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Impact of Nutrient Management on Okra (*Abelmoschus esculentus* L.) Growth and Yield: A Comprehensive Review

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ABSTRACT: Integrated nutrient management (INM) significantly enhances okra (*Abelmoschus esculentus* L.) growth and yield attributes, including plant height, number of leaves, leaf area, stem diameter, biomass accumulation, number of pods, pod length, pod weight, and total yield per hectare. By integrating organic manures such as farmyard manure, vermicompost, and poultry manure with inorganic fertilizers and biofertilizers like *Azotobacter*, *Azospirillum*, and phosphate-solubilizing bacteria, INM improves soil fertility, nutrient uptake, and microbial activity, fostering robust vegetative growth and higher yields. Research from 2010 to 2021 highlights INM's role in promoting sustainable okra production through enhanced nitrogen fixation, phosphorus solubilization, and improved soil structure. Organic manures provide slow-release nutrients, while biofertilizers boost nutrient availability, and inorganic fertilizers ensure immediate nutrient supply, creating a synergistic effect. However, challenges in adopting INM include the high cost and limited availability of organic manures and biofertilizers, particularly for smallholder farmers. Soil and climatic variability necessitate site-specific strategies, complicating uniform application. Overuse of inorganic fertilizers within INM risks nutrient imbalances, while labor-intensive preparation of organic amendments may deter adoption. Addressing these challenges through cost-effective INM formulations, scalable biofertilizer production, and policy support for organic input subsidies is essential to ensure sustainable okra cultivation and economic benefits for farmers.

Keywords: Integrated nutrient management, okra, growth attributes, yield attributes, organic manures, biofertilizers, sustainable agriculture.

INTRODUCTION

Okra (*Abelmoschus esculentus* L.), a member of the Malvaceae family, is a significant vegetable crop widely grown in tropical and subtropical regions for its nutrient-rich pods, which are high in vitamins, minerals, and dietary fiber (Gemede *et al.*, 2015). As a staple in various cuisines and an economically important crop for smallholder farmers, okra's leaves, pods, and seeds are valued for both culinary and medicinal purposes, including the use of its mucilage as a plasma replacement. However, low soil fertility, driven by continuous cropping, poor land management, and inadequate nutrient replenishment, often limits okra productivity (Kumar *et al.*, 2015). This has spurred extensive research into nutrient management strategies to enhance okra growth, yield, and quality while promoting sustainable agriculture.

Integrated nutrient management (INM), which combines organic manures, inorganic fertilizers, and biofertilizers, has gained prominence as an effective approach to improve soil fertility and okra performance (Sachan *et al.*, 2017; Yadav *et al.*, 2017). INM ensures a balanced supply of macro- and micronutrients, enhancing vegetative growth, pod yield, and nutrient uptake efficiency compared to exclusive use of chemical fertilizers (Kumar *et al.*, 2015). For example, combining farmyard manure (FYM), vermicompost, or poultry manure with reduced doses of nitrogen, phosphorus, and potassium (NPK) fertilizers has been shown to increase pod size, number, and total yield (Meena *et al.*, 2016). Biofertilizers, such as Azotobacter and phosphate-solubilizing bacteria (PSB), further improve nutrient availability, supporting sustainable production systems (Sachan *et al.*, 2017; Sharma *et al.*, 2018).

The overreliance on chemical fertilizers poses environmental risks, including soil degradation, nutrient leaching, and water pollution, highlighting the importance of INM (Kumar *et al.*, 2015). Organic amendments like FYM and vermicompost enhance soil structure, water-holding capacity, and microbial activity, contributing to long-term soil health (Yadav *et al.*, 2017). Studies from 2015 to 2021 demonstrate that INM practices, tailored to specific soil types and agroecological conditions, optimize okra growth and yield across diverse regions, such as India and Nigeria (Gemede *et al.*, 2015). Field trials have reported increased plant height, pod number, and yield with combined organic and inorganic nutrient applications (Meena *et al.*, 2016; Sharma *et al.*, 2018).

This review synthesizes research till 2021 to assess the impact of nutrient management on okra growth and yield. It examines the efficacy of INM, organic and inorganic fertilizers, and biofertilizers in improving productivity while addressing sustainability challenges. By analyzing field experiments, soil nutrient dynamics, and crop responses, the review provides actionable insights for farmers, researchers, and policymakers to advance sustainable okra cultivation. The focus on studies from this period ensures relevance to modern agricultural practices and lays a foundation for future innovations in nutrient management.

MATERIAL AND METHODS

Methodology

This review was conducted by systematically collecting and analyzing scientific literature related to nutrient management in okra (*Abelmoschus esculentus* L.). A comprehensive search was carried out across academic databases including Google Scholar, ScienceDirect, Scopus, and Web of Science, covering the period from 2000 to 2021. The search used combinations of keywords such as "okra," "nutrient management," "integrated nutrient management," "organic fertilizers," "biofertilizers," "growth," "yield," and "quality." Boolean operators and truncation techniques were applied to ensure a broad and relevant selection of publications. Only peer-reviewed journal articles, theses, conference proceedings, and institutional reports written in English were considered.

Studies were selected based on their relevance to okra nutrient management practices and their inclusion of quantitative data on growth, yield, quality, or economic parameters. Irrelevant studies, duplicate records, and non-English publications were excluded. The selected literature was categorized into thematic areas: organic fertilizers, inorganic fertilizers, biofertilizers, and integrated nutrient management (INM). Key data were extracted and summarized to identify trends, gaps, and the effectiveness of different nutrient sources. The findings were synthesized qualitatively to provide a comprehensive understanding of nutrient management's impact on okra cultivation.

RESULTS AND DISCUSSION

A. Growth Attributes and Nutrient Management

Plant Height. Plant height, a primary indicator of vegetative vigor, is significantly enhanced by balanced nutrient supply through INM. Studies show that combining organic manures like farmyard manure (FYM) or vermicompost with inorganic fertilizers promotes greater plant height than sole chemical applications. Similarly, Singh *et al.* (2010) found that integrating FYM with 75% NPK increased plant height by 18% compared to controls. The sustained nutrient release from organic sources, coupled with nitrogen-driven cell elongation, drives these improvements (Kumar *et al.*, 2015; Anisa *et al.*, 2016). Ingle *et al.* (2008) reported a plant height of 68.13 cm with 100% N (50 kg/ha) combined with Azotobacter and PSB, noting that biofertilizers enhanced nitrogen and phosphorus availability, critical for shoot elongation. Sahu *et al.* (2014) observed that PSB, Azotobacter, and a full dose of nitrogen with half phosphorus significantly increased plant height, likely due to improved nutrient solubilization and uptake. Gupta *et al.* (2018) found that a combination of vermicompost and half NPK (T_3 treatment) was most effective, achieving taller plants than controls, attributed to vermicompost's ability to enhance soil microbial load and nutrient cycling. Naidu *et al.* (2019) reported that organic manures, including compost, increased microbial populations in soil, leading to early vegetative growth and taller plants, with heights exceeding 100 cm in some treatments.

Number of Leaves and Leaf Area. The number of leaves and leaf area are pivotal for photosynthesis, directly impacting biomass production and yield potential in okra. Integrated nutrient management (INM) significantly enhances these parameters by improving nutrient availability and soil health. Sachan *et al.* (2017) reported that okra treated with poultry manure (5 t/ha), Azotobacter, and phosphate-solubilizing bacteria (PSB) produced 25-30 leaves per plant, compared to 15-20 leaves in plots treated with chemical fertilizers alone, highlighting the role of organic and microbial inputs in promoting leaf development. Bharadiya *et al.* (2007) found that applying 50% of the recommended dose of fertilizer (RDF) combined with 50% nitrogen through neem cake resulted in the highest number of leaves per plant, likely due to neem cake's slow-release nitrogen and growth-promoting compounds. Akanbi *et al.* (2007) observed a significant increase in leaf counts with pig droppings, attributing this to enhanced soil moisture and nutrient retention, which support leaf initiation and expansion. Garhwal *et al.* (2007) reported that nitrogen application at 90 kg/ha through vermicompost and urea significantly increased leaf area, facilitating greater photosynthetic capacity. Kadlag *et al.* (2010) recorded 32.36 leaves per plant with Azotobacter at 3 kg/ha, noting that nitrogen fixation by the biofertilizer enhanced leaf production. Shelar and Kadam (2011) found that a combination of 50% nitrogen through neem cake and 50% through RDF produced a leaf area of 293.74 cm², significantly higher than controls, due to improved nutrient uptake and soil fertility. Hisham *et* *al.* (2014) reported that FYM at 25 t/ha increased the number of leaves and leaf area, driven by higher soil organic matter and water-holding capacity. Similarly, Chitra *et al.* (2015) noted that seed treatment with PSB enhanced leaf number and total chlorophyll content, improving photosynthetic efficiency. The synergistic effects of organic manures, which provide sustained nutrient release, and biofertilizers, which enhance phosphorus and nitrogen availability, create optimal conditions for leaf growth (Yadav *et al.,* 2017; Attia *et al.,* 2011). Enhanced soil microbial activity, as reported by Naidu *et al.* (2019), further supports leaf development by improving nutrient cycling and root nutrient absorption, ensuring robust canopy development critical for okra's productivity.

Stem Diameter. Stem diameter, indicative of structural strength and nutrient transport capacity, is improved by INM. Singh *et al.* (2010) noted that biofertilizers like Azospirillum combined with FYM increased stem girth by 15%. Enhanced root development and nitrogen fixation from biofertilizers contribute to thicker stems, improving plant stability and pod-bearing capacity (Kumar *et al.,* 2015; Anisa *et al.,* 2016). These findings highlight INM's role in supporting robust stem growth.

Biomass Accumulation. Biomass accumulation, encompassing shoot and root dry weight, is a comprehensive measure of okra's growth response to nutrient management, reflecting the plant's ability to convert nutrients into vegetative and reproductive tissues. INM significantly enhances biomass by improving soil fertility and nutrient uptake. Yadav *et al.,* (2017) reported a 25% increase in shoot dry weight with vermicompost (4 t/ha) and 50% NPK, attributing this to improved soil organic matter and nutrient availability. Kumar *et al.* (2013) recorded a fresh weight of 352.2 g and dry weight of 286.1 g per plant with 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, highlighting the role of zinc in enhancing metabolic processes and biomass production. Dademal and Dongale (2004) found that FYM at 7.5 t/ha significantly increased dry matter production compared to no manure or low-dose vermicompost, as FYM improved soil structure and nutrient retention, facilitating robust root and shoot growth. Gupta *et al.* (2018) observed that a combination of vermicompost and half NPK (T3 treatment) was most effective for biomass accumulation, with plants exhibiting higher fresh and dry weights than controls. The authors noted that vermicompost's high microbial activity and nutrient content enhanced soil fertility, supporting vigorous growth. Naidu *et al.* (2019) reported that organic manures, such as compost, increased soil microbial populations, leading to enhanced nutrient cycling and a significant boost in biomass, with some treatments yielding 20-30% higher dry matter than inorganic fertilizer-only plots. Prabu *et al.* (2002) found that FYM application increased dry matter content, with post-harvest soil showing higher organic carbon, nitrogen, phosphorus, and potassium levels, indicating sustained fertility that supports biomass accumulation. Akanbi *et al.,* (2007) reported that pig droppings significantly increased plant fresh weight, likely due to improved soil moisture and nutrient availability. Attia *et al.* (2011) noted that compost (10 t/ha) with biofertilizers like PSB enhanced root and shoot biomass by improving soil organic matter and phosphorus uptake. These findings underscore INM's ability to enhance biomass through synergistic nutrient supply, improved soil health, and microbial activity (Gemede *et al.,* 2015; Sharma *et al.,* 2018). The mechanisms driving biomass accumulation include enhanced nutrient availability from organic manures, which provide slow-release nitrogen, phosphorus, and potassium, and biofertilizers, which increase nitrogen fixation and phosphorus solubilization (Naidu *et al.,* 2019; Kumar *et al.,* 2013). Improved soil structure from organic amendments enhances root proliferation, while microbial activity supports nutrient cycling, as noted by Gupta *et al.* (2018). These factors collectively result in higher biomass, critical for supporting reproductive growth and yield.

Mechanisms Underlying Growth Enhancement. INM enhances okra growth through multiple mechanisms. Organic manures provide slow-release nutrients, improving soil physical properties like porosity and water retention (Singh *et al.,* 2010). Biofertilizers, including Azotobacter and PSB, increase nitrogen fixation and phosphorus solubility, critical for vegetative growth (Sachan *et al.,* 2017; Attia *et al.,* 2011). Inorganic fertilizers ensure immediate nutrient availability, complementing organic sources (Kumar *et al.,* 2015). Enhanced soil microbial activity under INM supports nutrient cycling, further boosting growth attributes (Yadav *et al.,* 2017; Anisa *et al.,* 2016). These synergistic effects result in vigorous plant development.

B. Yield Attributes and Nutrient Management

Number of Pods per Plant. The number of pods per plant is a primary yield attribute in okra, directly influencing total productivity and economic returns. Integrated nutrient management (INM) significantly enhances this parameter by optimizing nutrient availability, promoting robust vegetative growth, and supporting reproductive development. Sachan *et al.* (2017) reported that okra treated with poultry manure (5 t/ha), Azotobacter, and phosphate-solubilizing bacteria (PSB) produced an average of 18-22 pods per plant, compared to 12-15 pods in plots with only chemical fertilizers. The organic and microbial inputs improved soil fertility and nutrient uptake, leading to increased flowering and pod set. Kumar *et al.* (2013) recorded 16.5 pods per plant with a combination of 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, highlighting the role of zinc in enhancing reproductive efficiency. Bharadiya *et al.* (2007) found that 50% recommended dose of fertilizer

(RDF) combined with 50% nitrogen through neem cake resulted in 17.8 pods per plant, attributed to neem cake's growth-promoting compounds and sustained nitrogen release. Kadlag *et al.* (2010) observed 20.4 pods per plant with Azotobacter at 3 kg/ha, noting that nitrogen fixation enhanced flower retention and pod formation. Gupta *et al.* (2018) found that vermicompost with half NPK yielded 18.6 pods per plant, driven by increased microbial activity and nutrient cycling. Hisham *et al.* (2014) reported that FYM at 25 t/ha increased pod number to 21 per plant, linked to higher soil organic matter and water-holding capacity, which supported sustained reproductive growth. Naidu *et al.* (2019) noted that organic manures like compost boosted pod numbers by 15-20% compared to inorganic fertilizers, due to enhanced microbial populations and nutrient availability. Prabu *et al.* (2002) observed that FYM application increased pod number, with post-harvest soil showing elevated nutrient levels, indicating sustained fertility that supports pod production. Attia *et al.* (2011) reported that compost (10 t/ha) with PSB resulted in 19.2 pods per plant, as phosphorus solubilization improved reproductive development. Sharma *et al.*, (2018) found that INM treatments with vermicompost and biofertilizers produced 20-22 pods per plant, compared to 13-15 with chemical fertilizers, emphasizing the synergistic effects of organic and microbial inputs. The mechanisms driving increased pod numbers include enhanced nitrogen and phosphorus availability, which support flower initiation and fruit set, and improved soil health, which ensures sustained nutrient supply during pod development (Yadav *et al.,* 2017; Anisa *et al.,* 2016). Organic manures improve soil water retention, reducing stress during flowering, while biofertilizers enhance nutrient uptake, leading to higher pod retention and yield.

Pod Weight. Pod length is a critical yield attribute in okra, influencing marketability and consumer preference, as longer pods are often preferred for culinary purposes. INM significantly increases pod length by providing balanced nutrition and supporting optimal pod development. Kumar *et al.* (2013) reported an average pod length of 14.8 cm with 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, compared to 11.2 cm in controls, attributing this to zinc's role in cell elongation and pod growth. Sachan *et al.* (2017) recorded pod lengths of 16-18 cm with poultry manure, *Azotobacter*, and PSB, driven by enhanced phosphorus availability for pod development. Kadlag *et al.* (2010) reported pod lengths of 15.7 cm with *Azotobacter* at 3 kg/ha, noting that nitrogen fixation supported vigorous pod growth. Gupta *et al.* (2018) observed that vermicompost with half NPK produced pods averaging 16.2 cm, linked to improved soil microbial activity and nutrient uptake. Hisham *et al.* (2014) found that FYM at 25 t/ha resulted in pod lengths of 15.9 cm, attributed to increased soil organic matter and water retention, which supported pod elongation. Naidu *et al.* (2019) reported that organic manures increased pod length by 10-15% compared to inorganic fertilizers, due to enhanced nutrient cycling and microbial activity. Prabu *et al.* (2002) noted that FYM application led to longer pods, with post-harvest soil showing higher nutrient levels, indicating sustained fertility for pod development. Attia *et al.* (2011) found that compost (10 t/ha) with PSB produced pods averaging 16.5 cm, as phosphorus solubilization enhanced cell division and elongation. Sharma *et al.* (2018) reported pod lengths of 15-17 cm with INM treatments, compared to 11-13 cm with chemical fertilizers, highlighting the role of organic inputs in pod quality. Bharadiya *et al.* (2007) observed that 50% RDF with neem cake produced pods of 15.4 cm, due to slow-release nitrogen and growth-promoting compounds. The mechanisms driving increased pod length include enhanced nutrient availability, particularly nitrogen and phosphorus, which support cell division and elongation, and improved soil health, which ensures consistent nutrient supply during pod growth (Yadav *et al.*, 2017; Anisa *et al.*, 2016). Organic manures improve soil structure, reducing stress during pod development, while biofertilizers enhance nutrient uptake, leading to longer, marketable pods.

Pod Weight. Pod weight is a key yield attribute in okra, reflecting the plant's ability to allocate resources to reproductive structures and directly impacting total yield. INM significantly increases pod weight by enhancing nutrient availability and supporting robust pod development. Kumar *et al.*, (2013) reported an average pod weight of 18.6 g with 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, compared to 13.4 g in controls, due to zinc's role in metabolic processes and pod filling. Sachan *et al.* (2017) recorded pod weights of 20-22 g with poultry manure, *Azotobacter*, and PSB, linked to improved phosphorus and nitrogen uptake. Kadlag *et al.* (2010) reported pod weights of 19.8 g with *Azotobacter* at 3 kg/ha, noting that nitrogen fixation enhanced pod filling. Gupta *et al.* (2018) observed that vermicompost with half NPK produced pods averaging 20.3 g, attributed to increased microbial activity and nutrient cycling. Hisham *et al.* (2014) found that FYM at 25 t/ha resulted in pod weights of 19.5 g, due to enhanced soil organic matter and water retention. Naidu *et al.* (2019) reported that organic manures increased pod weight by 15-20% compared to inorganic fertilizers, driven by improved nutrient availability. Prabu *et al.* (2002) noted that FYM application led to heavier pods, with post-harvest soil showing elevated nutrient levels. Attia *et al.* (2011) found that compost (10 t/ha) with PSB produced pods averaging 20.7 g, as phosphorus solubilization enhanced pod development. Sharma *et al.* (2018) reported pod weights of 19-21 g with INM treatments, compared to 13-15 g with chemical fertilizers, emphasizing the role of organic inputs. Bharadiya *et al.* (2007) observed that 50% RDF with neem cake produced pods of 19.3 g, due to sustained nitrogen release. The mechanisms driving increased pod weight include enhanced nutrient availability, particularly nitrogen and potassium, which support pod filling, and improved soil health, which ensures consistent nutrient supply during pod development (Yadav *et al.*, 2017; Anisa *et al.*, 2016). Organic manures and biofertilizers enhance nutrient uptake and reduce stress, leading to heavier pods and higher yields.

Pod Length. Pod length is a critical yield attribute in okra, influencing marketability and consumer preference, as longer pods are often preferred for culinary purposes. INM significantly increases pod length by providing balanced nutrition and supporting optimal pod development. Kumar *et al.* (2013) reported an average pod length of 14.8 cm with 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, compared to 11.2 cm in controls, attributing this to zinc's role in cell elongation and pod growth. Sachan *et al.* (2017) recorded pod lengths of 16-18 cm with poultry manure, *Azotobacter*, and PSB, driven by enhanced phosphorus availability for pod development. Kadlag *et al.* (2010) reported pod lengths of 15.7 cm with *Azotobacter* at 3 kg/ha, noting that nitrogen fixation supported vigorous pod growth. Gupta *et al.* (2018) observed that vermicompost with half NPK produced pods averaging 16.2 cm, linked to improved soil microbial activity and nutrient uptake. Hisham *et al.* (2014) found that FYM at 25 t/ha resulted in pod lengths of 15.9 cm, attributed to increased soil organic matter and water retention, which supported pod elongation. Naidu *et al.* (2019) reported that organic manures increased pod length by 10-15% compared to inorganic fertilizers, due to enhanced nutrient cycling and microbial activity. Prabu *et al.* (2002) noted that FYM application led to longer pods, with post-harvest soil showing higher nutrient levels, indicating sustained fertility for pod development. Attia *et al.* (2011) found that compost (10 t/ha) with PSB produced pods averaging 16.5 cm, as phosphorus solubilization enhanced cell division and elongation. Sharma *et al.* (2018) reported pod lengths of 15-17 cm with INM treatments, compared to 11-13 cm with chemical fertilizers, highlighting the role of organic inputs in pod quality. Bharadiya *et al.* (2007) observed that 50% RDF with neem cake produced pods of 15.4 cm, due to slow-release nitrogen and growth-promoting compounds. The mechanisms driving increased pod length include enhanced nutrient availability, particularly nitrogen and phosphorus, which support cell division and elongation, and improved soil health, which ensures consistent nutrient supply during pod growth (Yadav *et al.*, 2017; Anisa *et al.*, 2016). Organic manures improve soil structure, reducing stress during pod development, while biofertilizers enhance nutrient uptake, leading to longer, marketable pods.

Total Yield. Total yield per hectare is the ultimate measure of okra productivity, integrating the effects of all growth and yield attributes. INM significantly increases total yield by optimizing nutrient supply, enhancing vegetative growth, and supporting reproductive output. Kumar *et al.* (2013) reported a yield of 12.5 t/ha with 75 kg/ha N, 40 kg/ha P_2O_5, 40 kg/ha K_2O, 5 t/ha vermicompost, and 20 kg/ha $ZnSO_4$, compared to 8.7 t/ha in controls, due to improved pod number, length, and weight. Sachan *et al.* (2017) recorded yields of 14-15 t/ha with poultry manure, *Azotobacter*, and PSB, linked to increased pod production and weight. Kadlag *et al.* (2010) reported a yield of 13.8 t/ha with *Azotobacter* at 3 kg/ha, noting that nitrogen fixation boosted pod formation. Gupta *et al.* (2018) observed that vermicompost with half NPK produced 14.2 t/ha, attributed to improved soil health and nutrient uptake. Hisham *et al.* (2014) found that FYM at 25 t/ha resulted in 13.5 t/ha, due to enhanced soil organic matter. Naidu *et al.* (2019) reported that organic manures increased yield by 20-25% compared to inorganic fertilizers, driven by improved nutrient cycling. Prabu *et al.* (2002) noted that FYM application led to higher yields, with post-harvest soil showing sustained fertility. Attia *et al.* (2011) found that compost (10 t/ha) with PSB produced 14.7 t/ha, as phosphorus solubilization enhanced yield attributes. Sharma *et al.* (2018) reported yields of 13-15 t/ha with INM treatments, compared to 9-11 t/ha with chemical fertilizers. The mechanisms driving increased yield include enhanced nutrient availability, improved soil health, and synergistic effects of organic and microbial inputs, ensuring robust growth and high productivity (Yadav *et al.*, 2017; Anisa *et al.*, 2016). Bhushan *et al.* (2013) reported that Azotobacter with half NPK significantly enhanced okra yield, recording maximum fruit (183.6 q/ha) and seed yield (34.9 q/ha) in Hisar Unnat. Singh *et al.* (2019) observed that INM with Azotobacter + PSB + full NPK (T12) significantly improved okra yield in cv. Kashi Pragati, outperforming lower fertilizer and microbial input treatments. Dutta *et al.* (2019) reported that okra yield significantly increased (80.58 q/ha) with FYM, vermicompost, Azotobacter, PSB, and rock phosphate, highlighting the synergistic benefits of organic nutrient sources on growth and productivity. Meena *et al.* (2019) found that RDF + vermicompost significantly improved okra yield (19.56 t/ha) and fruit traits, likely due to enhanced nutrient solubilization and uptake, compared to the control treatment.

Mechanisms Underlying Yield Enhancement. INM enhances yield attributes through multiple mechanisms. Organic manures like FYM, vermicompost, and poultry manure provide slow-release nutrients, improving soil physical properties such as water-holding capacity and aeration (Singh *et al.*, 2010). Biofertilizers, including *Azotobacter*, *Azospirillum*, and PSB, enhance nitrogen fixation and phosphorus solubilization, ensuring nutrient availability during critical growth stages (Sachan *et al.*, 2017; Attia *et al.*, 2011). Inorganic fertilizers supply immediate nutrients, complementing organic sources to meet peak demand during pod development (Kumar *et al.,* 2015; Gaur *et al.,* 2014). Enhanced soil microbial activity under INM supports nutrient cycling and root health, leading to higher pod production and quality (Yadav *et al.,* 2017; Adekiya & Agbede 2016). These synergistic effects result in robust yield attributes and increased total productivity.

CONCLUSIONS

Nutrient management, particularly INM, significantly enhances okra's growth attributes, including plant height, leaf number, stem diameter, and biomass. Research from 2010 to 2021 underscores the efficacy of combining organic manures, inorganic fertilizers, and biofertilizers to improve soil fertility and plant vigor. These strategies offer sustainable solutions for optimizing okra productivity while addressing environmental concerns. Continued research and tailored INM practices can further enhance growth attributes, supporting food security and farmer livelihoods.

Nutrient management, particularly INM, significantly enhances okra's yield attributes, including pod number, pod weight, pod length, and total yield. Research from 2010 to 2021, encompassing diverse studies, underscores the efficacy of combining organic manures, inorganic fertilizers, and biofertilizers to optimize soil fertility and plant productivity. By improving nutrient uptake, soil health, and plant vigor, INM offers a sustainable approach to boost okra production while addressing environmental concerns. Overcoming challenges like input availability and variability through research and policy support can further enhance yield attributes, ensuring economic and ecological benefits for farmers and global food systems.

Challenges and Considerations. Despite INM's benefits, challenges include the availability and cost of organic manures and biofertilizers, particularly for resource-constrained farmers. Soil and climatic variability necessitate site-specific INM strategies (Gemede *et al.,* 2015). Overuse of inorganic fertilizers within INM can cause nutrient imbalances, requiring precise application (Sharma *et al.,* 2018; Singh *et al.,* 2010). Future research should focus on cost-effective INM formulations and scalable practices tailored to diverse agroecological conditions.

Despite INM's benefits, challenges include the high cost and limited availability of organic manures and biofertilizers, particularly for smallholder farmers (Adekiya & Agbede 2016). Soil and climatic variability necessitate tailored INM strategies, complicating universal recommendations (Gemede *et al.,* 2015; Mishra *et al.,* 2017). Overuse of inorganic fertilizers within INM can lead to nutrient imbalances and environmental issues like leaching (Sharma *et al.,* 2018; Singh *et al.,* 2010). The labor-intensive preparation and application of organic amendments may also hinder adoption (Anisa *et al.,* 2016). Future research should focus on cost-effective INM formulations, scalable biofertilizer production, and region-specific guidelines to address these challenges.

FUTURE SCOPE

The findings from this review highlight the significant role of integrated and balanced nutrient management in enhancing the growth, yield, and quality of okra. However, future research should focus on location-specific nutrient management strategies, considering variations in soil type, climate, and cropping systems. There is a need to explore site-specific nutrient recommendations using soil testing and crop nutrient modeling for precision farming practices.

Further studies should examine the long-term effects of organic and biofertilizer use on soil health and okra productivity, including microbial diversity and carbon sequestration. The integration of nano-fertilizers, liquid biofertilizers, and slow-release formulations also warrants investigation for their potential in improving nutrient-use efficiency. Additionally, the use of remote sensing and decision support systems for real-time nutrient management in okra could lead to more sustainable and cost-effective practices. Bridging research with farmer-level demonstrations and capacity building will be essential to promote the adoption of improved nutrient management techniques at the field level.

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Conflict of Interest. None.

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