compost provided higher K input than pomace vermicompost on a dry-matter basis (Baldi et al., 2022; Wu et al., 2024). More generally, Hu et al. (2023) found that K supply can also stimulate P uptake and redistribute nutrients among grapevine organs, with root K status and soil available K closely associated with scion K accumulation. Seasonal nutrient-partitioning studies show that K demand peaks after bloom and during berry development, and that nutrient distribution differs among organs and production systems, so the effect of organic K sources depends on synchronization with these periods of high uptake (Chen et al., 2025; Wang et al., 2026).

4.2 Effects on secondary and micronutrient nutrition

Organic fertilization can modify calcium and magnesium uptake, but the direction and magnitude of change are less consistent than for N, P, and K. Organic nutrition significantly affected leaf Mg in high-altitude grapevines and generally enhanced mineral composition, while long-term field data showed that some biofertilizer treatments increased soil Mg and pH, and liming improved leaf Ca status in one cultivar (Lisek and Popińska, 2025). In 'Syrah', goat manure increased must Mg in one season but reduced must Ca in others, indicating that secondary nutrient responses can vary by year and tissue evaluated (da Silva et al., 2024). More broadly, organic additions are reported to supply Ca and Mg, lower pH through organic acid release, and improve root-system performance, which can favor secondary nutrient acquisition under some soil conditions (Hasan et al., 2023).

Micronutrient availability often improves under organic fertilization, especially when organic amendments are combined with beneficial microorganisms. In grapevine, integrated organic amendments with Azospirillum, phosphate-solubilizing bacteria, potash-solubilizing bacteria, and Trichoderma produced the highest leaf Mn and Zn concentrations and increased soil Mn and Zn availability (Hazarika et al., 2024). Poultry manure with organic foliar fertilization significantly affected Fe, Cu, and other micronutrients in leaves, and organic nutrition generally enhanced leaf mineral content under high-altitude conditions (Tutuş and Sensoy, 2024). A three-year field study in 'Royal' grapes also showed treatment-related variation in Fe, Zn, B, Ca, and Mg accumulation, with some organic fertilizer–tillage combinations producing higher mineral contents, although these interactions were strongly year-dependent (Kaya et al., 2025). Seasonal uptake studies further show that boron uptake peaks during flowering, while Fe and Zn can accumulate to unusually high concentrations in specific organs or stages, reinforcing that micronutrient management under organic fertilization should be timed to developmental demand (Chen et al., 2025; Wang et al., 2026).

4.3 Root and rhizosphere mechanisms of nutrient acquisition

Organic fertilization influences nutrient acquisition partly by improving root growth, architecture, and activity. In grapevine seedlings, bio-organic fertilizers promoted root expansion, increased root activity, and up-regulated genes related to cell wall loosening and auxin signaling, consistent with stronger root growth and earlier attainment of transplantable shoot size (Liu et al., 2024). Broader rhizosphere evidence indicates that root traits such as lateral root density, root hair abundance, fine-root development, and exudation capacity are central to nutrient uptake because they enlarge the absorbing surface and help recruit beneficial microorganisms (Araujo et al., 2025). Organic inputs can support these processes by improving root-zone conditions and encouraging root-hair formation and root surface area expansion (Hasan et al., 2023).

Rhizosphere microorganisms are a second major mechanism through which organic fertilization enhances nutrient mobilization. Bio-organic fertilizer increased bacterial diversity and the abundance of symbiotic N-fixing Proteobacteria and Actinobacteria in grapevine rhizosphere soil, while combined organic amendments and biofertilizers increased bacterial and Actinomycete abundance in vineyards (Liu et al., 2024). Mechanistically, PGPR and related rhizosphere microbes convert plant-unavailable N, P, and Zn into available forms, produce phytohormones and siderophores, and enhance nutrient solubilization and nitrogen fixation through root-microbial crosstalk (Feng et al., 2026). Organic phosphorus mobilization is also regulated by interactions among amendment chemistry, root traits, and microbiome functions such as proton release, organic acid exudation, and phosphatase activity.