rise, and these mycorrhizal improvements correlate positively with soybean productivity in following crops (Pires et al., 2021; Guo et al., 2024). Together, these studies show that legumes and diversified management can foster rich AMF assemblages that contribute to nutrient use efficiency and yield stability.

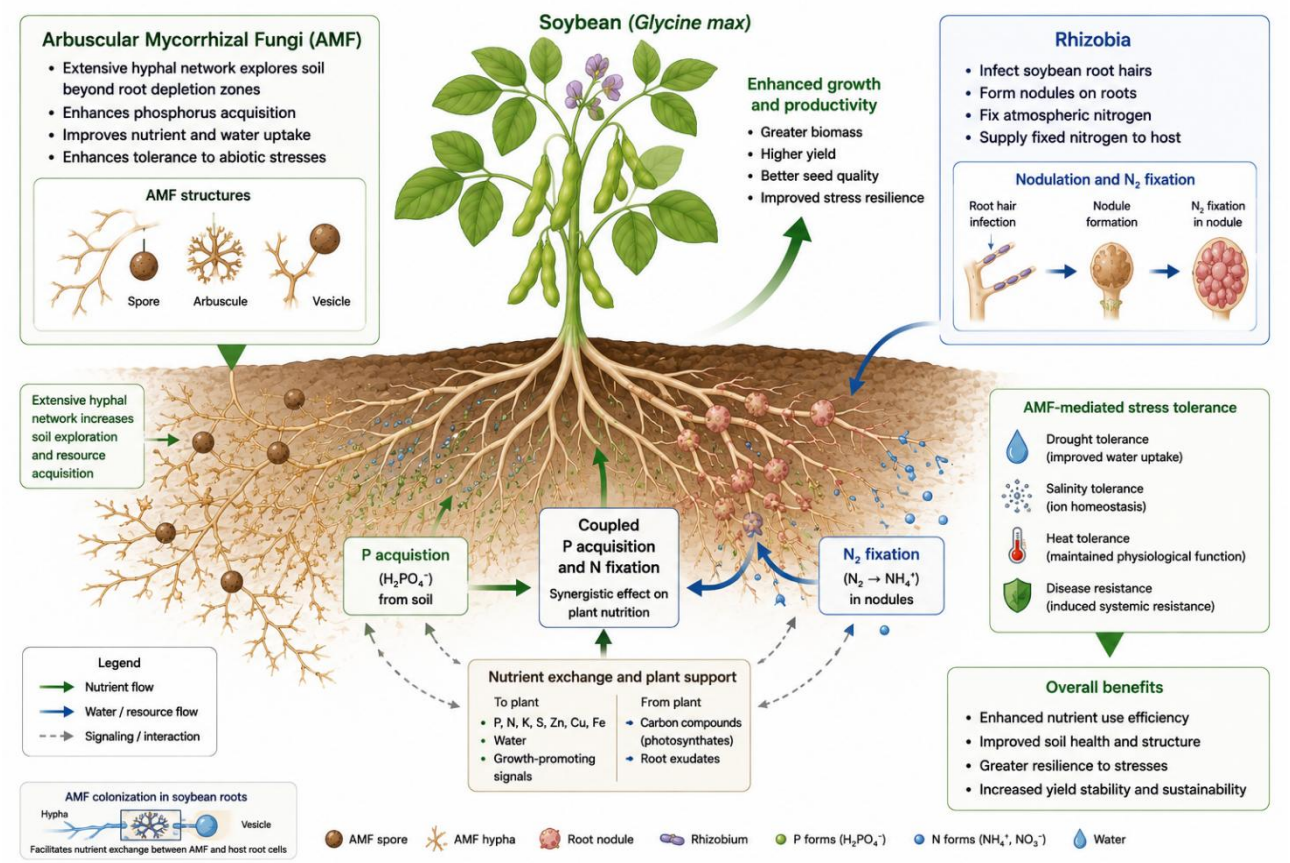

Figure 1 Illustrates the symbiotic interactions among arbuscular mycorrhizal fungi (AMF), legume roots, and rhizobia in the rhizosphere. AMF hyphae enhance phosphorus acquisition and stress tolerance, while rhizobia contribute to biological nitrogen fixation, together improving nutrient uptake and plant growth

3.3 Archaea, viruses, and other microorganisms

Beyond bacteria and fungi, legume rhizospheres host diverse archaea, phages, and other viruses whose ecological roles are only beginning to be elucidated. Conceptual and empirical work on rhizosphere “zoos” highlights that archaea, viruses, and other eukaryotes coexist with bacteria and fungi, contributing to nutrient turnover, organic matter decomposition, and plant health outcomes. Archaea, although less intensively characterized in legumes, are recognized as components of rhizosphere communities that may participate in nitrogen and carbon cycling, while protists and nematodes further shape microbial food webs and nutrient flows (Qin et al., 2025).

Recent advances in viromics demonstrate that soil and rhizosphere viral communities are taxonomically and functionally diverse, exhibiting strong spatial and temporal dynamics and exerting top-down control on bacterial hosts. Phages in rhizospheres regulate pathogen densities and suppress or exacerbate disease depending on whether they target pathogens or pathogen-suppressing bacteria, thereby influencing soil suppressiveness and plant health (Yang et al., 2023). Crop management and rotation can “prime” rhizosphere viral assemblages, altering DNA and RNA virus diversity and activity near roots and driving bacterial community succession through Kill-the-Winner dynamics (Braga et al., 2020; Muscatt et al., 2022). These findings, together with evidence that phage pressure can modify bacterial diversity and nitrogen availability, emphasize that viruses and associated microbial predators are integral but underappreciated drivers of rhizosphere community assembly and function in legume cropping systems (Wang et al., 2024).