3 Evaluation Indicators of Soil Biological Activity in Vegetable Production Systems

3.1 Soil microbial abundance and community structure

Soil microbial abundance in vegetable systems is commonly quantified using microbial biomass carbon and nitrogen (MBC, MBN) or gene-based proxies such as 16S rRNA and ITS copy numbers. In long-term organic vegetable production, frequent cover cropping and organic matter inputs can raise MBC to relatively high levels for sandy soils, and MBN responds in parallel, highlighting biomass as a sensitive integrator of management effects on soil biology. Global comparisons further show that microbial biomass and diversity covary strongly with soil carbon content, so shifts in soil organic matter under intensive fertilization or organic amendments directly influence biomass-based indicators (Bastida et al., 2021). These metrics therefore provide a robust, quantitative basis for assessing how biofertilizers and organic inputs modify the “size” of the active microbial community in vegetable systems.

Community structure and diversity indicators complement biomass data by revealing how taxa respond to intensive vegetable cultivation and management. High-throughput sequencing of greenhouse vegetable soils has shown that continuous cultivation can reduce bacterial and fungal richness and alter dominant phyla, with declines in OTU abundance and diversity after several years of high-input production. Conversely, agroecological and organic vegetable systems that include mulches, composts, or cover crops tend to increase bacterial and fungal diversity and shift communities toward beneficial groups such as Actinobacteria and other decomposers, changes that correlate with improved soil nutrients and organic matter (Moulin et al., 2023). Together, microbial biomass and community composition form core indicators to evaluate the impact of biofertilizers on soil biological activity and ecological resilience in vegetable production.

3.2 Soil Enzyme activity indicators

Soil enzyme activities provide functional indicators of microbial processes underpinning nutrient cycling and are widely used to assess soil quality in agroecosystems. Hydrolases such as urease, phosphatases, and β-glucosidase are particularly informative because they catalyze key steps in nitrogen, phosphorus, and carbon turnover and respond sensitively to changes in management, organic matter, and disturbance (Jat et al., 2021). Reviews emphasize that these enzymes are operationally practical and more responsive to tillage and structure modification than many physicochemical variables, making them useful early-warning indicators of biological changes in intensively managed soils (Attademo et al., 2021). In vegetable systems where biofertilizers and organic amendments are applied to improve fertility, monitoring these enzymes can directly reflect enhanced mineralization and nutrient availability.

Field and long-term management studies confirm that enzyme activities differentiate contrasting fertility regimes and cropping strategies. Under climate-smart cereal rotations, dehydrogenase, β-glucosidase, phosphatases, urease, and other enzymes vary significantly with management scenario, crop growth stage, and rhizosphere versus bulk soil, and are strongly regulated by soil organic carbon (Raimi et al., 2023). In vegetable-based systems, organic fertilization and manure inputs generally increase activities of dehydrogenase, β-glucosidase, and urease compared with conventional fertilization, with enzyme responses closely tied to microbial biomass and organic matter content (Antonious et al., 2020; Raimi et al., 2023). Because biofertilizers often supply both functional microbes and substrates, increases in these enzyme activities serve as key indicators that soil biological functioning and nutrient cycling capacity have been stimulated.

3.3 Soil respiration and microbial biomass carbon and nitrogen

Soil respiration, measured as CO_2 efflux, is a central indicator of overall microbial metabolic activity and carbon turnover. Seasonal monitoring in agricultural soils shows that microbial respiration tracks temperature and plant presence, with higher rates where soil organic carbon is greater and fresh residues are retained (Schnecker et al., 2023). In organic vegetable systems with frequent cover cropping or compost additions, soil respiration and related metrics such as the metabolic quotient often increase, reflecting enhanced decomposition and active microbial communities fueled by larger carbon inputs (Antonious et al., 2020). However, interpreting respiration alone can be misleading, so it is most informative when combined with microbial growth or biomass data to distinguish efficient biomass production from rapid C loss.