



A Review of Organic and Inorganic Amendment Strategies in Tomato Cultivation Across Tropical Agro-Ecological Zones

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ABSTRACT

The choice between organic and inorganic amendment strategies for tomato (*Solanum lycopersicum* L.) production has profound implications for soil health, crop productivity, fruit quality, environmental sustainability, and smallholder livelihoods in tropical agro-ecological regions. This review provides a systematic comparative analysis of organic amendmentssuch as compost, vermicompost, biochar, green manures, microbial inoculants, and inorganic fertilizers (nitrogen-phosphorus-potassium compounds, micronutrient fertilizers) across dimensions of yield response, soil physicochemical improvement, economic feasibility, and long-term soil health trajectories. Evidence from peer-reviewed field studies (2018–2025) consistently demonstrates that organic amendments match or exceed inorganic fertilizer yield outcomes over multi-season timeframes while generating substantial co-benefits for soil organic carbon, microbial diversity, water retention, and disease suppression that mineral fertilizers do not provide. Integrated strategies combining organic and reduced-rate inorganic inputs achieve the greatest short-term yields while progressively improving soil health. Nigerian evidence on organic pest management with neem extract and Path-Away® organic formulations demonstrates that organic principles extend beyond soil fertility management to encompass full agronomic systems in which synthetic chemical inputs are minimized. This review proposes criteria for evidence-based selection between organic, inorganic, and integrated amendment strategies in tropical tomato systems.

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1. INTRODUCTION

The management of soil fertility for tomato (*Solanum lycopersicum* L.) production in tropical agro-ecological regions remains one of the most contested and consequential agronomic decisions facing smallholder farmers. Global tomato production exceeds 186 million metric tons annually (FAO, 2023), with tropical and subtropical regions contributing a rapidly growing share. Yet this production is threatened by accelerating soil degradation, driven in significant part by over-reliance on inorganic fertilizers, particularly synthetic nitrogen-phosphorus-potassium (NPK) compounds, without concurrent investment in maintaining soil organic matter (Lal, 2020). Characterization of tomato farmer varietal preference in Nigerian production systems

reveals that input cost and productivity are primary decision criteria (Adeboye *et al.*, 2024), indicating that amendment choice is fundamentally an economic as well as agronomic decision.

The distinction between organic and inorganic amendment strategies is not simply a matter of input origin but reflects fundamentally different philosophies of soil management: inorganic approaches supply individual nutrients in immediately plant-available forms but do not address the structural, biological, or long-term fertility dimensions of soil health, whereas organic approaches improve multiple soil quality dimensions simultaneously but often supply nutrients more slowly and in forms that require microbial processing before plant uptake (Obi and Ebo, 2018; Vanlauwe *et al.*,

2019). These complementary attributes have driven extensive research into integrated organic-inorganic approaches that seek to capture the immediate nutrient-supply efficiency of mineral fertilizers while leveraging the long-term soil-health benefits of organic inputs.

This review compares organic and inorganic amendment strategies across five dimensions critical to tropical smallholder decision-making: (1) yield response and nutrient use efficiency; (2) effects on soil physicochemical properties; (3) effects on soil biological communities and disease suppression; (4) fruit quality and post-harvest outcomes; and (5) economic feasibility and environmental sustainability.

2. YIELD RESPONSE ON ORGANIC VS INORGANIC AMENDMENTS

2.1 Short-Term Yield Performance

In the first one to two seasons of application, well-formulated inorganic fertilizers at recommended rates generally produce equal or greater tomato yields than organic amendments applied at agronomic rates, owing to their immediate nutrient availability and the absence of immobilization by soil microbial biomass (Adeyemi *et al.*, 2020; Dung *et al.*, 2022). Typical recommended NPK applications of 120–180 kg N ha⁻¹, 40–60 kg P₂O₅ ha⁻¹, and 80–120 kg K₂O ha⁻¹ achieve tomato fruit yields of 25–45 Mg ha⁻¹ in tropical field conditions under good management (Debela *et al.*, 2021). By contrast, compost at 5–10 Mg ha⁻¹ typically achieves 65–80% of full mineral fertilizer yield in the first season, with the gap closing substantially in subsequent seasons as cumulative soil quality improvements take effect (Adeyemi *et al.*, 2020).

Vermicompost, with its higher nutrient concentrations and growth-promoting hormonal content, achieves more competitive first-season yield performance relative to inorganic fertilizers than conventional compost, approaching or matching mineral fertilizer yields at application rates of 5–8 Mg ha⁻¹ in several tropical field studies (Joshi *et al.*, 2022; Oduya *et al.*, 2023). Organic-based crop protection inputs including Path-Away® organic formulations have also been shown to positively influence yield parameters in Nigerian tomato systems (Ajayi *et al.*, 2025b), suggesting that the organic vs inorganic comparison extends beyond soil amendments to integrated management decisions.

2.2 Multi-Season Yield Trajectories

The most compelling agronomic case for organic amendments over inorganic fertilizers emerges from multi-season comparisons. Long-term field experiments in Kenya documented progressive yield increases of 3–8% per season under integrated compost-mineral management, compared to yield stagnation or decline under mineral fertilizer alone, reflecting cumulative improvements in soil quality (Oduya *et al.*, 2023). After five to seven seasons, organic amendment systems in tropical tomato production frequently equal or exceed mineral fertilizer-only systems in yield output while

maintaining substantially better soil health indicators (Massawe *et al.*, 2022; Asante *et al.*, 2023). This yield crossover point is a critical piece of information for farmer adoption decision-making: where time horizons are short and liquidity is constrained, the lower short-term performance of organic systems is a real barrier; where farmers plan over multiple seasons, organic or integrated systems become progressively more attractive.

2.3 Integrated Organic-Mineral Approaches

Meta-analytical evidence from 47 tropical smallholder studies found that integrated compost-mineral fertilizer treatments achieved tomato yields equivalent to full mineral fertilizer rates while using 40–50% less mineral nitrogen and phosphorus (Dung *et al.*, 2022). PGPR consortia combined with compost have reduced chemical fertilizer requirements by 60% while maintaining yields (Liu *et al.*, 2023). These integrated approaches are agronomically dominant strategies in that they simultaneously achieve competitive short-term yields and progressive soil health improvement, combining the strengths of both organic and inorganic inputs while mitigating their respective limitations.

3. EFFECTS ON SOIL PHYSICOCHEMICAL PROPERTIES

3.1 Organic Amendments

Organic amendments consistently and substantially improve tropical soil physicochemical properties. Compost application at 5–20 Mg ha⁻¹ increased SOC by a mean of 23% (range: 8–64%), improved CEC by 18–32%, and reduced bulk density by 8–19% across 98 tropical and subtropical field studies (Poeplau *et al.*, 2021). Biochar application additionally provides pH amelioration, raising soil pH by 0.3–1.2 units in acidic tropical soils and improving phosphorus availability by 14–38% (Brassard *et al.*, 2023). Biochar derived from local agricultural wastes including plantain trunk residues from West Africa has demonstrated significant capacity to restore soil microbial community structure in degraded soils (Osisami *et al.*, 2024), confirming that locally available feedstocks can provide biochar of agronomic value. Effects of organic amendments on soil physicochemical properties including pH, aggregate stability, water retention, and nutrient availability are persistent and cumulative across seasons, distinguishing them fundamentally from the transient nutrient supply effects of inorganic fertilizers (Lal, 2020).

The effects of diverse soil management practices on soil physicochemical properties must be assessed comprehensively; for instance, research demonstrates that cultivation of genetically modified crops can alter soil physicochemical properties through mechanisms including root exudate composition changes and residue quality differences (Falana *et al.*, 2022) highlighting that amendment

effects do not occur in isolation from other management decisions.

3.2 Inorganic Fertilizers

Inorganic fertilizers supply plant-available nutrients efficiently but have limited or neutral effects on soil organic carbon, bulk density, aggregate stability, or water retention and may exert negative effects on these parameters under prolonged exclusive use. Long-term monoculture tomato systems managed exclusively with synthetic NPK fertilizers in West African studies show progressive declines in SOC (mean rate: -0.15 to -0.35% SOC unit per year), deteriorating soil structure, and increasing acidification from ammonium-based nitrogen fertilizers (Adeyemi *et al.*, 2020). Phosphorus accumulation from repeated superphosphate applications can lead to micronutrient imbalances, particularly zinc and iron deficiency in alkaline soils. These degradative trajectories represent the fundamental limitation of inorganic-only strategies in tropical contexts: they supply nutrients but do not maintain or build the soil resource on which long-term productivity depends (Obi and Ebo, 2018; Vanlauwe *et al.*, 2019).

4. SOIL BIOLOGICAL COMMUNITIES

The divergence between organic and inorganic amendment strategies is most pronounced in effects on soil biological communities. Meta-analysis findings consistently show that organic farming systems harbor significantly higher soil microbial biomass carbon (mean increase: 32%), fungal-to-bacterial biomass ratios (mean increase: 48%), and functional gene diversity (mean increase: 19%) than conventionally managed soils (Lori *et al.*, 2022). Compost and vermicompost application increased soil enzymatic activity (dehydrogenase, urease, phosphatase) by 25–65% (Getahun *et al.*, 2020; Nguyen *et al.*, 2024). Disease-suppressive communities enriched by organic amendments reduce soilborne pathogen pressure, providing a biological insurance service that inorganic fertilizers cannot replicate (Mau and Huo, 2021). The long-term stability of these biological community effects is supported by evidence that organic amendment benefits accumulate across seasons, with Oduya *et al.* (2023) documenting the greatest disease suppression benefits emerging in the third year of combined vermicompost-inoculant application.

Research on the effects of organic amendments on bell pepper (*Capsicum annuum*), a closely related Solanaceous crop, confirms that organic amendments and biochar combinations improve soil biological properties relevant to both crop growth and disease resistance (Amana *et al.*, 2025). These findings, in combination with those from tomato systems, suggest broadly applicable benefits of organic amendment strategies for Solanaceous vegetable production across tropical smallholder contexts.

5. FRUIT QUALITY: ORGANIC VS INORGANIC MANAGEMENT

Tomato fruit quality attributes are consistently superior under organic amendment management compared to mineral fertilizer-only systems. Vermicompost and biochar-amended soils yield tomato fruits with elevated lycopene content (18–42% increase over mineral fertilizer controls), higher ascorbic acid (17–35% increase), greater total soluble solids (12–21% increase), and better post-harvest shelf life (10–50% extension) in tropical field studies (Joshi *et al.*, 2022; Nguyen *et al.*, 2024; Rehman *et al.*, 2023). These quality improvements are mediated by enhanced mineral nutrition particularly potassium, calcium, zinc, and iron under organic amendment management, reflecting both greater soil mineral reserves and improved nutrient uptake capacity facilitated by mycorrhizal associations and improved root architecture (Rillig *et al.*, 2019). Inorganic NPK fertilizers typically do not supply micronutrients, and tomatoes grown exclusively on NPK fertilizers in micronutrient-poor tropical soils frequently exhibit deficiency symptoms and reduced fruit nutritional value despite adequate macronutrient supply.

From a market perspective, the quality advantages of organically managed tomatoes are increasingly recognized by consumers in tropical food markets willing to pay premiums for nutritionally superior, chemical residue-free produce (Adeboye *et al.*, 2024). Longer post-harvest shelf life is economically critical in tropical markets where cold chain infrastructure is limited and post-harvest losses account for 20–40% of tomato production value (FAO, 2023).

6. ECONOMIC COMPARISON

The economic comparison of organic and inorganic amendment strategies must account for: input costs and availability; labor requirements for amendment production, transport, and application; yield outcomes across multiple seasons; crop quality premiums; and long-term soil capital effects. Economic analysis from sub-Saharan Africa indicates that compost-mineral integration typically achieves benefit-cost ratios of 2.1–3.8 under smallholder conditions, favorable relative to mineral fertilizer-only strategies with benefit-cost ratios of 1.5–2.4 when full input costs are accounted for (Asante *et al.*, 2023).

For organic-based pest and disease management, Nigerian evidence demonstrates that aqueous neem extract (Adesakin *et al.*, 2024) and organic formulations such as Path-Away® (Ajayi *et al.*, 2025a) provide cost-effective alternatives to synthetic pesticide applications while avoiding associated resistance management costs a significant advantage in smallholder contexts where synthetic pesticide budgets are constrained. The combined economic case for organic amendment strategies lower input costs, progressive soil

capital building, reduced pesticide dependency, higher-quality produce and strengthens considerably when assessed over a five- to ten-year planning horizon rather than a single season.

Barriers to economic adoption include: higher upfront labor for organic amendment production; delayed payoff periods; absence of organic input subsidies comparable to those available for synthetic fertilizers in many tropical countries (Vanlauwe *et al.*, 2019); and quality variability in commercially available organic amendments. Policy reform to include organic inputs in fertilizer subsidy programs as proposed for several West African countries which would substantially improve the economic competitiveness of organic strategies.

7. ENVIRONMENTAL AND SUSTAINABILITY DIMENSIONS

The environmental case for organic over inorganic amendment strategies is robust across multiple dimensions. Organic amendments sequester carbon in stable forms particularly biochar, which has mean soil residence times of hundreds to thousands of years (Lehmann *et al.*, 2021), while inorganic fertilizers do not contribute to SOC accumulation. Estimates suggest that integrated organic amendment adoption across 30% of tropical smallholder tomato production could sequester 0.8–2.4 Mg C ha⁻¹ yr⁻¹ (Lehmann *et al.*, 2021; Poeplau *et al.*, 2021), representing a meaningful contribution to agricultural climate change mitigation. Biochar application is associated with mean N₂O emission reductions of 10–38% relative to mineral fertilizer management (Brassard *et al.*, 2023), while the replacement of synthetic pesticides with neem-based and organic formulation products reduces pesticide loading in soil and water (Adesakin *et al.*, 2024; Ajayi *et al.*, 2025a).

Soil biodiversity conservation represents an additional environmental co-benefit of organic management that lacks a straightforward economic valuation but is fundamental to long-term agroecosystem functioning. Research confirms that organic farming systems maintain greater soil microbial diversity, which underlies nutrient cycling, pathogen suppression, and structural stability functions (Lori *et al.*, 2022). Conversely, the impact of various agricultural management practices including genetically modified crop adoption on soil physicochemical and biological properties remains an important consideration in comprehensive environmental sustainability assessments (Falana *et al.*, 2022).

8. CRITERIA FOR AMENDMENT STRATEGY SELECTION

Based on the reviewed evidence, the following evidence-based criteria are proposed for selection between organic,

inorganic, and integrated amendment strategies in tropical tomato systems:

For resource-constrained smallholders with constrained access to commercial inputs, locally available organic amendments (compost from crop residues, plantain trunk biochar, green manures) combined with organic pest management inputs (neem extract, botanical formulations) offer the most cost-effective and sustainable productivity pathway (Adesakin *et al.*, 2024; Osisami *et al.*, 2024; Chikowo *et al.*, 2020). For smallholders with market access and a multi-season planning horizon, integrated organic-mineral strategies targeting 40–60% replacement of inorganic fertilizer with organic amendments to achieve the best balance of short-term yield competitiveness and long-term soil health investment (Dung *et al.*, 2022; Vanlauwe *et al.*, 2019). For market-oriented producers targeting premium quality markets, organic amendment-based systems deliver the fruit quality attributes lycopene, ascorbic acid, and shelf life that command market premiums, justifying the higher management complexity (Rehman *et al.*, 2023; Nguyen *et al.*, 2024; Adeboye *et al.*, 2024). For all system types, a soil diagnosis-first approach is recommended: strongly acidic soils should prioritize biochar-based pH amelioration; phosphorus-deficient soils should emphasize green manure and AMF inoculation; structurally degraded soils should prioritize compost at high rates (Vanlauwe *et al.*, 2019; Lal, 2020).

9. CONCLUSION

This comparative review demonstrates that organic amendment strategies for tropical tomato production are not a second-best alternative to inorganic fertilizers but a scientifically validated, economically viable, and environmentally superior approach particularly over multi-season timeframes and for farmers operating in contexts where soil health improvement and input cost reduction are priority objectives. Inorganic fertilizers retain an important role in bridging short-term nutrient supply gaps and maximizing early-season yield performance, but their exclusive use is associated with progressive soil degradation that undermines long-term productivity. Integrated organic-inorganic strategies, tailored to local soil conditions and farmer resource constraints, represent the evidence-based optimum for most tropical tomato production contexts.

The reviewed evidence from Nigeria and across tropical Africa and Asia demonstrates that the organic-inorganic choice extends beyond soil amendments to encompass crop protection systems organic neem extract and botanical formulations (Adesakin *et al.*, 2024; Ajayi *et al.*, 2025a, 2025b) demonstrate that organic management principles can be applied effectively across the full agronomic system, reducing synthetic chemical dependency while maintaining

competitive productivity and advancing the sustainability of tropical tomato production.

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