Studies on grapevines have shown that microbial enrichment can promote nutrient mineralization and enhance soil biological fertility. Hazarika et al. (2024) reported that the combined application of organic amendments, biofertilizers, and biodynamic preparations increased soil total and available nutrient contents, cation exchange capacity, and bacterial abundance, while also improving the micronutrient status of grapevine leaves. Bio-organic fertilizers containing *Bacillus* or *Trichoderma* increased soil organic matter, available N, P, and K, enhanced catalase, urease, sucrase, and nitrate reductase activities, and improved seedling shoot and root growth (Liu et al., 2024). Likewise, compost inoculated with fungal consortia enhanced soil enzyme activity, while long-term compost use promoted microbial biomass, phosphorus-solubilizing bacteria, and enzymes involved in nutrient turnover (Lucchetta et al., 2023; Lucchetta et al., 2025). However, microbial amendments are not always sufficient as stand-alone replacements for mineral fertilization, especially where soil organic matter is low and nitrogen supply is limiting (Lisek and Popińska, 2025).

2.3 Factors determining organic fertilizer efficiency

A central factor determining the efficiency of organic fertilizers is the carbon-to-nitrogen ratio, because it strongly regulates whether nitrogen is mineralized and released to the vine or temporarily immobilized by microorganisms. Organic amendments with a C/N ratio below 30 generally release mineral N, whereas higher ratios tend to favor immobilization and reduce immediate N availability (Baldi et al., 2022). Shen et al. (2024), in a meta-analysis of agricultural residues, further demonstrated that an initial carbon-to-nitrogen ratio (C/N) of approximately 25-30 is generally more favorable for improving compost maturity and nutrient accumulation, whereas a C/N ratio of 30-35 often prolongs the composting period. This issue is especially relevant for winery wastes, since their lignin, cellulose, and polyphenol contents can slow decomposition unless the composting process is properly balanced and matured (Mitropoulou et al., 2025).

Efficiency also depends on application rate, maturity of the amendment, and environmental conditions in the soil. In degraded vineyard soils, compost applied at 22.4-33.6 t/ha increased soil N, C, pH, exchangeable K and Ca, available P, and petiole N, P, and K, while improving pruning weight, berry weight, and later vine yield without altering juice soluble solids or acidity (Wilson et al., 2021). Deep or repeated compost application also increased organic carbon, humification, microbial biomass, and shoot growth, and organic fertilization in semiarid vineyards enhanced aggregate stability, microbial activity, and long-term C and N protection in soil (Burg et al., 2023; Fracetto et al., 2025).

Responses vary with cultivar, soil type, rainfall, and prior fertility status, and excessive or overly rapid N mineralization can stimulate vegetative growth while reducing yield or berry quality (Kokkonen et al., 2025). Organic fertilizer efficiency in vineyards emerges from the interactions among fertilizer characteristics, application management, soil properties, grape cultivar, environmental conditions, and vineyard management practices, which collectively regulate responses across the soil-grapevine-fruit continuum (Figure 1). Accordingly, an effective organic fertilization strategy should not be defined by amendment type alone, but should instead match amendment composition, maturity, application rate, and microbial activity with vine nutrient demand and site-specific soil conditions.

3 Effects of Organic Fertilization on Vineyard Soil Health

3.1 Improvement of soil physical properties

Organic fertilization can consistently improve soil aggregation, porosity, and bulk density in vineyards. In a 10-year experiment conducted in a semiarid Mediterranean vineyard, the application of pruning residues combined with sheep manure or the use of a legume cover crop increased the proportion of stable soil aggregates compared with inorganic fertilization (García-Orenes et al., 2016). In a three-year greenhouse grapevine experiment, Wu et al. (2024) reported that organic fertilizers reduced soil bulk density and increased porosity, whereas the chemical fertilization control showed the lowest soil porosity.

These improvements in soil structure are closely associated with organic matter inputs. Reviews of viticulture have shown that organic fertilization can improve soil structure and increase soil organic matter (SOM) content, while