synthesis of active constituents in medicinal plants depends on nutrient status and rhizosphere ecology, this stronger and more buffered nutrient supply is likely to be important for coordinating rhizome growth with quality formation in *A. macrocephala* (Wang et al., 2022; Zhou et al., 2025).

2.3 Effects on soil microbial community structure

Organic fertilizer substitution markedly alters soil microbial community structure, usually with stronger effects on bacteria than fungi and with consequences for disease suppression, nutrient cycling, and crop performance. In maize rhizosphere soil, partial substitution changed both bacterial and fungal community composition, but the effect was stronger on bacterial alpha diversity, and community shifts were closely related to soil water, organic carbon, nitrate, and total nitrogen (Ren et al., 2021). Long-term organic fertilization in medicinal-plant systems has also been reported to promote microbial diversity and soil enzyme activity, whereas excessive chemical fertilizer can reduce microbial diversity and soil fertility. In acidified soils, organic fertilizer enhanced bacterial network complexity, increased microbial abundance, and improved network stability, indicating that substitution can reorganize microbial interactions rather than only changing taxonomic composition. Oilseed rape experiments further showed that a 25% chemical plus 75% organic treatment increased bacterial abundance, species diversity, and ecological network complexity, although it also increased potential plant pathogenicity risk.

Evidence from medicinal plants suggests that these microbial shifts can translate into better soil health and may influence medicinal quality, but the effects are not uniformly positive across all systems. In *Codonopsis pilosula*, bio-organic fertilizer produced stronger and more stable microbial networks than chemical fertilizer and reduced root-rot disease index by 76.60% while increasing emergence rate and yield by 21.12% and 33.65%, respectively (Huang et al., 2024). In *Fritillaria thunbergii*, organic fertilization increased saprotrophic fungi, enhanced Pezizales abundance tenfold, reduced Hypocreales by 51%, and was considered favorable for maintaining soil health and high yield (Du et al., 2024). For *A. macrocephala*, authentic production areas showed the most complex rhizosphere fungal networks, and fungi involved in organic matter decomposition, including *Mortierella* and Basidiomycota-related groups, were linked to medicinal quality. However, long-term work in Huajuhong found that organic fertilizer was not inherently superior to chemical fertilizer and could increase pathogenic fungi abundance, so the value of substitution in *A. macrocephala* likely depends on substitution ratio, fertilizer maturity, and local soil conditions.

3 Effects of Organic Fertilizer Substitution for Chemical Fertilizers on Growth Development and Yield Formation of *Atractylodes macrocephala*

3.1 Effects on vegetative growth characteristics of *Atractylodes macrocephala*

Organic fertilizer substitution generally promotes the vegetative growth of *Atractylodes macrocephala* by improving the rhizosphere conditions that support aboveground development and root activity. In a direct study on *A. macrocephala*, several organic fertilizers produced yields comparable to customary fertilization under basal application, and suitable dosage ranges were identified, indicating that organic nutrient supply can sustain normal plant growth in this species (Kim et al., 2016). Evidence from other medicinal plants shows the same growth-promoting direction: in *Polygonum cuspidatum*, organic residue amendment significantly increased plant height, stem diameter, leaf number, node number, and both aboveground and root biomass, with the intermediate rate performing best. In soybean, moderate organic-inorganic fertilization increased plant height, root length, biomass, nodulation, nitrogenase activity, and photosynthetic capacity relative to full chemical fertilization and full organic fertilization, showing that balanced substitution often supports stronger vegetative vigor than either extreme (Zhang et al., 2026).

The growth-promoting effect appears to depend on improved photosynthesis, hormone balance, and rhizosphere biological activity rather than nutrient input alone. In *P. cuspidatum*, organic amendment increased SPAD value, net photosynthetic rate, transpiration rate, and intercellular CO_2 concentration, while root IAA and zeatin riboside rose by 11.0~41.7% and 17.8~46.0%, respectively, and both hormones were positively correlated with root biomass. In white lupin, a PGPB-enriched organic fertilizer increased shoot weight by 70%-88%, total biomass by about 80%, and shoot elongation by up to 36%, supporting the view that organic matrices combined with