield per hectare, highest net returns and B: C. In brinjal the yield parameters like number of fruit per plant, length of fruit, diameter of fruit, weight of fruit, fruit yield per hectare were significantly superior in soil applications of 100% NPK + 25% N through Vermicompost which recorded by Ankit *at al.* (2022) [4]. Ramesh *et al.* (2021) [34] observed higher values of yield attributes such as number of fruits per plant, fruit yield per plant, fruit yield per plot and fruit yield per ha under RDF100% (100:50:50 NPK kg ha^{-1}). Kumar *et al.* (2017) [20] Studied that the soil application of integrated use of Tata Geo Green @ 3.75 t ha^{-1} along with 75% recommended dose of NPK fertilizer (150:60:100) in potato was found superior for higher plant growth, net returns and B:C ratio.

Cucurbitaceous Vegetables

In bottle gourd, application of 50% NPK + 25% Vermicompost + 25% Compost recorded superior for red pumpkin beetle population and powdery mildew with highest B:C and total soluble solids which revealed by Tomar *et al.* (2022) [49]. Another field experiment on bottle gourd was conducted by Patle *et al*. (2018) [33] and they revealed that soil application of 50% RDF (50:25:25 NPK kg ha^{-1}) + 2.5 t ha^{-1} FYM + 1.65 t ha^{-1} vermicompost and *Azotobacter*, *PSB* each 5 kg ha^{-1} to the crop found to be sound integrated practice, where it recorded maximum vine length, length of internode, number of female flowers, fruit set percent, yield per vine and yield per hectare. Cucumber Plants fertilized with RDF + vermicompost @5 t ha^{-1} + Azotobacter @5 Kg ha^{-1} + PSB @5 Kg ha^{-1} shown maximum value for yield and related traits and it is the best integrated nutrient management approach for protected cultivation of cucumber under Punjab conditions which experimented by Singh *et al.* (2020) [45]. An application of 75% RDF + 12.5% FYM + 12.5% VC in cucumber was found significantly superior in terms of growth, yield and quality parameters *i.e.* vine length, number of leaves plant^{-1}, number of primary branches plant^{-1}, length and width of leaf, days taken to first fruit formation, number of fruits plant^{-1}, length and width of fruit at edible maturity, weight of fruit at edible maturity, fruit yield plant^{-1}, fruit yield plot^{-1}, total fruit yield, TSS and peel thickness studied by Singh *et al.* (2020) [45]. Nayak *et al*. (2016) [28] noted length of vine, vine girth, no. of branches per plant, length of fruit, girth of fruit, single fruit weight, moisture content of fruit, total soluble solid, ascorbic acid, total sugar of pointed gourd in soil applications of Lime + Biofertilizer + Vermicompost @ 5 t ha^{-1} + RDF (100%). Saravaiya *et al*. showed that higher fruit yield of pointed gourd (17.93 t/ha) under INM system the vine should be fertilized with the combination of 50 per cent RDF (60:30:30 NPK kg ha^{-1}) along with 10 tones of bio-compost ha^{-1}. Bitter gourd plants treated with 100% RDF of NPK + FYM 5 t ha^{-1} + Biofertilizers 4 kg ha^{-1} (*Azotobacter* and Phosphate Solubilizing bacteria) has recorded maximum total soluble solids, protein content, ascorbic acid, shelf life, total fruit yield and higher benefit: cost ratio observed by Dudhat and Patel, (2020) [15]. Another field experiment was conducted on bitter gourd by Patel *et al.* (2020) [30] and they revealed that the growth parameters *viz*., vine length at 45 DAS and at 90 DAS with number of branches per plant at 90 DAS were recorded greater in soil applications of 75% RDN through vermicompost + 25% N through urea + *Azotobacter* @ 2.5 L ha^{-1} + PSB @ 2.5 L ha^{-1}. Patel *et al.* (2021) studied that applications of 50% RDF + 25% RDN from Bio-compost + Azotobacter 2.5 L ha-1 + PSB 2.5 L ha-1 was found better with respect to different growth and yield parameters of ridge gourd. Patel *et al.* (2014) [32] recorded that soil application of Bio-compost along with 50% RDF was observed to be the best treatment for better growth and yield of little gourd.

Cruciferous Vegetables

Chaudhari *et al.* (2023) [13] in cauliflower, they studied that the applications of 100% RDF + *Azospirillium* (5 l ha^{-1}) + PSB (5 l ha^{-1}) + KMB (5 l ha^{-1}) recorded maximum plant height, stalk length, number of leaves plant^{-1}, N-S plant spread, E-W plant spread, curd diameter, gross weight of curd, net weight of curd, yield plot^{-1} and total yield. Tekasangla *et al.* (2015) evaluated that application of 50% NPK + 50% FYM + bio-fertilizers gave maximum plant height, stalk length, number of leaves plant^{-1} and plant spread in cauliflower. In cauliflower Sangeeta *et al.* (2014) also in revealed that application of 50% NPK + FYM @ 5 t ha^{-1} + Poultry manure @ 2 t ha^{-1} + *Azospirillium* @ 2 Lha^{-1} recorded maximum plant height and plant spread. Kumar *et al.* (2017) [20] also conducted experiment on cabbage, they noted maximum plant spread, number of leaves plant^{-1}, length of stalk, number of non-wrapper leaves plant^{-1}, leaf area, length of leaf, leaf width and minimum day to maturity with soil application of FYM 50% + *Azotobacter* 50%. Kumar *et al.* (2013) [24] recorded that 50% NPK ha^{-1} + vermicompost @ 2.5 tonnes ha^{-1} + *Azospirillium* @ 5 kg ha^{-1}+ VAM @ 5 kg ha^{-1} had noted maximum height, number of leaves, width of leaf, length of stalk and spread of the plant in cauliflower. Another field experiment on cabbage was carried out by Sharma *et al.* (2013) [43] and they found that plant height, number of leaves plant^{-1}, diameter of stem and plant spread recorded maximum by applying 4 kg ha^{-1} *Azospirillium*. Upadhyay *et al.* (2012) [50] found minimum number of non-wrapper leaves and maximum number of wrapper leaves with soil application of 100% NPK + *Azospirillium* in cabbage. Kumari *et al.* (2019) [25] recorded maximum head yield plant^{-1}, head yield plot^{-1}, and total head yield in application of GA_3 @ 50 ppm + *Azotobacter* @ 5 kg ha^{-1} in broccoli. The experiment was carried out by Mishra *et al.* (2014) [27] in knol-khol and they reported that 100% NPK + vermicompost @ 2.5 t ha^{-1} + @ 2 kg ha^{-1} *Azotobacter* + @ 2 kg *Azospirillium* + @ 2 kg PSB gave maximum yield. Abou *et al.* (2018) [1] stated that 100% mineral K + potassium bio-fertilizer gave maximum head diameter, head height and head yield of chines cabbage.

Bulbous Vegetables

Yadav *et al.* (2015) [53] showed that the maximum plant height, bulb diameter, neck thickness, bulb length and number of leaves per plant were recorded with applications of RDF (50%) + Vermicompost (50%) at 90 DAT. Brinjh *et al.* (2014) [11] also studied INM in onion and revealed that maximum plant height was recorded under the RDF 75% + Vermicompost 25% while length of leaves, number of leaves, neck thickness and number of scales were found in RDF 75% + *Azotobacter* 25%. Where, diameter of bulb, bulb length and yield were observed in RDF 75% + *Phosphobacteria* 25%. In garlic, the maximum plant height, numbers of leavesat 120 DAP, maximum yield plot^{-1}, yield ha^{-1}, average fresh weight, average dry weight of bulb, equatorial diameter, polar diameter, average fresh weight of cloves, number of cloves bulb^{-1}, length of cloves, neck thickness and dry matter content were recorded with the application of 100 per cent RDF + Vermicompost @ 6 t ha^{-1} + Sulphur @ 45 kg ha^{-1} which experimented by Kumar *et al.* (2019) [22].

Root vegetables

Experiment was carried out by Shanu *et al.* (2019) [42] and resulted that higher percentage of total soluble solids, ascorbic acid content, carotene content, cortex to core ratio, highest gross return, net return and best benefit cost ratio were recorded with 25% RDF + 50% FYM @ 6 t ha^{-1} + 50% Vermicompost @ 3 t ha^{-1} + 50% *Rhizosphere* Bacteria, while lower percentage of cracked roots and forked roots were recorded in FYM 12 t ha^{-1}. Babi *et al.* (2021) revealed that highest germination percentage, plant height, root length, root diameter and yield per ha was recorded higher in 50% recommended N through chemical fertilizer + 50% N through poultry manure.

Conclusion

Integrated Nutrient Management has emerged as a promising approach in vegetable crop production. Its advantages, such as improved nutrient use efficiency, enhanced soil health, reduced environmental pollution, and improved crop quality and nutrition, make it a sustainable and beneficial practice for farmers. By adopting INM, farmers can optimize nutrient management, reduce input costs, and contribute to the overall sustainability of vegetable crop production. It is essential for researchers, policymakers, and farmers to promote and encourage the adoption of INM practices for a more productive and environmentally friendly vegetable farming sector.

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