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Effects of Organic Mulching on Soil Biological Functions in Tomato Fields

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Abstract Organic mulching is increasingly recognized as an effective soil management practice for enhancing soil health and promoting sustainable tomato production. In tomato cultivation systems, particularly under intensive and continuous cropping conditions, organic mulches can modify the soil microenvironment, regulate moisture and temperature dynamics, and provide a continuous source of organic matter that supports biological activity in the rhizosphere. This review synthesizes current knowledge on the effects of organic mulching on soil biological functions and tomato productivity. Special emphasis is placed on changes in rhizosphere microbial communities, including microbial biomass, diversity, and the abundance of beneficial microorganisms involved in nutrient cycling and plant growth promotion. The influence of mulching on soil enzyme activities associated with carbon, nitrogen, and phosphorus transformations is also examined, together with its role in enhancing nutrient availability and fertilizer-use efficiency. Furthermore, the review discusses how organic mulching affects soil food webs and suppresses soil-borne pathogens through biological regulation and improved microbial interactions. These biological responses contribute to increased soil organic matter accumulation, improved soil structure and water retention, enhanced root development, and greater ecosystem stability. Consequently, organic mulching can improve tomato growth, marketable yield, and fruit quality attributes such as soluble solids, vitamin C, and lycopene content. A case study from tomato-based production systems is included to demonstrate the practical benefits and limitations of different mulching strategies. Future research should focus on long-term field experiments, rhizosphere microbiome engineering, and integrated soil management approaches to optimize the biological functions of mulched soils and support resilient tomato production systems.

Keywords Organic mulching; Tomato rhizosphere; Soil microbial communities; Soil-borne disease suppression; Tomato yield and fruit quality

1 Introduction

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops worldwide, cultivated in open-field and protected systems for both fresh and processing markets, and contributing substantially to farm income, employment, and value chains in diverse agroecosystems (Gatahi, 2020). Rising consumer demand for healthy diets, growing interest in organic produce, and pressure to reduce the environmental footprint of intensive horticulture have pushed tomato production toward sustainability standards that emphasize reduced synthetic inputs, improved soil health, and enhanced ecosystem services. Within these transitions, soil biological functioning-microbial activity, nutrient cycling, and resilience to stress-has emerged as a central pillar for sustaining yields and quality while meeting environmental and certification requirements in both organic and conventional tomato systems.

Organic mulching is increasingly promoted as a multifunctional soil management practice in tomato production, capable of modifying the microclimate, conserving water, and supplying organic matter while simultaneously influencing belowground biological processes. Field and greenhouse studies in tomato systems demonstrate that cover crop mulching or straw-based mulches can alter soil moisture, temperature regimes, and nutrient storage, thereby shaping microbial activity, functional diversity, and ultimately tomato yield under contrasting climatic conditions (Zhang et al., 2023). In organic tomato farming systems, combinations of organic substrates with straw mulching have been shown to substantially increase soil microbial biomass C, microbial activity, and potentially mineralizable N compared with synthetic-fertilizer controls, underscoring the key role of residue and mulch management in regulating biologically mediated nutrient supply.

Beyond tomato, work in orchards and diversified cropping systems provides mechanistic insights into how organic mulches regulate soil biological functions relevant to tomato fields. Long-term studies using cornstalk or ryegrass mulches show that organic mulching can enhance β-glucosidase, cellobiohydrolase, β-xylosidase, N-acetylglucosaminidase, and urease activities, while increasing the abundance of genes linked to carbon and nitrogen cycling and carbon fixation, thereby improving soil quality and nutrient cycling capacity relative to conventional tillage or inorganic mulches (Wang et al., 2020). In multi-cropping systems, organic material mulching regulates core bacterial and fungal groups, enhances soil aggregate stability, and stimulates C- and N-acquiring enzymes, with structural equation models indicating that shifts in microbial diversity and carbon cycling efficiency translate into higher legume productivity, highlighting the potential of mulches to leverage soil microbiomes for yield gains (Ren et al., 2025).

This review synthesizes evidence on the effects of organic mulching on soil biological functions in tomato fields, with a focus on how different organic mulches influence microbial communities, enzyme activities, nutrient cycling, and yield under field and protected cultivation. Drawing primarily on studies from tomato-based systems and complementary research from orchards and multi-crop rotations, the review aims to contextualize organic mulching within sustainable tomato horticulture, summarize current knowledge of mulch-induced changes in soil microbial biomass, community composition, and functional diversity, and evaluate how these biological changes feed back to soil quality, nutrient availability, and tomato performance. By identifying consistent patterns and key knowledge gaps-particularly regarding climate sensitivity, mulch type, and interactions with fertilization-the review seeks to guide the design of mulch strategies that enhance soil biological functioning and support resilient, resource-efficient tomato production systems.

2 Characteristics and Types of Organic Mulching Materials

2.1 Crop residues and straw mulches

Crop residues and straw mulches are among the most widely used organic mulching materials because they are locally available, inexpensive, and easy to apply after harvest. Reviews and field studies show that straw mulch acts as a surface barrier that reduces soil water evaporation, moderates temperature, and suppresses weed emergence by restricting light penetration, with especially strong effects against annual and small-seeded weeds. In groundnut and other field systems, straw mulch has also been associated with better crop vigor and improved retention of soil moisture, making it particularly useful in warm or water-limited environments (Ren et al., 2025).

Beyond short-term surface protection, straw-based mulches can alter soil properties in ways that support longer-term soil improvement. Rice-straw mulching increased soil moisture and organic carbon while reducing bulk density in a three-year vineyard trial, and weed control improved at higher application rates, showing that mulch thickness and replacement timing are important management variables. Broader reviews likewise indicate that straw mulching commonly increases soil organic matter and water-use efficiency, although responses vary with climate, crop, and management, and excessive residue retention can sometimes favor pests, diseases, or shifts in microbial communities (Du et al., 2022).

2.2 Compost, manure, and green waste mulches

Compost-, manure-, and green waste-based mulches differ from residue mulches in that they function not only as soil covers but also as nutrient-bearing amendments. Composted manure supplies organic matter together with macro- and micronutrients, improves soil structure, aeration, porosity, pH balance, and water-holding capacity, and typically releases nutrients gradually enough to support plant growth over time. Similarly, green waste compost application has been shown in meta-analysis to lower bulk density while increasing soil organic matter, organic carbon, total nitrogen, available phosphorus, available potassium, and dehydrogenase activity, confirming its broad soil-improving capacity (Auriemma et al., 2025).

The main distinction within this category is that material maturity and nutrient composition determine whether benefits are predominantly physical, nutritional, or both. Field evidence from poor sandy soils shows that farmyard manure and composted municipal or sewage-derived wastes increased cation exchange capacity, available nutrients, and crop yield, with residual benefits persisting into the second harvest. However, composted materials are not universally rapid nutrient sources: nutrient release can be slow, residual, and sometimes preceded by a period of nitrogen immobilization, so timing and dose must be matched to crop demand to avoid nutrient imbalance or excess loading (Dukare et al., 2020).

2.3 Biodegradable organic mulching materials and their properties

Biodegradable organic mulching materials include films or liquid-applied covers made from degradable polymers of natural or synthetic-biobased origin, including starch, cellulose, polyhydroxyalkanoates, PLA, PBAT, and their blends. Their core design challenge is to balance field durability during crop production with sufficient biodegradability after soil incorporation, because biodegradability depends not only on whether a material is bio-based but also on its physicochemical properties and the receiving soil environment. Recent materials research shows that PLA-based composites filled with vegetable-processing wastes can achieve tensile strengths of 10-24 MPa, elongation at break up to 460%, and water-vapor permeability comparable to commercial products, indicating that fully biobased mulch films can now approach the performance required for field use (Gao et al., 2022).

Despite this promise, the environmental behavior of biodegradable mulches remains more complex than simple replacement narratives suggest. Experimental studies show that degradation rates vary widely among polymers, with PLA and PBAT degrading incompletely over 18 months and generating measurable microplastic particles while also stimulating microbial activity and CO_2 emissions. Other work indicates that some starch-alginate liquid mulches can degrade completely within 25 days and increase soil organic matter, whereas longer-term field studies of biodegradable films report improvements in total nitrogen, available phosphorus, available potassium, and microbial activity relative to polyethylene mulch, suggesting that environmental outcomes depend strongly on material formulation, degradation pathway, and duration of use (Zhang et al., 2023).

3 Responses of Tomato Rhizosphere Microbial Communities to Organic Mulching

3.1 Changes in rhizosphere microbial biomass and diversity

Organic mulching in tomato fields generally increases rhizosphere microbial biomass and alters community diversity. In low-input tomato, wheat-straw mulch significantly increased rhizosphere populations of total fungi, actinomycetes and rhizobia compared with non-mulched soil, indicating higher microbial biomass and functional group abundance under organic cover (Dukare et al., 2020). A wood-derived biodegradable topsoil cover in greenhouse tomato similarly enhanced soil microbial metabolic diversity and increased the early soil N pool by about 20%, without strongly changing bulk community structure, suggesting functional enrichment even when taxonomic diversity is relatively stable (Auriemma et al., 2025).

However, diversity responses can depend on mulch type and combination with other materials. In a three-year tomato field trial, straw mulching alone slightly increased soil organic C and N but had limited effect on overall bacterial and fungal diversity, whereas combining straw with plastic film (dual mulching) significantly reduced bacterial and fungal α-diversity despite improving soil properties and yield (Li et al., 2026). Studies in forest and urban systems show a similar pattern, where organic mulching mainly shifts bacterial and fungal community composition and temporal trajectories, while effects on α-diversity are minor or time-dependent, emphasizing that mulching often restructures communities rather than uniformly increasing diversity (Sun et al., 2021).

3.2 Shifts in beneficial bacteria and fungal communities

Organic mulches can selectively enrich beneficial rhizobacteria and fungi in tomato rhizospheres. In low-input tomato, wheat-straw mulch increased counts of rhizobia, actinomycetes and other beneficial groups, which coincided with improved plant growth and mineral uptake, indicating that organic cover favors symbiotic and decomposer taxa that support nutrient acquisition (Dukare et al., 2020). In another greenhouse study, a wood-derived topsoil cover supported indigenous Proteobacteria (e.g., Pseudomonas) and Firmicutes and increased microbial metabolic diversity while maintaining community structure, consistent with a functionally active, plant-associated microbiome under biodegradable organic cover (Auriemma et al., 2025).

Mulch composition and structure also influence the balance between beneficial and pathogenic fungi. In a three-year tomato field experiment, film-straw dual mulching substantially increased the relative abundance of plant growth-promoting Firmicutes and functional microorganisms involved in C and N cycling, while suppressing several pathogenic fungal groups compared with straw or plastic alone (Li et al., 2026). Conversely, straw or film mulching alone tended to increase pathogenic fungi, helping explain their lower yield benefits relative to dual mulching and underscoring that residue type and combination determine whether mulching shifts communities toward mutualists or pathogens.

3.3 Microbial functions related to nutrient cycling and plant growth promotion

Organic mulches strongly influence microbial functions linked to C and N cycling. In tomato fields, film-straw dual mulching enriched bacterial taxa and functional groups associated with C-N cycling, including Firmicutes and other putative plant growth-promoting rhizobacteria, and these shifts were positively related to soil organic C, total N and available P and K, as well as to improved plant growth and yield (Li et al., 2026). More broadly, metagenomic work in mulched orchards shows that organic mulches increase the abundance of genes involved in C degradation, N cycling and amino acid metabolism compared with inorganic covers, indicating enhanced microbial functional diversity for nutrient turnover under organic surface inputs (Wang et al., 2020).

Organic mulching can also modulate specific N-cycling pathways and plant nutrient uptake. In semiarid systems, combining film mulching with organic manure raised microbial biomass C and N, dehydrogenase activity and functional diversity, and these biological indicators correlated positively with grain N accumulation and yield, suggesting tighter microbe-mediated N cycling and improved plant nutrition under organic inputs. In low-input tomato, both plastic and wheat-straw mulches increased rhizosphere populations of P-solubilizing organisms and enhanced plant uptake of macro- and micronutrients, indicating that mulching favors functional microbes that mobilize nutrients and support plant growth promotion in tomato systems (Dukare et al., 2020).

4 Effects of Organic Mulching on Soil Enzyme Activities and Nutrient Availability

4.1 Carbon-cycling enzymes in tomato rhizosphere soils

Organic mulching supplies fresh carbon to the rhizosphere and strongly stimulates enzymes that mediate carbon turnover. In urban forest soils, organic mulch increased invertase and dehydrogenase activities-key enzymes for sucrose hydrolysis and overall oxidative metabolism-especially in rhizosphere soil where microbial growth and dissolved organic C were highest (Sun et al., 2022). These increases were closely associated with higher microbial biomass C and dissolved organic matter, indicating that mulch-derived substrates and improved microclimate jointly drive enhanced C-cycling capacity (Sun et al., 2021).

Mulching effects on carbon-cycling enzymes are often depth- and time-dependent. In citrus orchards, eight years of living grass mulching significantly increased β-glucosidase and cellobiohydrolase activities in the 0-20 cm layer, and boosted total C-cycling enzyme activity by up to several-fold compared with clean tillage. Redundancy analysis showed that microbial biomass C and P, soil organic C and available N together explained most of the variation in these enzymes, suggesting that sustained surface inputs and improved nutrient status are primary controls on C-depolymerizing activities under long-term mulching (Wang et al., 2022).

4.2 Nitrogen and phosphorus transformation processes

Nitrogen- and phosphorus-cycling enzymes respond sensitively to organic mulching, with important implications for mineral N and P dynamics. In a Ligustrum rhizosphere, organic mulch altered urease and peroxidase activities; urease sometimes decreased while dehydrogenase rose by up to 75%, and enzyme activities were tightly linked to dissolved N pools and microbial biomass N rather than total N, implying that mulch mainly regulates the labile N cycle (Sun et al., 2022). Similarly, in maize soils mulched with wheat straw, urease and phosphatase activities in the 0-0.1 m layer rose by about 15% and 11%, respectively, alongside substantial increases in available N and P, indicating accelerated mineralization and P release under higher residue inputs.

Straw and grass mulches also modify phosphatase and N-acquiring activities over the profile and with mulching duration. In a Camellia-Cassia intercropping system, rice straw mulching significantly increased acid phosphatase and urease activities across 0-40 cm, with stronger responses where soil organic C and microbial biomass C were greatest, highlighting biological control of nutrient-releasing enzymes (Duanyuan et al., 2023). In subtropical citrus orchards, eight-year living grass mulching enhanced available N and P and sharply increased N-acetylglucosaminidase, leucine aminopeptidase and acid phosphatase activities, with available nutrients and microbial biomass explaining nearly 70% of enzyme variation, underscoring that improved nutrient status feeds back to more active N and P cycling (Wang et al., 2022).

4.3 Implications for nutrient uptake and fertilizer use efficiency

Enhanced enzyme activities and labile nutrient pools under mulching often translate into better plant nutrient uptake and higher fertilizer use efficiency. In low-input tomato, plastic film and wheat-straw mulching increased rhizosphere populations of bacteria, fungi, actinomycetes and phosphorus-solubilizing organisms, and substantially improved shoot growth and mineral uptake of macro- and micronutrients compared with bare soil, demonstrating that mulching can enhance biological nutrient acquisition even when external inputs are limited (Dukare et al., 2020). In maize systems, high-rate straw mulching raised soil organic C, available N and P, and boosted grain and biomass yields and water use efficiency, suggesting that residue-induced biochemical changes improve both nutrient and water capture.

Legume-based organic mulches can also act as significant in situ N sources that reduce reliance on synthetic fertilizers in tomato production. In Mediterranean no-till tomato, mulches derived from winter hairy vetch, subclover or medic provided 54-189 kg N ha^{-1}, increased marketable yields compared with conventional tillage and bare no-till, and raised tomato N uptake, while nitrogen use efficiency remained high at moderate fertilizer rates. Beyond tomato, fertigation combined with mulching in okra increased N, P and K uptake in stems, leaves and fruits and achieved the highest fertilizer and water use efficiencies relative to soil-applied fertilizers, illustrating how matching soluble nutrient supply with mulch-improved soil conditions can maximize nutrient capture and minimize losses in horticultural systems (Nagegowda et al., 2020).

5 Organic Mulching, Soil Food Webs, and Soil-Borne Disease Suppression

5.1 Effects on soil fauna and trophic interactions

Organic inputs linked to mulching can restructure soil food webs by stimulating microbivores and higher trophic levels. In jackfruit systems, increasing the proportion of organic manure raised soil organic matter, microbial biomass C, nematode diversity, and the abundance of total, microbivorous, and omnivorous-predatory nematodes, while reducing plant-parasitic nematodes; network analysis showed more positive correlations between beneficial nematodes and microbes and negative links between plant parasites and certain fungi, indicating reinforced belowground control pathways under organic amendments (Su et al., 2021). Long-term organic mulches in apple orchards similarly elevated protozoa, bacterivorous nematodes, and enrichment-opportunist nematodes, increasing modeled N and P fluxes through microfauna, and reduced populations of the root-lesion nematode Pratylenchus penetrans relative to herbicide or plastic mulch management.

Residue frequency and quality further determine whether bacterial- or fungal-based decomposition channels dominate. In a 10-year no-till mulching experiment, high-frequency stover mulching promoted bacterial PLFAs and bacterivorous nematodes, with higher nematode enrichment indices and stronger C flow into the food web, whereas low-frequency mulching favored fungal PLFAs and fungivores, yielding a more structurally stable food web (Kou et al., 2020). Vermicompost substitution in intensive vegetable rotations (pepper-tomato-spinach) enhanced soil multifunctionality by fostering complex food-web structures centered on omnivorous nematodes, but excessive vermicompost simplified the web and decreased multifunctionality, underscoring the need for moderate organic inputs to maintain trophic complexity and multiple soil functions (Zhu et al., 2024).

5.2 Suppression of soil-borne pathogens in tomato fields

In tomato systems, organic amendments and mulching-related inputs often reduce soil-borne disease incidence by reshaping rhizosphere microbiota. Long-term application of bio-organic fertilizers in tomato fields induced suppressiveness against *Ralstonia solanacearum*, with metagenomics revealing enrichment of Sphingomonadaceae and Xanthomonadaceae producing secondary metabolites upon pathogen invasion;

inoculation of these taxa into conducive soil significantly reduced pathogen abundance, demonstrating microbiome-mediated bacterial wilt suppression (Deng et al., 2022). A three-season tomato field experiment showed that organic, amino-acid organic, and bio-organic fertilizers progressively and significantly suppressed soil-borne diseases compared with chemical fertilizer, with bio-organic fertilizer achieving the strongest reduction and shifting both bulk and rhizosphere communities away from Ralstonia and *Fusarium dominance*.

Organic matter can also suppress fungal root rots and wilts in tomato. Under organic management, compost, plant residues, cow manure, vermicompost, and humic acid all reduced in vitro growth of *Fusarium oxysporum*, *F. solani*, *Pythium*, *Rhizoctonia solani*, and *Sclerotium rolfsii*, and *in vivo* application of these materials before transplanting significantly lowered tomato root-rot incidence while increasing survival, growth, and fruit yield and quality, with compost giving the strongest overall benefits (Ahmed et al., 2022). In container media, on-farm green composts suppressed damping-off and root rots caused by Pythium irregulare, Rhizoctonia solani, Phytophthora cinnamomi, Sclerotinia minor, and Fusarium oxysporum in several hosts, including tomato, with suppression linked to total fungal-bacterial bioactivity or to specific antagonists such as Trichoderma, Aspergillus, Pseudomonas, and actinomycetes, indicating that compost-like mulches can contribute to broad-spectrum disease control through enriched antagonistic guilds.

5.3 Biological mechanisms enhancing disease resistance

Disease suppression under organic mulching and amendments is underpinned by multiple, interacting biological mechanisms. Long-term bio-organic fertilization in tomato rhizospheres “primed” bacterial communities so they reacted to *R. solanacearum* invasion by enriching secondary-metabolite producers (Sphingomonadaceae, Xanthomonadaceae) and increasing nonribosomal peptide synthetase genes, leading to strong reactive suppression of the pathogen (Deng et al., 2022). Manipulating bulk soil microbiota with organic, amino acid organic, and bio-organic fertilizers generated distinct bulk communities that subsequently shaped rhizosphere assemblages; genera correlated between bulk and rhizosphere were associated with lower disease incidence, highlighting a legacy effect where bulk-soil management steers the recruitment of protective rhizosphere consortia.

Plant-microbiome signaling also contributes to resistance. In a multi-generation tomato study, organic fertilizer more effectively reduced bacterial wilt and R. solanacearum loads than mineral fertilization, partly because organic inputs stimulated secretion of specific tomato root microRNAs (sly-miR159, sly-miR319c-3p) via exosome-like vesicles; these miRNAs directly inhibited R. solanacearum proliferation and promoted expansion of beneficial Streptomyces and Bacillus, which themselves can secrete antifungal and antibacterial metabolites (Tang et al., 2023). Bio-organic manures inoculated with Bacillus strains further enhanced microbial abundance, diversity, and beneficial taxa while decreasing pathogens and Fusarium wilt incidence across seasons, suggesting combined direct antagonism by the biocontrol agent and indirect suppression via community re-assembly and improved soil properties (Figure 1) (Bonanomi et al., 2020).

6 Impacts of Organic Mulching on Soil Health and Tomato Performance

6.1 Soil organic matter accumulation and carbon sequestration

Organic mulching contributes to soil organic matter build-up by adding carbon-rich materials and improving conditions for stabilization. In a three-year organic rotation including tomato, compost, chipped wood, and cover-crop mulches increased soil organic carbon (SOC) to 6.81%, 2.07%, and 3.17%, respectively, compared with 1.24% in the unmulched control, demonstrating substantial SOM accumulation under repeated mulching (Rossi et al., 2024). Long-term mulching on sloping cropland similarly raised SOC concentrations by 4%-83% in the 0-30 cm layer relative to conventional tillage, with straw mulching particularly enhancing SOC in macro-aggregates that protect carbon against decomposition (Horimoto et al., 2022).

Mulch management can also affect the vertical distribution of carbon and its fractions. In an urban Ligustrum plantation, repeated addition of small amounts of organic mulch promoted SOC accumulation and DOC enrichment, especially in deeper layers via increased C content in fine roots, indicating downward transfer of carbon and potential deep sequestration (Sun et al., 2021). At the landscape scale, straw mulching and ridge-furrow plastic systems increased macro-aggregate-associated SOC by 24%-56% and reduced spatial variability along slopes, suggesting that mulching not only raises SOC stocks but also stabilizes them against erosion and mineralization (Horimoto et al., 2022).

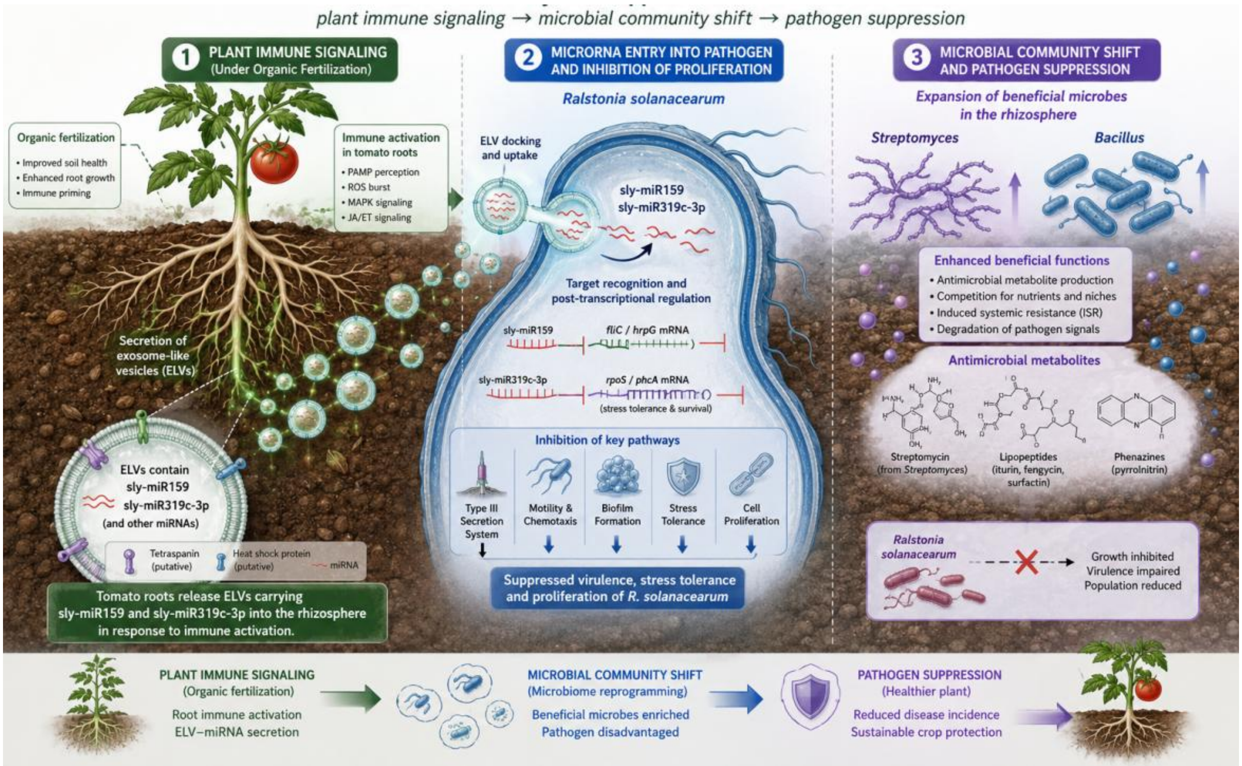

Figure 1 Plant-microbiome signaling mediated by root-derived microRNAs and exosome-like vesicles under organic fertilization

6.2 Improvements in soil structure, water retention, and root development

By increasing SOM and biological activity, organic mulching improves soil physical-mechanical properties relevant to tomato root growth. After three years of mulching in an organic vegetable rotation, compost mulch reduced bulk density from 1.22 to 0.89 Mg/m^3, more than doubled infiltration rate, and sharply lowered soil deformation and cracking, while chipped wood and cover crops also improved structure relative to no mulch (Rossi et al., 2024). A broader review confirms that organic mulches enhance soil organic matter and raise soil water retention capacity, thereby reducing degradation and creating more favorable conditions for roots and soil biota.

Mulching also enhances soil moisture regimes and root system development in systems relevant to tomato. In a study of greenhouse tomatoes under different drip irrigation volumes, film mulching increased soil water content in the 0-60 cm profile and concentrated roots in the 0-20 cm layer, with root length density showing strong relationships with soil water and temperature, and a mulching factor improving root distribution model accuracy (R^2 up to 0.98) (Sun et al., 2023). In urban forest soils, a 5cm organic mulch layer decreased bulk density and increased fine-root biomass, with roots extending deeper as mulching altered specific root length and surface area, indicating that reduced compaction under mulch supports more extensive and dynamic root systems (Gao et al., 2023).

6.3 Effects on tomato growth, yield, and fruit quality

Organic mulching can directly enhance tomato growth and productivity through improved hydrothermal conditions and nutrient supply. In unheated winter greenhouses, newspaper, bran, and grass mulches increased soil moisture by 14%-21%, narrowed daily soil temperature ranges, and raised tomato biomass by 18%-83% and yield by 11%-82% compared with bare soil, while also improving water use efficiency and conserving water in the upper 30 cm (Zhang et al., 2023). Field trials with pine-needle, rice-straw, and wheat-straw mulches similarly increased soil moisture through 0.1-0.5 m, reduced maximum soil temperature by up to 3.3 °C, and boosted tomato yield and irrigation water use efficiency by up to 29% relative to no mulch (Mendonça et al., 2021).

Mulching can also influence marketable yield and fruit quality traits. In open-field tomato, mulberry woodchip mulch increased fresh-marketable yields by 16%-57% over a weed-free control, while reducing the proportion of dehiscent (cracked) fruits by 46%-86%, partly through moderated fruit exposure to direct sunlight (Cao et al., 2026). Meta-analysis of organic fertilizer use in tomato systems shows that increasing soil organic matter by organic inputs raises yield by ~3%-42% and improves fruit quality parameters such as soluble sugars, lycopene, and vitamin C, suggesting that organic amendments applied as mulches or incorporated residues can synergistically enhance both productivity and quality in tomato production (El-Beltagi et al., 2022).

7 Case Study: Organic Mulching for Improving Soil Biological Functions and Tomato Productivity

7.1 Experimental design and mulching treatments

A representative case study can be framed around multi-factor field experiments that combine mulching with organic nutrient management in tomato. In a two-year conservation-agriculture trial in Italy, five organic itineraries contrasted deep versus reduced tillage, use of a vetch-barley cover crop, and either biodegradable mulch film plus mechanical weeding or false seedbed plus mechanical weeding before processing-tomato transplanting. Treatments with biodegradable mulch (ST, M2) were compared to non-mulched systems for weed biomass, yield, and economic performance, allowing the specific contribution of mulch to be disentangled within otherwise organic management (Gagliardi et al., 2023).

Complementary experiments in greenhouse or net-house conditions have used factorial designs to separate effects of organic fertilizers from mulching. In Bangladesh, a completely randomized design with nine treatments tested two rates of mustard oil cake, poultry manure, and vermicompost, each applied with or without an organic surface mulch, on a sandy loam soil transplanted with tomato. Plot-scale measurements of plant growth, root traits, and fruit production across mulched and non-mulched subplots enabled assessment of how organic mulching modulates the response of tomato to contrasting organic nutrient sources and doses (Naznin et al., 2024).

7.2 Responses of soil biological indicators and rhizosphere processes

Organic mulching consistently enhanced soil biological functioning in tomato and related systems. In long-term organic tomato farming on coastal sandy soil, adding straw mulch on top of organic substrates (composted cotton gin trash, animal manure, rye/vetch green manure) increased microbial biomass C and activity by 42% and 64%, respectively, and raised potentially mineralizable N by 30% relative to non-mulched organic plots, indicating greater microbial capacity to supply N (Morra et al., 2021). In low-input tomato under semi-arid conditions, wheat-straw mulch increased rhizosphere populations of fungi, actinomycetes, rhizobia, and P-solubilizing microbes compared with bare soil, which coincided with improved plant growth and mineral uptake (Zhang et al., 2023).

Mulching effects on microbial communities and enzyme activities can be inferred from rhizosphere studies in other systems. In a 15-year Ligustrum forest, organic mulching significantly altered rhizosphere bacterial and fungal composition and increased dehydrogenase and urease activities, with microbial shifts closely related to fine-root traits and rhizosphere soil properties such as water content and dissolved organic C (Li et al., 2026). A companion study in the same system showed that organic mulching raised invertase and dehydrogenase activities in rhizosphere soil and that enzyme activities correlated strongly with dissolved C, available N, and microbial biomass C and N, suggesting that mulch-driven inputs of labile substrates and moisture stimulate faster C and N cycling at the root-soil interface (Figure 2) (Sun et al., 2021).

7.3 Effects on tomato yield, quality, and economic returns

Across case studies, organic mulching generally increased tomato yield and improved fruit traits. In the Italian conservation-agriculture trial, the highest marketable yields were obtained in itineraries using biodegradable mulch, with processing-tomato yields up to ~42 Mg/ha in 2020, substantially exceeding non-mulched reduced-tillage treatments; despite higher operational costs, mulched systems achieved the greatest gross income (≈31,000 €/ha in 2020) under drought-prone conditions (Gagliardi et al., 2023). In winter greenhouse production in cold-zone China, newspaper, bran, and grass mulches increased soil moisture by 14%-21% and raised biomass and yield by 11%-82% compared with bare soil, while strongly enhancing water-use efficiency, indicating that organic mulches can buffer climatic limitations and support productivity (Sun et al., 2022).

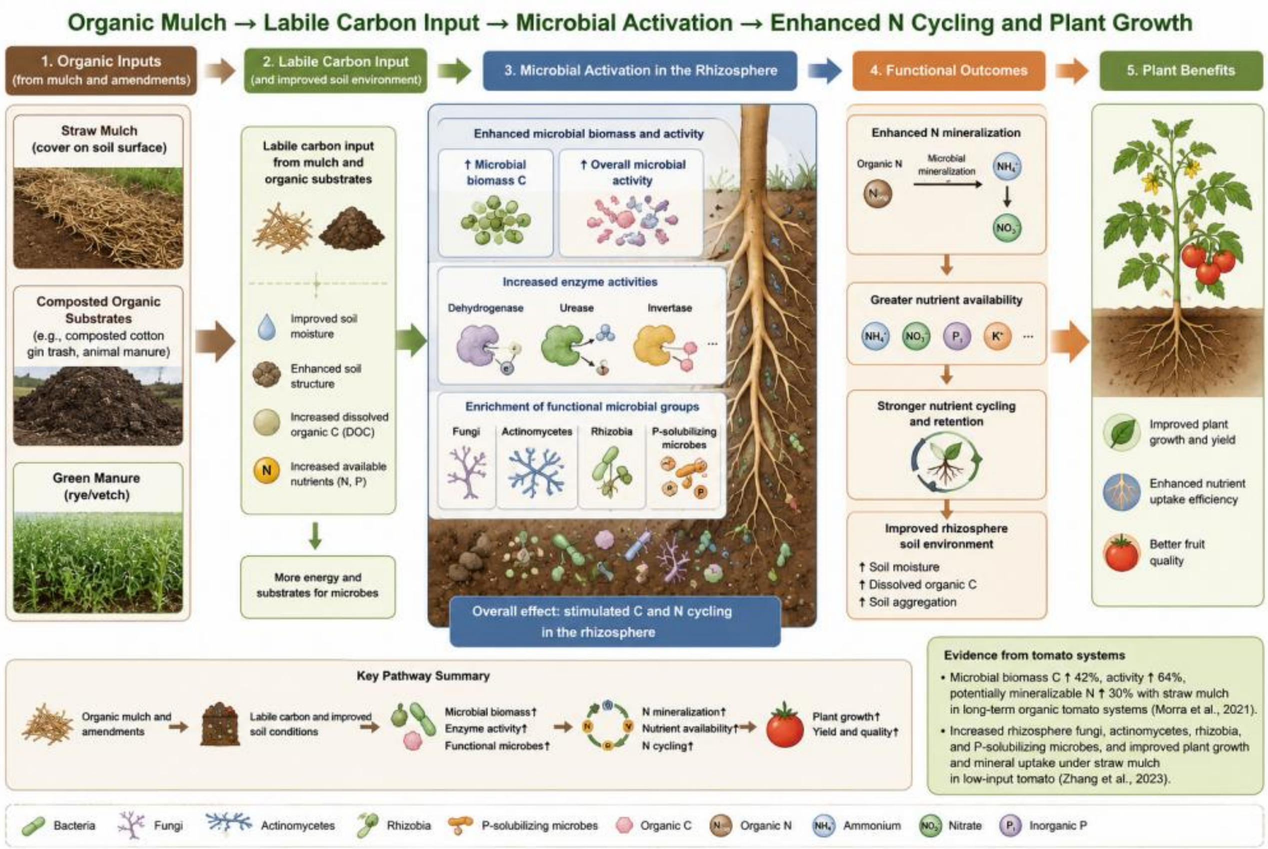

Figure 2 Conceptual framework of organic mulching effects on soil microbial functioning and nitrogen cycling in tomato systems

Mulching combined with organic nutrient inputs also benefits fruit quality and nutrient content. In a net-house experiment, vermicompost at 4 t/ha with mulching produced the highest fresh biomass per tomato plant and markedly increased the P, K, S, Ca, and Mg concentrations in green fruits compared with unfertilized controls, reflecting improved nutrient supply and uptake under mulched, organically fertilized conditions (Naznin et al., 2024). In processing tomato, biodegradable mulch together with digestate-based fertilization maintained or increased yield relative to full mineral NPK and significantly improved key quality parameters, including fruit color, firmness, total soluble solids, and titratable acidity, while enabling reductions in chemical N and P inputs and supporting better cost-income balances (Dukare et al., 2020).

8 Challenges and Future Perspectives

Continuous greenhouse tomato monoculture leads to soil degradation, including nutrient imbalances, decreased microbial diversity, fungal dominance, and impaired C-N cycling, which ultimately reduce yield and soil health. Long-term monoculture also increases the relative abundance of soil-borne pathogens (e.g., Fusarium, Alternaria) and decreases putative antagonistic genera (Bacillus, Paenibacillus, Streptomyces), indicating a shift toward disease-conducive soils that challenges the long-term effectiveness of organic mulching alone.

Organic inputs can partially restore microbial diversity and soil fertility under continuous cropping, but evidence is still limited for tomato-specific mulching strategies. In greenhouse continuous tomato, vermicompost increased SOC, TN, TP, TK and improved bacterial Shannon diversity compared with chemical fertilizer, and was considered more suitable for sustainable production in long-term protected systems. Similarly, combining biochar with microbial inoculants in a 21-year monoculture system improved P and K bioavailability, increased beneficial Bacillus and Paenibacillus, and enhanced tomato yield and quality, suggesting that mulching must be complemented by targeted organic and microbial amendments to overcome continuous-cropping barriers.

Future mulching systems in tomato production will likely rely on integration with optimized fertilization regimes and microbial biostimulants to improve nutrient use efficiency and resilience. A comprehensive review of nutrient management in tomato highlights that conventional nutrient-focused practices often degrade soil fertility under long-term cultivation, and calls for integrative soil-tomato system strategies combining organic inputs, soil amendments and biostimulants to correct nutrient imbalances and sustain yield and quality. Field experiments show that Trichoderma-enriched bio-organic fertilizer, combined with a 25% reduction in chemical fertilizer, maintained tomato yield and markedly improved fruit quality, with benefits linked to enhanced soil microflora and fertility, illustrating how bio-organic inputs can substitute part of mineral fertilization.

Microbial consortia and biofertilizers offer additional opportunities to complement mulching by enhancing nutrient acquisition and stress tolerance. In long-term monoculture soil, co-application of biochar and microbial inoculants increased tomato yield by 23%, improved Vc and soluble sugars, and raised P and K accumulation by up to 57% and 29%, respectively, through shifts in bacterial communities. Likewise, microbial consortia and PGPM-based biofertilizers improved tomato growth, nutrient uptake and yield, particularly under nutrient and water deficits, and modified rhizosphere communities, supporting their use as precision tools to stabilize mulched systems under variable climatic and resource conditions.

Current evidence indicates that organic mulching can enhance soil fertility, microbial functioning and tomato performance, but most studies are short-term and rarely address interactions with continuous cropping, precise nutrient supply, and advanced microbial technologies. Reviews and field studies emphasize critical gaps in long-term, comparative assessments of integrated soil-tomato management strategies, including how different mulch types interact with composts, biochar, bio-organic fertilizers and biostimulants to shape soil microbial networks, nutrient cycling and yield stability over many cropping cycles. Long-term monoculture studies further show that accumulation of SOM, N and P can paradoxically drive microbial degradation and loss of functional genes, underscoring the need to understand thresholds where organic inputs and mulching shift from beneficial to detrimental.

Future research should prioritize multi-factor experiments that combine organic mulching with optimized fertilizer regimes (including reduced mineral inputs), microbial consortia, and bio-organic fertilizers in continuous tomato systems, monitored with high-resolution microbial and functional indicators. Particular attention is needed to how mulches influence disease-suppressive versus disease-conducive microbiomes across monoculture durations, and how precision application of PGPMs and biostimulants can reinforce saprotrophic and antagonistic guilds under mulched soils. Integrating these approaches into holistic, site-specific management frameworks will be essential for designing organic mulching strategies that not only enhance soil biological functions in the short term, but also sustain soil health, yield, and product quality in intensive tomato production over the long term.

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