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Effects of Organic Fertilization on Soil Biological Functions in Sweet Potato Fields

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Abstract Organic fertilization is widely recognized as a sustainable strategy to improve soil health and crop productivity. This review focuses on the effects of organic fertilizers on soil biological functions in sweet potato (*Ipomoea batatas*) fields. Different types of organic fertilizers, including animal-derived, plant-based, and industrial by-products, influence soil physicochemical properties, microbial community structure, and enzyme activities. Organic amendments enhance the abundance and functional diversity of soil microorganisms, particularly those involved in carbon and nitrogen cycling, thereby promoting nutrient availability and soil ecological stability. A case study highlights empirical evidence of organic fertilization improving microbial functions, linking soil biological activity with sweet potato yield and quality. The findings emphasize the critical role of organic inputs in maintaining soil fertility and suggest integrated management strategies for sustainable sweet potato production. Future research should further elucidate the mechanistic pathways of microbial-mediated nutrient transformations under long-term organic fertilization.

Keywords Organic fertilization; Soil microbial functions; Sweet potato; Soil enzyme activity Soil health

1 Introduction

Sweet potato (*Ipomoea batatas* L.) is a major food and nutrition security crop, often cultivated on low-input soils where fertility depletion constrains yield and root quality. In many regions, it has been treated as a “poor man’s crop,” receiving little or no fertilizer, which accelerates soil nutrient mining and threatens long-term productivity. At the same time, demand is rising for roots with enhanced nutritional value, including higher contents of starch, sugars, β-carotene, and health-promoting phytochemicals (Nunes et al., 2020). These agronomic and nutritional challenges have stimulated interest in fertilization strategies that can sustain yields, improve root quality, and maintain soil health in sweet potato systems (Sun et al., 2026).

Organic fertilization—using manures, composts, crop residues, and biochar-based inputs—offers a promising pathway to reconcile production and sustainability objectives. In sweet potato, organic amendments and manures can match or replace mineral fertilization in terms of yield, while improving soil chemical attributes and reducing dependence on synthetic inputs (Daunoras et al., 2024). For example, bovine or poultry manures and farmyard residues have been shown to increase storage root yield, vine biomass, and marketable production, and to maintain soil total C and N over successive seasons (Antonious, 2024). Organic inputs can also enhance root nutritional quality, increasing vitamin C, β-carotene, soluble sugars, and phenolic compounds, and improving eating quality and sensory traits when combined with biochar or formulated organic fertilizers. Such benefits position organic fertilization as a key component of high-quality, nutrient-dense sweet potato production systems.

Beyond yield and quality responses, organic fertilization directly modulates soil biological functions, including microbial diversity, enzyme activities, and nutrient cycling. Long-term organic inputs enhance soil organic matter, aggregation, and macroaggregate-associated C, N, and K stocks, which in turn stimulate microbial biomass and enzyme activities linked to C, N, and P transformations (Mishra et al., 2025). Meta-analyses and long-term field trials indicate that organic amendments increase bacterial diversity indices, favor copiotrophic bacterial and fungal taxa, and elevate activities of N- and P-acquiring enzymes, thereby strengthening soil multifunctionality and nutrient cycling capacity. In cropping systems, these shifts in microbial community composition and function are closely associated with improved nutrient availability, higher crop productivity, and more resilient soil fertility under continued fertilization (Nyarko et al., 2022). However, systematic evidence linking specific organic fertilization regimes to soil biological functions in sweet potato fields—such as microbial community structure, extracellular enzyme profiles, and their relationship to tuber yield and quality—remains limited. The present study addresses this gap by evaluating how different organic fertilization strategies regulate soil biological functions and their contribution to productivity and quality in sweet potato fields.

Organic fertilization in sweet potato systems can simultaneously support yield, enhance root nutritional and sensory quality, and improve soil biological functions through effects on structure, microbial communities, and enzyme-mediated nutrient cycling. Yet, targeted evidence on how specific organic fertilization regimes organize soil biological functions in sweet potato fields is still scarce, justifying detailed investigation in this study.

2 Types and Characteristics of Organic Fertilizers

2.1 Animal-derived organic fertilizers

Animal manures supply organic matter and a broad suite of nutrients, and they strongly influence soil microbial communities and biological functions. Cattle and poultry manures increase soil organic matter and improve plant growth relative to chemical fertilizers alone, while also enriching bacterial taxa associated with nutrient cycling. In short-term field trials, poultry litter caused more pronounced shifts in soil chemistry and bacterial community structure than cattle manure, with higher enrichment of bacterial groups that may signal enhanced fertility (Yadav et al., 2023). These changes are often driven by alterations in soil pH and available nutrients, which act as key filters for bacterial assemblages.

Manure inputs can increase soil microbial biomass, enzyme activities, and functional genes related to nitrogen transformations, thereby intensifying N cycling processes. Long-term applications of farmyard manure or press mud raised soil microbial biomass C and N, dehydrogenase and phosphatase activities, and were closely associated with higher soil organic carbon under cereal systems (Minkina et al., 2022). In organic farming, manure enhanced nitrification, nitrite oxidation, and denitrification potentials and increased abundances of genes such as ureC, amoA, and nxrB compared with unamended soil, indicating stronger N mineralization and nitrification but also higher N loss potential than compost. Studies on chicken manure and other livestock manures similarly report increases in microbial diversity and shifts in dominant phyla that underpin C, N, and S cycling and key soil enzymes, supporting improved fertility but requiring management to minimize nutrient losses.

2.2 Plant-based organic fertilizers

Plant-based fertilizers such as crop residues and composts contribute carbon-rich substrates that fuel microbial metabolism and build soil organic matter. Incorporating partially composted residues from crops like sesame, groundnut, or pearl millet increased microbial biomass C, N, and P and stimulated dehydrogenase and phosphatase activities under wheat, with the greatest effects when combined with higher mineral NPK rates. Residue addition also modifies C and N mineralization dynamics: microcosm studies with pea, wheat, and rapeseed residues showed enhanced C mineralization, transient N immobilization, and strong shifts in bacterial and fungal community composition linked to residue biochemical quality (Zhang et al., 2025). Over the longer term, combining chemical fertilizer with wheat straw markedly increased labile organic C fractions and activities of cellulase and β-glucosidase, along with a higher carbon pool management index compared with fertilizer alone, indicating improved soil quality.

Composts derived from on-farm plant residues can specifically enhance soil biological activity and crop performance. Tomato-residue composts increased soil basal respiration, dehydrogenase, β-glucosidase, phosphatase, and arylsulfatase, while improving nutrient uptake and yields in intensive tomato systems. Comparative work on compost, digestate, and ferment made from the same residues shows that each amendment carries distinct microbial communities that differently reshape soil biota; compost increased soil pH and introduced diverse bacteria and fungi, but ferment and digestate more strongly altered native community composition and nutrient status, particularly dissolved organic C and ammonium (Sant’Anna et al., 2024). Meta-analytic evidence further indicates that residue retention and straw plus fertilizer regimes substantially increase soil organic carbon, total N, and key extracellular enzymes such as urease and phosphatase, confirming residue-based inputs as central levers for soil biological functioning.

2.3 Organic fertilizers derived from industrial by-products

Industrial by-products, including biofertilizers, digestates, and antibiotic fermentation residues, are emerging organic fertilizers that can both recycle wastes and enhance soil biological functions. Long-term field experiments show that co-application of biochar with organic fertilizers such as pig manure increases soil microbial functional genes involved in C, N, P, and S cycling and raises agroecosystem multifunctionality by nearly 20%-30% relative to sole chemical fertilization, reflecting higher enzyme activities, nutrient storage, and microbial biomass. Improved organic fertilizers made from compost, biochar, and anaerobic digestate similarly enhanced plant biomass and soil biological activity more than any single component, likely due to stimulated microbial activity and nutrient release, though intensified microbial N demand reduced plant N concentration and altered N dynamics (Kumari et al., 2024).

Fermentation-derived residues can also function as organic fertilizers, but their impacts on soil biology and environmental risks require careful assessment (Figure 1). Composted cyclosporin A fermentation residue increased soil nutrient contents and enzyme activities, while shifting bacterial diversity toward taxa that promote organic matter decomposition and degradation of residual antibiotic compounds. Soil cyclosporin A and associated resistance genes initially rose after application but were rapidly degraded or returned to background levels within weeks to months, suggesting that properly composted residues can improve fertility without long-term antimicrobial resistance risks (Ouyang et al., 2018). Microbial biofertilizers—formulations of beneficial bacteria or fungi often carried on compost, biochar, or other organic matrices—can further modulate soil communities; inoculants such as Bacillus- or Trichoderma-based products have increased crop yields and available nutrients while enriching “probiotic” microbial taxa and stabilizing microbial networks compared with conventional fertilization. Collectively, these industrial by-product–based fertilizers offer promising tools to enhance soil biological functions and close nutrient loops when their composition and safety are rigorously managed.

3 Soil Microbial Community Structure in Sweet Potato Fields

3.1 Composition and functions of bacterial communities

Organic fertilization consistently reshapes bacterial community composition, often enriching copiotrophic groups adapted to higher nutrient and carbon availability. Global syntheses show that organic amendments increase the relative abundance of Proteobacteria and Bacteroidetes, while often reducing oligotrophic groups such as Acidobacteria and Chloroflexi in fertilized soils. Long-term organic or organic–inorganic fertilization similarly drives copiotroph-dominated assemblages, with Proteobacteria and Bacteroidetes paralleling gains in soil multifunctionality and nutrient cycling capacity (Pan et al., 2025).

These compositional shifts are closely tied to soil C and nutrient status and translate into functional changes. In long-term field experiments, combined organic-inorganic fertilization raised soil organic C and total N and favored taxa implicated in decomposition and C, N, and P transformations, which acted as keystone nodes in co-occurrence networks. Short-term organic amendments increased the geometric mean of enzyme activities and altered bacterial, but not fungal, community-function linkages, indicating that bacterial composition is a primary driver of microbial activities and nutrient-use efficiencies in amended soils (Ye et al., 2019).

3.2 Composition and functions of fungal communities

Fungal responses to fertilization differ from those of bacteria and are strongly context-dependent. A global meta-analysis found that organic amendments did not consistently increase fungal diversity indices, in contrast to their positive effects on bacterial Shannon and Chao1 diversity. Field surveys further showed that fungal communities can be more sensitive to mineral N inputs than to manure, with inorganic fertilization exerting stronger control on fungal composition in some fluvo-aquic soils (Guo et al., 2018).

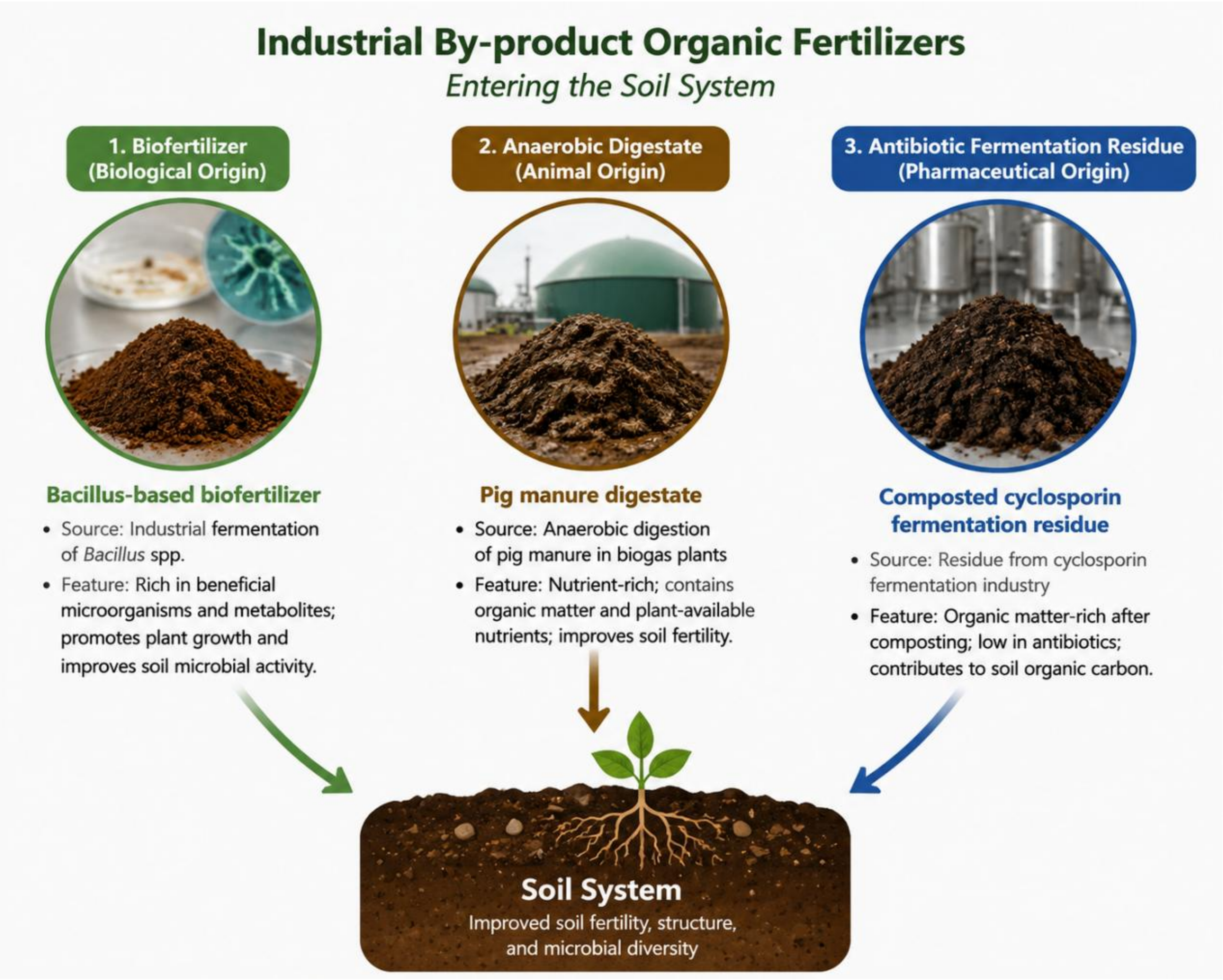

Figure 1 Types of industrial by-product–based organic fertilizers and their inputs to soil systems

Where organic manure is dominant, fungal community structure can still be substantially modified, particularly at finer taxonomic levels. Long-term manure applications with equal N input altered fungal alpha diversity and reduced the abundance of soil-borne pathogens such as Fusarium, suggesting a disease-suppressive role linked to enhanced soil organic C and improved properties. In acidic Ultisols, however, decades of mineral and organic fertilization did not change overall fungal diversity, although literature synthesis indicated diversity losses mainly when fertilization raised soil pH above 6, highlighting fungal sensitivity to pH shifts mediated by fertilizer regimes (Kong et al., 2024).

3.3 Soil microbial diversity indices and their influencing factors

Organic amendments generally enhance microbial diversity metrics and are positively associated with ecosystem functioning. A global meta-analysis of 219 studies reported that organic amendments significantly increased Shannon, richness, and phylogenetic diversity and improved community structure compared with mineral fertilization, with diversity and structure both positively related to microbial functionality and crop yields (Cui et al., 2023). Another worldwide synthesis focusing on composition confirmed that organic amendments increased bacterial Shannon and Chao1 indices, while fungal diversity remained largely unchanged, emphasizing group-specific responses of diversity indices.

The magnitude and direction of diversity responses depend strongly on environmental and management factors. For bacterial communities, soil pH emerged as the main driver of how organic and chemical–organic fertilization affected alpha diversity and community structure across agroecosystems (Luo et al., 2022). Beyond pH, soil texture, organic fertilizer type, crop type, and climate modulated the response of dominant bacterial and fungal phyla to organic amendments, and shifts in soil organic C and N were tightly coupled to changes in both diversity metrics and functional gene abundances linked to C and N cycling.

4 Effects of Organic Fertilization on Soil Physicochemical Properties

4.1 Soil pH and buffering capacity

Organic fertilization can substantially modify soil pH dynamics and the capacity of soils to resist acidification. In a sweetpotato-wheat rotation, long-term NPK fertilization accelerated acidification, whereas adding swine-manure organic fertilizer (NPKM) slowed the pH decline and significantly increased cation exchange capacity and pH-buffering capacity compared with unfertilized soil. Similar evidence from long-term red soils shows that chemical NPK alone gradually lowered pH, while organic fertilizer raised pH slightly each year, indicating a net mitigation of acidity under mixed fertilization (Khan et al., 2024).

Beyond crop- and region-specific trials, meta-analyses and mechanistic studies clarify how manure-derived organic matter increases buffering. Across multiple fertilization regimes, manure additions increased pH-buffering capacity by up to 80%, largely through protonation of organic functional groups and the release of base cations from organic matter surfaces (Seyedsadr et al., 2022). In vegetable systems, substituting mineral N with organic manure also tended to increase pH, with intermediate substitution ratios (35%-70% organic N) giving both higher pH and yields, especially in initially acidic soils (Dong et al., 2021). Together, these results indicate that organic fertilization does not necessarily raise pH strongly but consistently strengthens buffering capacity and slows acidification in intensively fertilized systems.

4.2 Soil organic matter content and nutrient availability

Organic fertilizers are a primary tool to rebuild soil organic matter (SOM) while improving nutrient stocks. A broad review shows that organic inputs such as manures, composts, and biochar-based fertilizers generally increase SOM, cation exchange capacity, and microbial activity, which in turn enhance nutrient uptake and nutrient use efficiency. In gray desert soil, progressively replacing mineral N and P with organic N from fertilizers increased soil organic matter and available N, P, and K over three years, with higher organic substitution treatments showing significantly greater nutrient availability than mineral fertilizer alone.

Long-term comparisons of mineral versus organic fertilization further highlight SOM-related benefits. Experiments with manure and slurry applications showed higher soil organic carbon, humic substances, and available nutrients, along with lower acidity, than NPK-only treatments, indicating improved humus quality and nutrient-supplying capacity under organic manuring. At the same time, studies of organic amendments emphasize that nutrient release from farmyard manure is spread over several years and depends on factors such as livestock type and management, making re-application schedules crucial for sustaining nutrient supply (Shi et al., 2018). Thus, organic fertilization enhances SOM and nutrient availability, but its slower nutrient release patterns require careful integration with mineral inputs in high-demand crops like sweet potato.

4.3 Changes in soil moisture retention and aeration

By modifying soil structure, organic fertilizers influence water retention and aeration, both critical for root growth and microbial processes. Reviews of long-term organic waste recycling show that organic amendments generally increase plant available water by up to about 30% (volumetric basis), largely via higher organic carbon and lower bulk density, which improve pore-size distribution and aggregation. Field experiments confirm that amendments such as farmyard manure and biochar increase soil moisture content and water-holding capacity, contributing to improved crop growth under water-limited conditions.

At the pore-scale, recent work demonstrates that compost and manure can enhance both macroporosity and aeration. In semiarid corn fields, compost and stover incorporation increased mean pore size, air-filled porosity, and gas diffusivity, indicating better aeration and higher saturated hydraulic conductivity relative to unamended soil. Similarly, large one-time additions of industrial organic sludges increased soil macroporosity by 20%-27%, improving aeration and rapid infiltration several years after application. Short-term pot studies with composts, vermicomposts, and digestate also reported improved water retention and water use efficiency, associated with more complex pore networks and increased macroporosity (Fan et al., 2024). Collectively, these findings suggest that organic fertilization can simultaneously enhance water storage and gaseous exchange, creating more favorable physical conditions for sweet potato root development and soil biota.

5 Regulatory Effects of Organic Fertilization on Soil Enzyme Activities

5.1 Activities of key carbon- and nitrogen-cycling enzymes

Organic fertilization generally stimulates β-glucosidase activity, reflecting enhanced decomposition of cellulose and turnover of soil organic carbon (Figure 2). Long-term dairy manure increased β-glucosidase by 6%-14% compared with inorganic fertilizers in a corn-soybean rotation, in parallel with higher cold-water extractable C and N, indicating greater labile pools and active C cycling (Liu et al., 2020). Across many systems, manure raised C-acquiring hydrolases, including β-glucosidase, by 1.3-3.3 times relative to unfertilized soils, showing that organic inputs accelerate C cycling by providing substrates and promoting microbial growth.

Urease responds similarly, linking organic fertilization to nitrogen mineralization and availability. In the same long-term rotation, urease activity under dairy manure averaged 26.8% higher than with inorganic fertilization at planting, and correlated with microbial community structure, suggesting tight coupling between N-cycling enzymes and microbial assemblages. A global synthesis found that manure, especially swine manure, produced large gains in N-cycle indicators, with urease increasing by more than 250% compared with non-manured soils, evidencing strongly accelerated N turnover and potential for both improved N supply and higher risk of N losses.

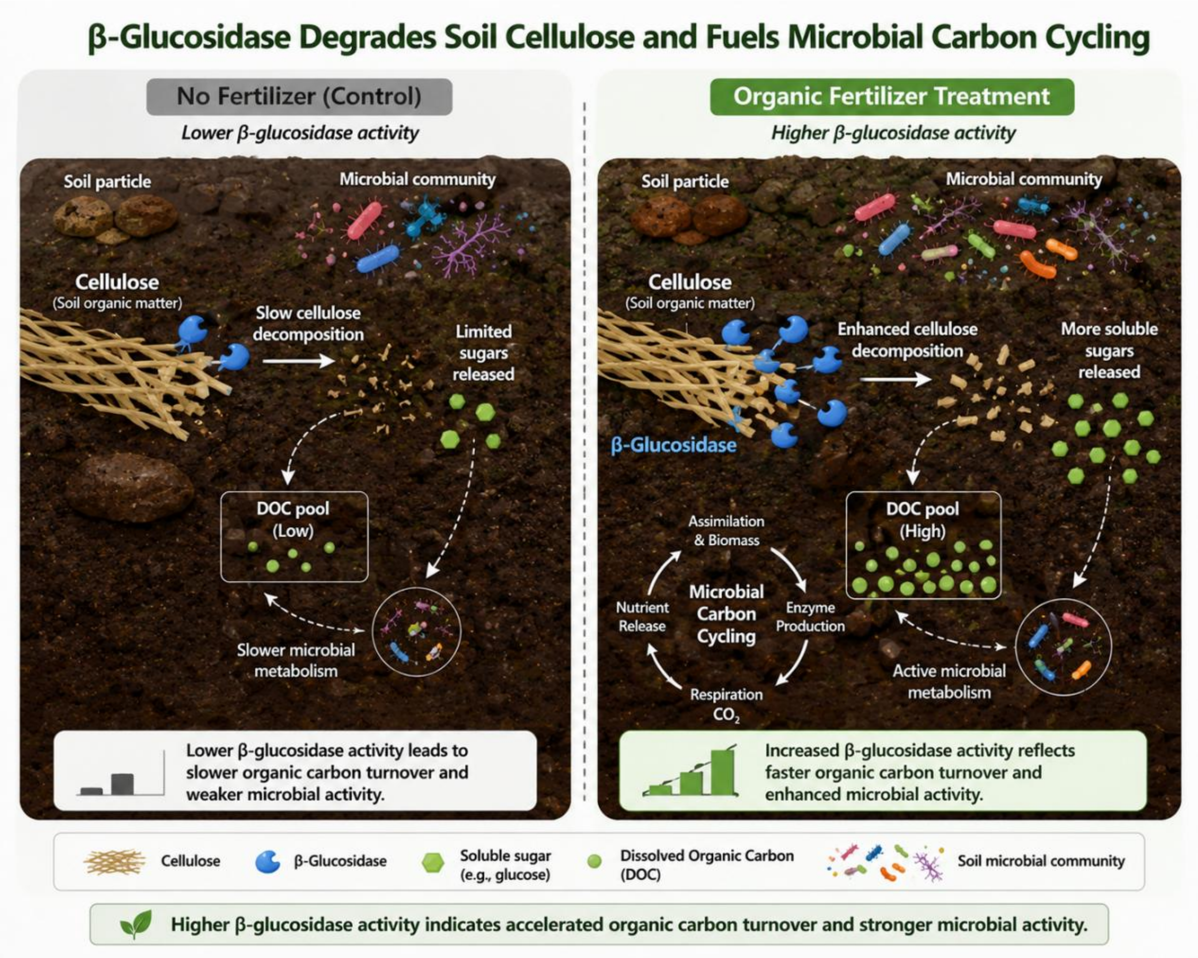

Figure 2 Mechanism of β-glucosidase-mediated cellulose decomposition and soil organic carbon turnover under organic fertilization

5.2 Phosphorus-cycling enzymes and micronutrient mobilization

Phosphatases are highly responsive to organic amendments and mediate P mobilization from organic pools. Meta-analysis of 106 studies showed that organic amendments increased acid and alkaline phosphatase activities by 22% and 53%, respectively, alongside higher soil organic C, total N, available P, and microbial biomass, indicating that improved C:N:P stoichiometry supports phosphatase-producing microbes (Bhosale et al., 2024). A broader synthesis of P-cycling genes found that organic matter alone or combined with inorganic fertilizer enhanced microbial P, phosphatase activity, and phoD gene abundance, especially with longer experimental duration and warmer, wetter climates.

Organic P sources can also mobilize micronutrients through phosphatase-linked processes. In calcareous soil, phosphate-rich organic manure (PROM) reduced pH and $CaCO_3$ while increasing organic C and availability of N, P, K and micronutrients such as Fe and Mn; alkaline phosphatase and urease rose in tandem with these nutrient gains, with strong positive correlations between enzyme activities and micronutrient availability. Similar PROM effects were observed in calcareous and non-calcareous soils, where 100% P_2O_5 as PROM most strongly enhanced alkaline phosphatase and urease and improved P and micronutrient supply over 120 days of incubation (Wang et al., 2025).

5.3 Impacts of enzyme activity changes on soil nutrient dynamics

Shifts in enzyme activities under organic fertilization feed back on soil C and N storage and fluxes. Global analysis of N fertilization showed that increases in β-glucosidase, urease and related hydrolases coincided with higher soil organic C and total N, and that the combined response of C-acquiring enzymes tracked microbial biomass, suggesting enzyme activities can act as proxies for active C turnover and microbial C demand (Bhosale et al., 2024). A manure meta-analysis likewise reported much larger increases in microbial C and N (≈+80%) than in bulk organic C and N pools, interpreting the 1.3-3.3-fold rise in C-, N-, P- and S-acquiring enzymes as evidence of accelerated nutrient cycling and improved fertility, while cautioning about enhanced mineralization and possible nutrient loss if not well managed.

Phosphatase responses under organic amendments also have clear implications for P dynamics. Meta-analysis of phosphatase-harboring communities showed that soil C:P and N:P ratios and microbial biomass C were dominant predictors of phosphatase gene abundance and activity, meaning that organic inputs which raise labile C and adjust stoichiometry can intensify biological P mineralization. A complementary synthesis of fertilization effects on P-related genes found that organic matter and organic–inorganic combinations increased microbial P, phosphatase activity, and phoD or phoC gene abundance, while structural equation models linked phosphatase activity to soil organic C, pH, and functional gene abundance, underscoring that enzyme-mediated P mobilization is tightly governed by both resource availability and microbial functional capacity.

6 Effects of Organic Fertilization on Soil Microbial Functions

6.1 Responses of carbon-cycling functional microbial groups

Organic fertilization alters the genetic potential and structure of carbon-cycling microbes, often shifting pathways of C fixation and degradation. In long-term black soil trials, manure increased genes associated with C fixation via the rTCA cycle (icd) but decreased genes linked to CO oxidation (coxS) and the reductive acetyl-CoA pathway (cooC), indicating a reorganization of autotrophic carbon metabolism under organic inputs. The same study showed organic fertilization enriched Proteobacteria and Planctomycetes carrying C-cycling genes, while suppressing oligotrophic Verrucomicrobia, suggesting a shift toward copiotrophic carbon processors in manure-amended soils (Hu et al., 2022).

Across systems, organic amendments generally increase the abundance of genes for decomposition of starch, cellulose, chitin, and lignin, but they may also slow overall transformation rates by promoting more diverse and stable communities. In black soils, chemical fertilization enhanced the abundance of genes for C degradation and accelerated conversion of recalcitrant C to labile pools, whereas manure and combined regimes increased diversity and stability and decelerated nutrient transformation processes. Long-term manure use similarly raised functional genes for C, N, P, and S cycling and increased C and N cycling rates, with dissolved organic C emerging as a key driver of community shifts and C-cycle functioning (Lazcano et al., 2021).

6.2 Responses of nitrogen-cycling functional microbial groups

Nitrogen-cycling microbes respond strongly to fertilizer form, with organic inputs often broadening the spectrum of N transformations. Metagenomic work in black soils found chemical fertilizers boosted genes for N degradation, nitrification, and anammox, while manure preferentially enhanced assimilatory and dissimilatory nitrate reduction genes, and chemical-manure combinations greatly increased denitrification potential, implying higher N_2O risk under excess N. At the aggregate scale, manure and peat decreased DNRA genes (napA, nrfA) but increased amoA, nirK, and nasB, concentrating nitrification and denitrification potential in microaggregates that also held more SOC and NO_3^- (Ahmed et al., 2023).

Long-term organic fertilization tends to increase total N-cycling gene abundance and diversify pathways beyond simple nitrification. In a 35-year wheat system, manure alone or with mineral N raised total N-cycling genes by 8%-12% over mineral N, increasing genes for nitrification, denitrification, and both assimilatory and dissimilatory nitrate reduction, while mineral N alone mainly increased nitrification genes (Luo et al., 2022). Meta-analysis across 47 field studies showed N fertilization in general elevated amoA, nirK, nirS, and nosZ abundances, with organic fertilizers exerting stronger positive effects than inorganic forms, and gene responses modulated by fertilization duration, rotation, and soil pH.

6.3 Changes in microbial stress resistance and ecological stability

Organic fertilization often enhances microbial resistance and resilience to disturbance by increasing diversity and stabilizing network properties. In drought mesocosms, soils with organic fertilizer maintained higher bacterial diversity and showed faster compositional recovery after rewetting than chemically fertilized soils, with improved pathogen-inhibiting functions during late recovery stages. Similar patterns in semi-arid systems, where manure and compost raised network modularity and density, indicate strengthened ecosystem resilience and tighter links between key genera (e.g., Nitrospira) and nutrient status (Hoang et al., 2022).

At broader scales, balanced mineral–organic fertilization has been shown to increase microbial diversity, functional gene abundance, and functional resilience to environmental stressors, partly through improved soil structure and organic C. Long-term organic inputs also promoted microbial diversity and community stability while slowing nutrient transformation processes, revealing a trade-off between rapid turnover and stable multifunctionality under different fertilization strategies. Experiments manipulating biodiversity further show that organic fertilization accelerates resilience of soil multifunctionality to biodiversity loss, with bacterial diversity–multifunctionality relationships several-fold stronger than under mineral fertilization, emphasizing the role of diverse copiotrophic taxa in stabilizing ecosystem functions (Khan et al., 2025).

7 Case Study: Empirical Evidence of Organic Fertilization Effects on Soil Microbial Functions in Sweet Potato Fields

7.1 Experimental design and fertilization treatments

Field studies on sweet potato under organic fertilization typically use randomized block designs with multiple fertilizer types and doses to capture variation in soil and crop responses. Newly reclaimed land experiments, for example, tested graded rates of commercial organic fertilizer, sheep manure, mushroom residue, and a fixed chemical NPK treatment plus an unfertilized control, with three replicates over three consecutive years (Shu et al., 2022). Fertilizers were incorporated into the 0-20 cm soil layer before transplanting sweet potato seedlings, and plant and soil samples were collected at a fixed time each season to ensure comparability across treatments and years.

Other sweet potato trials emphasize combinations of organic inputs with mineral or bio-based fertilizers. Under plastic film-mulched drip fertigation, treatments compared no fertilizer, water-soluble NPK, biofertilizer (containing Bacillus and Trichoderma) plus water-soluble NPK, and split versus basal applications, in a continuous monoculture system (Mishra et al., 2025). Additional work contrasted inorganic compound fertilizer with stand-alone organic fertilizer and biochar-based organic fertilizers with different biochar ratios, to assess how integrating biochar modifies soil properties, yield, and tuber quality traits under field conditions (Figure 3).

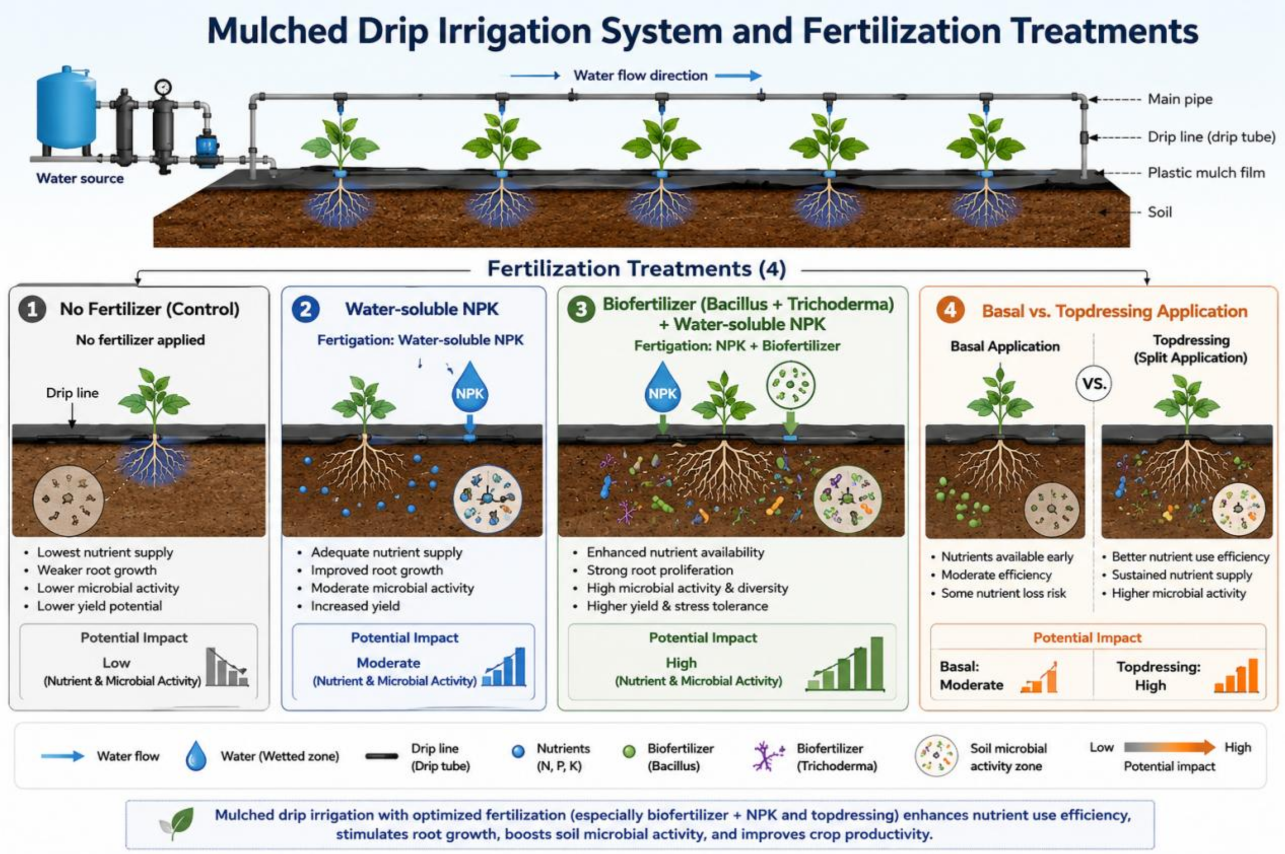

Figure 3 Drip fertigation under plastic film mulch with different combinations of organic, biofertilizer, and mineral inputs in continuous sweet potato monoculture

7.2 Methods for assessing soil microbial communities and functions

Soil microbial communities in organic fertilization trials are commonly characterized using high-throughput amplicon sequencing. Several studies extracted DNA from rhizosphere or bulk soil and sequenced bacterial 16S rRNA and fungal ITS regions to compare community structure under organic versus chemical fertilization, revealing distinct bacterial and fungal assemblages and higher decomposer diversity in organically managed soils. In sweet potato systems on newly reclaimed land, rhizosphere samples stored at -80 °C were used to profile bacterial and fungal composition, allowing links between specific taxa, organic matter increases, and soil improvement to be identified (Shu et al., 2022).

Microbial functions are assessed through a suite of biochemical and molecular indicators. Enzyme assays such as dehydrogenase, phosphatase, sucrase, and urease activities are widely measured to reflect overall microbial activity and nutrient cycling; in sweet potato under biofertilizer and split fertigation, these activities were quantified colorimetrically to relate fertilization practices to nutrient activation and soil organic matter accumulation (Mishra et al., 2025). Broader functional potential can be evaluated using high-throughput qPCR arrays targeting C-, N-, P- and S-cycling genes, or metagenomic and functional gene approaches, which quantify changes in functional gene abundance under different organic and combined fertilization regimes.

7.3 Major findings and data interpretation

Across systems, organic amendments consistently enhance soil biological functions compared with mineral fertilization alone. Meta-analysis of 219 studies showed that organic amendments increased microbial diversity (Shannon, richness, phylogenetic diversity) and shifted community structure, with both diversity and structure positively related to microbial functionality and crop yields. In long-term fertilized soils, organic fertilizer also improved soil multifunctionality relative to inorganic inputs, with rare microbial taxa emerging as disproportionately important drivers of multiple biogeochemical processes.

Sweet potato–specific trials confirm these general patterns while highlighting context-dependent responses. In continuous sweet potato cropping under drip fertigation, biofertilizer combined with split water-soluble fertilization increased dehydrogenase, alkaline phosphatase, sucrase, and soil organic matter, along with higher available P and improved nutrient use efficiency, leading to better yields and tuber quality than non-biofertilized treatments (Mishra et al., 2025). On newly reclaimed land, different organic fertilizers all raised soil organic matter and altered bacterial and fungal communities, providing a microbial basis for improved soil quality and demonstrating that organic amendments can rapidly make immature soils suitable for sweet potato production. Together, these findings indicate that well-designed organic fertilization regimes can restructure soil microbiomes, stimulate key biological functions, and support sustainable sweet potato yields.

8 Indirect Effects of Organic Fertilization on Sweet Potato Yield and Quality

8.1 Relationships between soil microbial functions and yield performance

Studies in sweet potato systems show that organic fertilization improves soil biological functioning and can support high yields, but responses depend on fertilizer type and rate. In newly reclaimed land, commercial organic fertilizer, sheep manure, and mushroom residue all increased soil organic matter and altered bacterial and fungal communities, providing a microbial basis for better soil quality and productive sweet potato cultivation in immature soils. Under subtropical semiarid conditions, sweet potato cultivation with compost or biochar increased enzyme activities and microbial biomass P relative to bare fallow, indicating more active nutrient cycling, although yields still lagged behind the cultivar’s potential, pointing to the need for optimized nutrient supply and salinity management (Antonious, 2024).

Evidence from other root and tuber crops links microbial diversity and function more directly to yield. A global meta-analysis demonstrated that organic amendments increase microbial diversity and functionality, and both are positively related to crop yields, with microbial functionality and abiotic properties exerting the strongest influence. In potatoes, combined biochar and organic fertilizer enhanced soil fertility, rhizosphere bacterial diversity, and particularly beneficial taxa; structural equation modeling showed that bacterial diversity directly increased tuber yield, while soil fertility acted indirectly through its effects on microbial diversity (Zhang et al., 2024).

8.2 Soil health and improvement of sweet potato quality

Organic fertilization not only enhances yield components but can also improve sweet potato nutritional and sensory quality through its effects on soil health. In savanna soils without prior cultivation, poultry and cattle manure or composts increased soil organic matter and P, and higher organic matter and satisfactory P were closely associated with greater commercial root mass and number, translating into higher yields (Tan et al., 2024). In similar systems, organic amendments improved availability of N, P, K, Ca, Mg, and organic C, and were linked to increased β-carotene and protein content in sweet potato roots, highlighting quality gains alongside yield improvements.

Specific organic inputs can markedly enhance root composition and eating quality when soil properties are improved. Cow manure applied to field-grown sweet potato significantly increased storage root yield and raised vitamin C, β-carotene, soluble sugars, and total phenols compared with several other organic amendments and an unfertilized control, indicating superior nutritional quality (Dias et al., 2021). Biochar-based organic fertilizers in sweet potato further improved soil physical conditions, pH, and available nutrients, leading to higher yields and enhanced starch, sugar, sucrose, and β-carotene contents, as well as better texture and flavor scores than mineral fertilization alone.

8.3 Recommendations for integrated soil fertility management

Integrated soil fertility management (ISFM) frameworks emphasize combining organic and mineral sources with attention to microbial processes to sustain yields and soil health. In a wheat–sweet potato rotation, long-term application of mineral NPK with straw return or farmyard manure substantially improved macroaggregation, soil organic carbon, available K, and enzyme activities relative to NPK alone, and the manure treatment achieved the highest soil quality index, indicating strong benefits of combined fertilization for this rotation system (Sande et al., 2024). Broader reviews of tropical agro-ecosystems similarly conclude that combining manure or compost with mineral N and P consistently raises grain yields by 50%-100% and enhances long-term soil fertility compared with either source alone.

Meta-analyses and system-level reviews suggest several practical guidelines that can be adapted for sweet potato fields. Organic amendments should partially substitute mineral fertilizers rather than fully replace them, as mixed strategies maintain high yields while conserving microbial diversity and functionality. Reviews of integrated nutrient management highlight that optimal combinations often involve 20%-50% of nutrient requirements supplied by high-quality organic resources (e.g., vermicompost, manures) with the remainder from mineral fertilizers, sometimes complemented by biofertilizers to improve nutrient-use efficiency and soil biological health (Hou et al., 2024; Wang et al., 2024). Such integrated approaches are particularly promising for sweet potato systems that demand high N, P, and K, yet require sustained microbial activity and good soil physical structure for stable root yield and quality.

9 Conclusions and Future Perspectives

Across the preceding sections, a consistent picture emerges that organic fertilization improves the biological functioning of soils cultivated with sweet potato. Organic inputs increase soil organic matter, enhance aggregate stability, and moderate pH dynamics, which together create a more favorable habitat for diverse microbial communities. Bacterial and, to a lesser extent, fungal assemblages shift toward groups better adapted to high carbon and nutrient availability, with clear enrichment of decomposers and nutrient-transforming taxa in organically amended soils. These structural changes are closely linked to enhanced microbial processes. Activities of key C-, N- and P-cycling enzymes generally increase under organic or combined organic-inorganic fertilization, supporting more efficient nutrient mineralization and tighter coupling between microbial metabolism and plant demand. Functional microbial groups involved in carbon degradation, nitrogen transformation, and phosphorus mobilization respond strongly, while network analyses indicate improved community stability and stress resistance. In sweet potato systems specifically, these biological improvements translate into higher biomass and yield, better nutrient use efficiency, and greater suitability of newly reclaimed or degraded soils for productive cultivation.

Despite clear benefits, several limitations constrain the current understanding of organic fertilization effects in sweet potato fields. Many experiments are short- to medium-term and conducted at single sites, which limits inference about long-term trajectories of soil organic matter stabilization, greenhouse gas emissions, and cumulative impacts on soil biota. Sweet potato-focused studies remain fewer than those for other root and tuber crops, and often use a narrow range of organic materials or application rates. Methodologically, most work emphasizes community composition and bulk enzyme activities, while providing less detail on in situ process rates, root-microbe interactions, and micro-scale heterogeneity within the rhizosphere. Links between specific microbial taxa, functional gene expression, and plant health (for example, disease suppression or tolerance to drought) are still only partially resolved. In addition, potential trade-offs—such as micronutrient imbalances, contaminant loads in manures, or increased nitrous oxide emissions—are rarely quantified in an integrated way, especially under intensive sweet potato production regimes.

Future studies should prioritize long-term, multi-site experiments that compare different organic sources, substitution ratios with mineral fertilizers, and tillage or mulching practices under sweet potato. Combining high-resolution microbiome and functional gene profiling with direct measurements of nutrient fluxes, greenhouse gas emissions, and root traits would clarify causal pathways from management to microbial processes and crop performance. Particular attention is needed for newly reclaimed, acidic, or structurally degraded soils, where sweet potato is often expanded and where responses to organic amendments may be especially pronounced. On the application side, there is substantial potential to design site-specific organic fertilization strategies that balance yield, soil health, and environmental performance. Optimizing rates and timing, integrating biochar or biofertilizers, and coupling organic inputs with cover crops or diversified rotations could further enhance microbial diversity and multifunctionality in sweet potato systems. Developing decision-support tools that incorporate soil biological indicators, together with clear guidelines for quality control and safe use of organic amendments, will help farmers implement these practices effectively. In the longer term, such biologically informed fertilization regimes can contribute to resilient, low-input sweet potato production and to broader goals of climate-smart and sustainable agriculture.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

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