

## **ORGANIC AND BIOFERTILIZER APPLICATIONS IN VEGETABLE PRODUCTION: A SHORT REVIEW**

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### **ABSTRACT**

Alternatives to synthetic fertilizers that maintain productivity and improve soil health are needed for the sustainable expansion of vegetable production. This paper combines recent advances in organic fertilizers, biofertilizers, and integrated nutrient management (INM) in the production of vegetable and horticultural crops. Organic amendments, especially vermicompost, and microbial inoculants (plant growth-promoting rhizobacteria and arbuscular mycorrhizal fungi) have consistently improved growth, yield, and seedling vigor over the sole use of chemical fertilizers in leafy vegetables (amaranthus, spinach, and lettuce), fruiting vegetables (okra, tomato, brinjal, chili pepper, and cucumber), and nursery production systems. Integrated approaches (50% organic + 50% inorganic inputs) yielded the highest yields (85–120% improvement over control) and improved soil biological quality. Vermicompost application increased fresh weight by 70–95% and leaf production by 35–45% compared with the control. Biofertilizer seed inoculation improved the germination percentage by 10–22%, reduced the mean germination time by 15–35%, and increased the seedling vigor index by 25–50%. These findings support the adoption of bio-organic strategies in mixed crop-livestock systems and commercial horticulture to achieve sustainable productivity in these systems.

**Keywords:** *organic fertilizers, vermicompost, biofertilizers, integrated nutrient management, PGPR, AMF, vegetable production, sustainable agriculture*

### **INTRODUCTION**

Global vegetable production faces two simultaneous challenges: meeting the growing demand for food and doing so in an environmentally sustainable manner. Chemical fertilizers have increased productivity but also caused soil deterioration, nutrient imbalances, greenhouse gas emissions, and water contamination. Organic fertilizers (compost, farmyard manure (FYM), and vermicompost) are sustainable options because of their ability to deliver nutrients, build soil organic matter, improve water retention, and maintain beneficial microbial populations (Agbede *et al.*, 2014). Plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal fungi (AMF) are biofertilizers that improve nutrient availability and plant stress tolerance through symbiotic interactions.

Integrated nutrient management (INM), which employs organic inputs alongside reduced inorganic inputs, has proven to be an effective strategy that frequently equals or exceeds the yields obtained from exclusive reliance on chemical fertilizers while simultaneously improving soil health and economic profitability (Tonfack *et al.*, 2009). Despite the growing body of information, species-specific responses and appropriate integration methodologies remain inadequately characterized in vegetable crops.

This review synthesizes recent experimental evidence on the comparative effects of organic fertilizers, biofertilizers, and integrated approaches on vegetative growth, yield, flowering, and seedling vigor in major vegetable and horticultural species, with an emphasis on practical applications for sustainable production systems.

## **2. Organic Fertilizers and Integrated Nutrient Management in Leafy Vegetables**

### **2.1 Growth and Yield Responses**

Leafy vegetables, including amaranthus (*Amaranthus* sp.), spinach (*Spinacia oleracea*), and lettuce (*Lactuca sativa*), are high-value crops with short growth cycles and intensive nutrient requirements. Recent field trials have demonstrated that fertilizer sources significantly influence both biomass accumulation and leaf production, with clear differentiation among chemical, organic, and integrated treatments of the latter. Integrated fertilizer management (50% urea + 50% compost by nitrogen content) consistently produces the highest fresh weight across leafy crops, achieving 210 g/plant in lettuce, 175 g/plant in spinach, and 165 g/plant in amaranthus, representing yield increases of 85–120% over unfertilized controls and 15–30% over sole chemical fertilizers (urea or NPK). Vermicompost was the most effective single organic input, enhancing the fresh weight by 70–95% and leaf number by 35–45% compared with the control.

Chemical fertilizers (urea and NPK) provide rapid nutrient release, promoting biomass accumulation; however, they generally produce fewer leaves than organic treatments. Urea and NPK increased leaf number by only 10–18% compared to the control, which was significantly less than the 30–45% increases observed with vermicompost or integrated management. This pattern reflects a balanced micronutrient supply and growth-regulating compounds provided by organic amendments, both of which support leaf initiation and expansion.

### **2.2 Mechanisms and Soil Health Implications**

The advantages of organic and integrated therapies are not solely due to the provision of nutrients but also due to several other factors. Organic amendments improve soil physical properties (reduced bulk density and increased water retention), cation exchange capacity, and support diverse microbial communities involved in nutrient cycling, disease suppression, and the production of bioactive compounds (Agbede et al., 2014). Vermicompost, which is enriched with humic substances, plant hormones, and beneficial microbial metabolites, is particularly effective because of its high nutrient concentration, better nutrient availability, and enhanced microbial populations that improve nutrient solubilization and uptake (Lim et al. 2015).

Long-term sustainability considerations favor organic and integrated pest-management approaches. Although chemical fertilizers increase plant-available nitrogen in the short term, they do not significantly increase soil organic matter, phosphorus, or potassium levels, and their continuous use often results in soil acidification, micronutrient depletion, and reduced microbial diversity. Combined organic and inorganic applications provided a more sustained mineral-N supply over the growth period a faster increase in microbial biomass than inorganic fertilizer alone.

### **2.3 Species-Specific Responses**

Leafy vegetables exhibit differential responses to different fertilizer sources, warranting crop-specific management strategies. Lettuce showed the highest biomass gains in absolute terms under integrated management, whereas amaranthus was particularly responsive to organic amendments in terms of leaf number, producing 18–24 leaves per plant under optimal organic or integrated treatments. Spinach benefits from synchronizing nitrogen release with crop demand via combined small inorganic additions and predominantly organic nitrogen, which increases the fresh weight while maintaining favorable vitamin C levels and safe nitrate concentrations in the leaves.

## **3. Organic and Inorganic Fertilizer Effects on Fruiting Vegetables**

### **3.1 Vegetative Growth and Flowering**

Fruiting vegetables, such as okra (*Abelmoschus esculentus*), tomato (*Solanum lycopersicum*), and brinjal (*Solanum melongena*), require balanced nutrition to support vegetative and reproductive development. Comparative trials across six fertilizer treatments (control, urea, diammonium phosphate, compost, FYM, and vermicompost) revealed significant differences in plant height, leaf production, and flowering (George 2022).

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Vermicompost produced the highest values across all measured parameters, with plant height improvements of approximately 35% compared to the control (52–55 cm vs. 35–40 cm), leaf count increases of approximately 40%, and superior flowering performance across all three crops. Tomatoes exhibited the greatest flowering response to vermicompost (23 flowers per plant), followed by brinjal (19 flowers) and okra (16 flowers), reflecting species-specific nutrient demands and reproductive strategies (George, 2022). Inorganic fertilizers (urea and DAP) provide an immediate nutrient supply that stimulates height growth but are less effective in enhancing reproductive traits. Urea promotes rapid early vegetative growth, but when applied excessively, it may favor vegetative development at the expense of flowering. Organic fertilizers consistently enhance both foliage and flowering due to slow-release nutrients, improved soil microbial activity, and the provision of growth-regulating compounds (George, 2022).

### **3.2 Comparative Performance**

Among the organic amendments across all crops and parameters, vermicompost was found to be better than compost and FYM, probably owing to its enrichment with humic substances and phytohormones, which promote root nutrient absorption and flowering signals. Compost and FYM showed intermediate results, performing better than the control and approaching the effectiveness of chemical fertilizers in some crops, thereby confirming their value as locally accessible and cost-effective organic inputs for sustainable agriculture.

The persistent outperformance of vermicompost in leafy and fruiting vegetables highlights its potential as an organic amendment of choice when it can be generated or procured at a low cost. In addition to providing nutrients, it improves soil structure, water-holding capacity, and biological activity, thereby promoting prolonged crop growth.

## **4. Biofertilizers and Organic Amendments in Seedling Production**

### **4.1 Germination and Early Vigor**

Seed germination and early seedling growth are critical determinants of the final crop yield and quality of horticultural crops that require transplantation. Microbial inoculants, particularly PGPR (e.g., *Azospirillum*, *Azotobacter*, and *Bacillus* species) and AMF (e.g., *Glomus* species), enhance germination and seedling vigor through multiple mechanisms, including nitrogen fixation, phosphate solubilization, phytohormone synthesis, and improved water relations in plants.

Across controlled studies on tomatoes, chili peppers, cucumbers, and other horticultural species, the typical effect range demonstrates consistent benefits. PGPR inoculation alone increased the germination percentage by 5–15%, reduced the mean germination time (MGT) by 10–30%, and increased the seedling vigor index (SVI) by 15–35% compared with uninoculated controls. AMF inoculation produced similar improvements: germination percentage increased by 4–12%, MGT decreased by 8–20%, and SVI increased by 18–32%.

Co-inoculation with PGPR and AMF produced synergistic effects that exceeded those of single inoculations, with increases in germination percentage of 10–22%, reductions in MGT of 15–35%, and improvements in SVI of 25–45%. Synergy arises from complementary mechanisms: PGPR-solubilized nutrients are readily taken up by AMF hyphal networks, whereas both groups contribute to improved root architecture and stress tolerance (Kumar *et al.*, 2021).

### **4.2 Integration with Organic Fertilizers**

The combination of biofertilizers with organic amendments produced the largest early stage effects. Treatments integrating PGPR with organic fertilizers (compost, vermicompost, and neem cake) increased the germination percentage by 12–25%, reduced the MGT by 18–38%, and improved the SVI by 30–50% compared with the controls. Organic materials provide readily available carbon sources and nutrients that support microbial proliferation and improve soil physical properties and moisture retention (Chaudhary *et al.*, 2021).

Specific combinations exhibit particularly strong performances. Castor or neem cake combined with AMF and *Trichoderma harzianum* produced the earliest germination time, highest germination percentage, and

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maximum seedling vigor in papaya (Verma et al., 2025). Vermicompost integrated with PGPR consistently outperformed other organic and biofertilizer combinations across multiple horticultural species.

### **4.3 Seedling Quality and Transplant Success**

In addition to germination attributes, seedling quality measures were greatly improved by biofertilizer and organic treatments. Treatment with AMF resulted in a 40–60% increase in root length compared to that in the controls, indicating increased root proliferation and mycorrhizal hyphal extension. Integrated bio-organic treatments often result in a 30–50% increase in shoot length and a 50–80% increase in the dry weight of seedlings

Bio-organic techniques produce high-vigor seedlings that better tolerate transplanting shock and early establishment in the field, leading to lower mortality and more uniform crop stands (Kumar *et al.*, 2021). Root colonization by AM fungi was 40–60% in treatments with organic fertilizers and 20–35% in AMF-only treatments, showing that organic matter is a suitable substrate for the development and activity of these fungi.

## **5. Practical Implications for Sustainable Vegetable Production**

### **5.1 Integrated Nutrient Management Strategies**

This research convincingly supports integrated nutrient management as the most effective approach for sustainable vegetable production in the future. The combination of organic amendments with reduced chemical fertilizers (commonly at a 50:50 ratio by nitrogen content) provides several complementary benefits: (i) chemical nitrogen provides immediate availability for early vegetative growth, whereas organic nitrogen mineralizes progressively to support nutrient supply at later growth stages; (ii) the organic component provides micronutrients, improves soil structure, and supports microbial populations that enhance nutrient use efficiency; and (iii) reduced chemical fertilizer use decreases input costs and environmental impacts while maintaining or surpassing yields (Tonfack *et al.*, 2009).

Economic assessments support the use of the INM strategy for managing RKN. The highest net returns and benefit:cost ratios in amaranth production were obtained from studies combining appropriate fertilizer dosages with vermicompost. Combined NPK+FYM+biofertilizer treatments provided a good net income for the lettuce. The economic benefits include lower chemical fertilizer costs, higher yields, and greater soil fertility, thereby minimizing the need for inputs in subsequent cropping cycles.

### **5.2 Applications in Mixed Crop-Livestock Systems**

The effectiveness of organic and integrated management approaches is especially evident in mixed crop–livestock (MCL) systems, where farm-derived manure is an available organic input. MCL systems enable nitrogen recycling, boost agricultural yields, and sustain soil fertility, particularly in smallholder farming settings. Household compost and manure produced from MCL activities are sources of organic carbon and nutrients for the soil, and modest application rates of 5–10 t/ha have been reported to boost crop output and soil fertility. Integrated management is particularly suitable for MCL systems because it allows farmers to use organic resources on the farm and reduces the use of purchased chemical fertilizers on the farm. This technique is a dependable and sustainable nutrient management system that efficiently closes the nutrient loops on farms.

### **5.3 Biofertilizer Implementation in Commercial Horticulture**

The adoption of biofertilizers for commercial nurseries and transplant production requires attention to several practical factors. Inoculant quality is critical; PGPR formulations should contain  $10^7$ – $10^8$  colony-forming units per gram, and AMF inocula should provide 100–150 viable propagules per liter of substrate volume. Seed priming or substrate incorporation methods ensure effective colonization, whereas carrier materials (peat, talc, and alginate beads) influence shelf life and delivery efficiency.

Host specificity matters: *Bacillus* species excel on solanaceous crops (tomato, pepper, and brinjal), *Azospirillum* is effective in cucurbits, and arbuscular mycorrhizal fungi (AMF) hyphal networks enhance drought resilience across all species. Compatibility with other inputs is essential; fungicides that kill beneficial microbes must be avoided, and organic amendments should be incorporated to support the

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establishment of microbes in the soil. Under abiotic stress conditions (drought and salinity), the benefits of biofertilizers often increase owing to improved osmotic adjustment and water uptake, making them particularly valuable in climate-resilient production systems.

### **6. Research Gaps and Future Directions**

Despite substantial evidence supporting organic and biofertilizer approaches, several knowledge gaps remain.

1. **Long-term soil health implications:** Extended studies measuring the cumulative effects of various fertilizer regimes on soil organic matter, microbial diversity, and nutrient cycling are essential for a comprehensive long-term evaluation of sustainability.
2. **Optimal organic-inorganic ratios:** Although 50:50 combinations demonstrate consistent advantages, tailored adjustments based on crop and soil characteristics may enhance their efficiency and economic benefits.
3. **Produce quality parameters:** A systematic assessment of vitamin content, nitrate concentrations, shelf life, and sensory characteristics across various fertilizer regimes would provide valuable insights into quality-oriented production.
4. **Environmental effect assessment:** The quantification of nitrate leaching, greenhouse gas emissions, and carbon sequestration across organic, integrated, and chemical fertilizer systems will enhance the arguments for environmental sustainability.
5. **Biofertilizer standardization:** The development of quality standards, viability testing protocols, and shelf-life specifications would support commercial adoption and regulatory frameworks.
6. **Economic analysis across contexts:** Cost-benefit analyses of diverse farming systems (smallholder vs. commercial, tropical vs. temperate) would identify context-specific adoption barriers and opportunities.
7. **Multi-omics approaches:** Linking microbial colonization patterns with plant metabolic shifts through genomic, transcriptomic, and metabolomic studies would elucidate mechanisms and identify targets for strain improvement.

### **CONCLUSIONS AND RECOMMENDATIONS**

Organic fertilizers, biofertilizers, and integrated nutrient management offer viable and sustainable alternatives to relying solely on chemical fertilizers for vegetable production. The key conclusions from the synthesized evidence are as follows

1. **Integrated management superiority:** Combining 50% organic and 50% inorganic inputs consistently produces the highest yields across leafy and fruiting vegetables (85–120% increase over control and 15–30% over sole chemical fertilizers) while improving soil health.
2. **Vermicompost effectiveness:** Vermicompost is the most effective single organic amendment, enhancing biomass (70–95% increase), leaf production (35–45% increase), and flowering in various vegetable species.
3. **Biofertilizer benefits:** PGPR and AMF inoculation significantly improved germination (10–22% increase), reduced germination time (15–35% decrease), and enhanced seedling vigor (25–50% increase), with the greatest effects observed from co-inoculation or integration with organic amendments.
4. **Species-specific responses:** Leafy vegetables show strong leaf-number responses to organic amendments, fruiting vegetables benefit from balanced nutrition for reproductive development, and all species respond positively to integrated approaches.

Based on these findings, the following practical recommendations are proposed:

#### **For leafy vegetable production:**

- Adopt integrated nutrient management (50% urea + 50% compost) to maximize fresh weight and leaf production.
- Prioritize vermicompost (5 t/ha) as the preferred organic amendment where economically feasible

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- Tailor strategies to crop requirements—amaranthus for leaf number and lettuce for biomass response

#### **For fruiting vegetable production:**

- Apply vermicompost (3–5 t/ha) to enhance both vegetative growth and flowering
- Use organic amendments to support reproductive development, particularly in tomato and brinjal
- Avoid excessive nitrogen from urea that may suppress flowering

#### **For nursery and transplant production:**

- Seed priming with PGPR (*Azospirillum*, *Azotobacter*, *Bacillus*) at  $10^7$ – $10^8$  CFU/g
- Incorporate AMF inocula (100–150 propagules/L) into the growing media
- Combining biofertilizers with vermicompost or compost for synergistic effects on seedling vigor
- Ensure inoculant quality and avoid fungicide applications that harm beneficial microbes

#### **For mixed crop-livestock systems:**

- Maximize the use of on-farm manures and composts at 5–10 t/ha
- Combining organic resources with reduced chemical fertilizer rates (50–60% of standard recommendations)
- Implement regular soil testing and organic matter management for long-term sustainability.

The adoption of bio-organic vegetable production methods has several advantages, such as maintaining or improving yield, improving soil health, reducing input costs, reducing environmental impacts, and the possibility of premium prices for organically produced vegetables in the market. Successful implementation must consider inoculant quality, host compatibility, integration with organic amendments, and context-specific optimization. However, the information gathered indicates clear pathways for sustainable vegetable production.

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