REVIEW ARTICLE

An overview of the effect of integrated nutrient management on vegetable crops

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The overview on the effects of Integrated Nutrient Management (INM) on vegetable crops highlights its multifaceted benefits. INM integrates organic and chemical fertilizers, enhancing soil fertility and structure while optimizing nutrient supply to vegetable crops. INM practices are important in vegetable crop production, enhancing the quantity and quality of crops like tomato, brinjal, chilli, radish, carrots, cabbage, cauliflower, broccoli, okra, cucumber pumpkin, melons, gourd and leafy vegetables. By combining natural and inorganic fertilizers with bio-fertilizers, INM methods reduce input costs and enhance crop quality and nutrition. This sustainable approach optimizes nutrient use efficiency, enhances soil health, reduces environmental pollution and contributes to overall sustainability. It is essential for researchers, policymakers and farmers to promote and encourage INM practices for a more productive and environmentally friendly vegetable farming sector. This balanced nutrition leads to increased vegetables yields, improved crop quality and enhanced nutrient use efficiency. Additionally, INM practices promote sustainable soil management, reducing environmental impact and encouraging resilience to abiotic stresses. By minimizing reliance on synthetic inputs, INM contributes to economic viability for growers while preserving natural resources.

Key Words: *Sustainability; Soil health; Natural resources; Vegetables yield*

INTRODUCTION

Integrated Nutrient Management (INM) is pivotal for optimizing vegetable crop productivity while ensuring environmental sustainability. By combining organic and inorganic fertilizers alongside microbial inoculants, INM enhances soil fertility and structure, encouraging strong plant growth and higher yields. By limiting losses and the hazards of environmental contamination associated with synthetic fertilizers, this strategy maximizes nutrient efficiency. As so, it improves soil quality, crop water uptake efficiency and soil health. Furthermore, INM reduces the need for pharmaceutical treatments by encouraging resilience to pests and environmental challenges. Notably, the method improves crop quality, satisfying customer demands for superior, nutrient-dense fruit. In terms of economics, INM maximizes input costs and supports vegetable farming's long-term viability. It is often known that vegetables are an essential dietary supplement for preserving good health and guaranteeing nutritional security. They are significant providers of proteins, carbs, minerals and vitamins. Integrated nutrient management refers to applying both organic and inorganic fertilizers to increase crop yield. Essentially, the INM approach involves applying synthetic fertilizers in addition to agricultural wastes, organic manures, biofertilizers and other biologically related materials in an equivalent ratio [1]. Farmers that cannot afford to utilize chemical fertilization to supply nutrients for any crop can also benefit from the INM approach. In order to boost agricultural output and lessen soil erosion, it also seeks to enhance the biological, mechanical, hydrological and physical qualities of the land [2]. The use of nitrogenous fertilizers excessively or carelessly is detrimental to crop productivity and soil health. Therefore, the application of biofertilizer and organic manure in moderation in addition to chemical fertilizers promotes soil fertility maintenance and lucrative and sustainable crop production [3]. When viewed appropriately, integrated nutrition management can help improve the quantity and caliber of vegetables produced [4]. By combining different nutrient sources, the INM strategy seeks to maximize vegetable crop nutrient usage efficiency. Using both natural and artificial fertilizers in addition to other management techniques, this strategy guarantees crop production that is both ecologically benign and sustainable. INM has drawn a lot of attention lately and is now a significant part of managing vegetable crops [5].

Need of integrated nutrient management in vegetable crops production

Improved soil fertility: In addition to chemical fertilizers, the regular use of organic manures such compost, farmyard manure and green manure helps enhance the fertility, texture and structure of the soil. Better nutrient availability, aeration and water retention result from this, all of which are essential for the growth and development of vegetable crops.

<u>Increased yield and quality:</u> Increased crop yields and better quality characteristics, such vegetable size, color, taste and nutritional content are frequently the outcomes of proper nutrient management using integrated nutrient management. Optimal plant growth and development are supported by balanced nutrition, which raises productivity and produces goods that may be sold.

<u>Enhanced nutrient availability:</u> INM ensures a balanced supply of essential nutrients, including Nitrogen (N), Phosphorus (P), Potassium (K), micronutrients and organic matter. This balanced nutrition promotes vigorous vegetative growth, root development, flowering and fruit set in vegetable crops.

<u>Enhanced soil health:</u> Through the addition of organic matter and the development of beneficial microbial communities, INM methods increase biological activity in the soil. This promotes improved nitrogen cycling, soil health and the long-term sustainability of vegetable cropping systems. It also inhibits soil-borne diseases.

<u>Resistance to abiotic stress:</u> Vegetable crops are more resilient to abiotic stressors like salt, drought and high temperature changes when they are properly nourished, especially when it comes to balanced levels of macro- and micronutrients. Plants that receive proper nutrition are more resilient to environmental shocks and can continue to produce even under difficult circumstances.

<u>Reduced nutrient losses:</u> INM assists in lowering nutrient losses due to volatilization, runoff and leaching by using organic nutrient sources and effective nutrient management techniques. By doing this, the chance of environmental contamination is reduced, nutrient utilization is enhanced and natural resources are preserved.

<u>Improved economic returns:</u> In spite of the possibility of greater upfront expenses associated with organic inputs and management techniques, INM usually yields longer-term advantages. For vegetable producers, more yields,

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better quality, less input needed and more environmental sustainability all translate into higher financial benefits.

Adaptation to climate change: INM techniques can improve crop resilience, water usage efficiency and soil carbon sequestration, all of which can help vegetable production systems adapt to climate change. Sustainable nutrient management practices support agricultural resilience and lessen the negative effects of climatic variability.

LITERATURE REVIEW

Effect of integrated nutrient management in Solanaceous vegetables

Tomato: INM optimizes tomato cultivation through a blend of organic and chemical fertilizers, microbial inoculants and efficient practices. Growers and the environment all gain from this all surround strategy, which improves tomato output, quality and sustainability. In tomato variety Kashi Amrit, the integrated application of 100% Recommended Dose of Fertilizers (RDF)+*Azotobacter*+Phosphate Solubilizing Bacteria (PSB)+Vesicular Arbuscular Mycorrhizae (VAM) may give the highest fruit production together with favorable fruit set and quality characteristics [6]. According to Singh et al., tomato plants treated with 50% RDF+10 t ha^{-1} Farm Yard Manure (FYM)+5 t ha^{-1} poultry manure+biofertilizer had the highest number of leaves per plant, the most fruits per plant, the longest fruits per plant, the mean fruit weight, the yield per plant, the yield per plot and the highest ascorbic acid content [7]. According to Sepat et al., applying 50% Nitrogen Phosphorus Potassium (NPK)+FYM+*Azotobacter* resulted in values for $plant^{-1}$ height, branches, fruit clusters, fruit size, fruit weight and fruit yield $plant^{-1}$ in tomatoes [8]. By utilizing both organic and inorganic fertilizers in integrated nutrient management, the soil environment is enhanced, the nutrient level is maintained and the perfect conditions are created for the healthy development of tomatoes with large yields [9].

Brinjal: INM maximizes brinjal cultivation by blending organic and chemical fertilizers, biofertilizers and efficient practices. Customized nutrient programs are guided by soil analysis and organic inputs such as farmyard manure and compost are added to the soil to enhance it. Paswan et al., found that the fruit production metrics, such as fruit number per plant, fruit length, fruit diameter, fruit weight and fruit yield per hectare, considerably improved with soil treatments of 100% NPK+25% N through vermicompost [10]. Brinjal output is increased and soil health is maintained with the application of 50 kg nitrogen through urea and 50 kg nitrogen through chicken manure per acre [11]. Under vermicompost at 10 t/ha+75% RDF (NPK), noticeably higher values of yield characteristics were reported, including fruit yield per plot and fruit yield ton per hectare. Under control FYM at 20 t/h+75% RDF, however, noticeably minimum values of yield characteristics were noted [12].

Chilli: The effects of NPK, organic manure and their combination on the development, yield and nutrient absorption of chilli plants were studied by Altaf et al., [13]. The fruit's width, length and weight increased significantly, as did the plant's height at harvest, the number of branches per plant and the number of fruits per plant. In a similar manner, NPK 100%+FYM at 8 tons per hectare increased ascorbic acid concentration and oleoresin production. The yield was increased by using FYM at 8 tons per acre together with NPK 100%. In an experiment on integrated nitrogen management in chillies, Behera et al., sought to ascertain the effects of various combinations of nitrogen sources on chilli production, uptake, quality measures and economics [14]. Due to a 50/50 mixture of urea and vermicompost, T5-50% RDF+50% N *via* vermicompost exhibited the greatest levels of chilli production, including fruit output (14511.4 kg hectare) and nitrogen absorption by fruit (122.31 kg hectare). In terms of chilli quality attributes such oleoresin, capsaicin and ascorbic acid (100 percent RDF), T2 had the greatest B:C ratio.

Effect of integrated nutrient management in Cucurbitaceous vegetables

INM plays an important role in the cultivation of cucurbitaceous vegetables such as cucumbers, pumpkins, water melon, musk melon, bitter gourd, bottle gourd and pointed gourd etc. In an experiment conducted by Singh et al., cucumber plants fertilized with RDF+vermicompost at 5 t ha^{-1}+*Azotobacter* at 5 Kg ha^{-1}+PSB at 5 Kg ha^{-1} demonstrated the highest yield and related traits [15]. This is the best integrated nutrient management approach for protected cucumber cultivation under Punjabi conditions. In soil applications of lime +biofertilizer+vermicompost@5 t ha^{-1}+RDF (100%). Nayak et al., noted the length of the vine, vine girth, number of branches per plant, length of fruit, girth of fruit, single fruit weight, moisture content of fruit, total soluble solid, ascorbic acid and total sugar of pointed gourd [16]. According to Saravaiya et al., a mixture of 50% RDF (60:30:30 NPK kg ha^{-1}) and 10 tons of bio-compost ha^{-1} should be applied to the vine in order to achieve the greater fruit output of pointed gourds (17.93 t/ha) under the INM system [17]. The ascorbic acid, protein content, shelf life, total fruit yield and benefit:cost ratio of bitter gourd plants treated with 100% RDF of NPK+FYM at 5 t ha^{-1}+Biofertilizers at 4 kg ha^{-1} (*Azotobacter* and PSB) have all reached their maximums. According to research by Patel et al., soil treatments of 75% RDN by vermicompost+25% N through urea+*Azotobacter* at 2.5 L ha^{-1}+PSB at 2.5 L ha^{-1} in bitter gourd resulted in increased growth metrics, such as vine length at 45 Days After Sowing (DAS) and at 90 DAS with the number of branches per plant at 90 DAS [18]. Applications of 50% RDF+25% Recommended Dose of Nitrogen (RDN) from Bio-compost+*Azotobacter* 2.5 L ha^{-1}+PSB 2.5 L ha^{-1} were shown to be superior with regard to several growth and yield characteristics of ridge gourd [19]. According to Patel et al., applying 50% RDF and compost to the soil was shown to be the most effective treatment for improving tiny gourd growth and production [20].

Effect of integrated nutrient management in root vegetables

INM significantly impacts the cultivation of root vegetables, such as carrots, potatoes, radishes and beets. A study on the effects of biofertilizers on carrot growth and yield was conducted by Roshni et al., [21]. The experiment used a mix of several biofertilizers and the prescribed NPK level; the factorial Randomized Block Design (RBD) design included three replications. The combination of *Azospirillum*+PSB+*Azotobacter*+VAM generated a superior outcome in terms of growth and yield characteristics, with weight of root (121.99 g), yield per plot (5.12 kg) and yield per hac (194 qt/ha). Such biofertilizers would improve long-term soil health and assist pull in more nutrients for crop development and production when used in conjunction with traditional fertilizers. Shanu et al., conducted an experiment on carrots and the results showed that 25% RDF+50% FYM at 6 t ha^{-1}+50% vermicompost at 3 t ha^{-1}+50% rhizosphere bacteria produced the highest percentage of total soluble solids, ascorbic acid content, carotene content, cortex to core ratio, highest gross return, net return and best benefit cost ratio, while FYM at 12 t ha^{-1} produced the lowest percentage of cracked and forked roots [22]. Basnet et al., found that radish grown with 50% recommended N from chemical fertilizer and 50% N from chicken manure had the highest germination percentage, plant height, root length, root diameter and yield per hectare [23].

Effect of integrated nutrient management in bulb vegetables

Two significant bulbous vegetable crops grown in India are onions and garlic. Higher onion yields were seen when 52.5 kg of nitrogen were applied per hectare using *Azotobacter* biofertilizer. Yadav et al., shown that applications of RDF (50%)+vermicompost (50%) at 90 DAT were associated with the maximum plant height, bulb diameter, neck thickness, bulb length and number of leaves per plant [24]. In a study conducted on onion INM, Brinjh et al., discovered that the RDF 75%+vermicompost 25% produced the highest plant height, whereas the RDF 75%+*Azotobacter* 25% produced the longest leaves, most leaves, thickest necks and most scales. Whereas bulb diameter, length and yield were noted in 75% RDF+25% phosphobacteria [25]. With the application of 100% RDF+vermicompost at 6 t ha^{-1}+sulphur at 45 kg ha^{-1}, which was tested by Kumar et al., the maximum plant height, number of leaves at 120 Days After Planting (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 in garlic [11]. According to research by Patil et al., applying 120:60:60::N:P:K (RDF) kg/ha+20 t FYM/ha produced the greatest values of all growth parameters, including number of umbels/plant, number of seeds/umbel, weight of seeds/umbel, 1000 seed weight and maximum seed yield [26]. According to Mahanthesh et al., under irrigated circumstances throughout both the kharif and rabi seasons, the plants given *Azospirillum*+100% NPK (125:50:125 kg/ha) recorded the maximum plant height, number of leaves, neck thickness, bulb diameter, bulb weight and bulb yield [27]. Jawadagi et al., used RDF (125:50:125::N:P:K kg/ha)+FYM at 30 t/ha to onions and recorded the maximum leaf length and number of leaves [28]. According to Vachan et al., applying 100% RDF+*Azospirillum*+PSB produced the maximum bulb yield and yield components, including bulb weight, diameter and length, as well as gross and net returns [29]. The application of 60 kg Nitrogen (N)+36 kg Phosphorus pentoxide (P_2O_5)+60 kg Potassium oxide (K_2O) per hectare+vermicompost at 15 t/ha produced the highest plant height, stem diameter, leaf length, leaf breadth and yield components in garlic [30]. Verma et al., found that while the application of 5 t/ha vermicompost and 60 kg/ha sulphur together was superior in terms of weight of bulb, bulb yield and net returns of garlic, the application of 7.5 t/ha vermicompost and 90 kg/ha sulphur individually produced maximum plant height, number of leaves per plant, chlorophyll content in leaves, fresh weight of leaves, neck thickness, number of cloves per bulb, weight of bulb, bulb diameter and bulb yield [31]. According to research by Damse et al., the application of 75:40:40:40 kg Nitrogen Phosphorus Potassium Sulfur (NPKS)+7.5 t FYM+3.75 t poultry manure per hectare produced the highest bulb yield and benefit-cost ratio, indicating that garlic benefited from the application of lower doses of chemical fertilizers combined with one or two organic sources [32].

Effect of integrated nutrient management in leafy vegetables

Spinach growth and production were shown to be enhanced by using various combinations of nutritional sources. The best method for improving spinach growth and yield was determined to be an integrated application of 50% RDF+50% RDF using VC (vermicompost) [33]. Khadse et al., conducted a research with nine treatment combinations and four replications using a factorial randomized block design [34]. In addition to three vegetables-coriander, fenugreek and spinach-three nitrogen sources are employed in the treatments: 100% nitrogen from urea, 50% nitrogen from FYM+50% nitrogen from urea and 50% nitrogen from FYM+50% nitrogen from vermicompost+biofertilizers. All crop growth parameters were considerably boosted by using 50% nitrogen *via* FYM+50% urea, then 50% nitrogen *via* FYM+50% nitrogen *via* vermicompost+biofertilizers. 50% N *via* FYM+50% N *via* urea was the highest producing INM treatment; it was followed by 50% N *via* FYM+50% N vermicompost+biofertilizers.

Effect of integrated nutrient management in other vegetables

Okra: Applying NPK (100:50:50 kg/ha)+PSB (7.5 kg/ha) will maximize okra's growth and production. In addition to maintaining soil health in okra, the application of N, P and K at 37.5:37.5:37.5 kg per hectare and vermicompost at 1 t per hectare combined with microbial consortia at 3.5 kg per hectare enhanced fruit output. Okra yield was observed to increase using a combination of N, P and K at 50:50:50 kg per hectare with FYM at 10 t per hectare [11]. Maximum plant height and maximum number of leaves were also noted when Azotobacter+PSB+NPK at 120:60:60 was applied. The highest average fruit length was discovered when PSB+NPK at 100:50:50 was used. In terms of the various growth characteristics, treatment with Azotobacter+PSB+NPK at 100:50:50 resulted in yield and quality reports that were considerably higher [35].

DISCUSSION

Integrated Nutrient Management (INM) is a sustainable approach to nutrient management in vegetable crops, offering multifaceted benefits. By combining organic and chemical fertilizers, integrated nutrient management improves soil fertility and structure, optimizing nutrient supply. This approach reduces input costs, enhances crop quality and nutrition and contributes to overall sustainability. By promoting integrated nutrient management practices, it enhances vegetable yields, improves soil health and reduces environmental impact. By minimizing reliance on synthetic inputs, INM contributes to economic viability for growers while preserving natural resources. INM techniques produce ideal growth conditions for vegetable crops by boosting microbial activity, replenishing organic matter and improving soil structure. Therefore, INM practices are significant for a more productive and environmentally friendly vegetable farming sector. Therefore, researchers, policymakers and farmers should promote INM practices for a more productive and environmentally friendly vegetable farming sector [2]. The improvement in production and quality is one of the main impacts of INM on vegetable crops. INM guarantees that crops receive the vital nutrients needed for their growth and development by offering a balanced supply of nutrients. Using both organic and inorganic fertilizers together ensures a steady supply of nutrients for the duration of the growth season. Vegetables with this consistency have better sizes, colors and tastes and their yields are increased. For instance, it has been demonstrated that INM increases fruit size, improves lycopene content and raises the total marketable output in tomato growing [6]. Not only can INM increase crop production and quality, but it also plays a major role in promoting soil health. Aeration, water-holding ability and soil structure are all enhanced by adding more organic matter to the soil through the use of biofertilizers and organic manures. These enhancements encourage the growth of advantageous soil microbes, which are essential to the cycling of nutrients and their availability to plants. Consequently, the soil's long-term fertility is preserved, which lessens the requirement for chemical inputs during subsequent growth seasons.

INM can lessen reliance on chemical fertilizers, which is one of its main benefits. Even while chemical fertilizers are useful, they can be expensive and have unfavorable long-term consequences on the ecosystem and soil health. Without sacrificing the yield of their vegetable crops, farmers can lower the total amount of chemical fertilizers applied by using organic sources of nutrients, such as compost or farmyard manure. In addition to lowering input costs, this decrease in chemical fertilizer use also lessens the environmental risks such as soil deterioration, water pollution and greenhouse gas emissions that come with over-fertilizer application. Moreover, by reducing the negative environmental effects of intensive farming, INM supports sustainable agricultural practices. It promotes the use of environmentally benign and sustainable fertilizer sources, which helps ensure the long-term viability of agricultural systems. Furthermore, INM-grown vegetable crops frequently exhibit greater resistance to biotic and abiotic stressors. Because of the balanced nutrient supply that INM offers, plants are more resilient to environmental challenges like drought and severe temperatures as well as diseases and pests. Farmers may profit greatly from INM in terms of the economy. By lowering the demand for pricey chemical fertilizers, integrating several nutrition sources can save costs. Farmers may lower their total input costs while maintaining or even increasing crop yields by using locally sourced organic manures and biofertilizers. In addition to its environmental advantages, INM's higher profitability makes it a desirable choice for vegetable producers [32].

Future aspects of integrated nutrient management

Future demand for Integrated Nutrient Management (INM) in vegetable production is expected to rise due to the growing importance of sustainability in agriculture. INM offers a holistic approach to nutrient management, improving soil health, reducing environmental impact and encouraging ecosystem resilience. With population growth and climate change challenges, INM is significant for crop resilience and adaptation. The development of INM procedures is driven by customer demands for premium, sustainably produced vegetables. Data-driven decision-making and precision agriculture can maximize fertilizer applications and increase vegetable production output.

CONCLUSION

Integrated Nutrient Management (INM) is a sustainable approach to nutrient management in vegetable crops. It involves combining organic and chemical fertilizers, enhancing soil fertility and structure and optimizing nutrient supply. This approach reduces input costs, improves crop quality and contributes to overall sustainability. By promoting INM practices, it enhances vegetable yields, improves soil health and reduces environmental impact, promoting economic viability and preserving natural resources. By combining bio-fertilizer and organic manure in moderation, INM promotes soil fertility maintenance and sustainable vegetables production. By combining natural and artificial fertilizers, INM ensures ecologically benign and sustainable crop production, making it a significant part of vegetable crop management. INM's capacity to promote soil health is one of its main advantages. INM techniques produce the ideal growth conditions for vegetable crops by boosting microbial activity, replenishing organic matter and improving soil structure.

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