

2 Effects of Organic Fertilizer Substitution for Chemical Fertilizers on the Growth Environment of *Atractylodes macrocephala*

2.1 Improvement effects on soil physical and chemical properties

Organic fertilizer substitution improves soil structure mainly by increasing soil organic matter and aggregate stability, which then enhances aeration and water retention. In a long-term field experiment, manure and compost increased soil organic matter by 1.86~2.47% and also increased water-stable aggregates and air permeability at two soil depths (Acar et al., 2025). The same study found that organic fertilizer treatments increased field capacity and available water content in surface soil and improved bulk density and total porosity in deeper soil layers, indicating broad physical improvement beyond short-term nutrient input. A review of organic amendments similarly concluded that they lower bulk density by more than 5% relative to sole urea fertilization and increase water-holding capacity as soil organic matter rises (Aytenew and Bore, 2020). Under drought- and salinity-prone conditions, organic-input systems also maintained higher maximum water-holding capacity and lower bulk density than chemical-based systems, showing that the structural benefits of organic matter can strengthen soil resilience under stress (Sharma, 2022).

Organic substitution also tends to moderate adverse chemical conditions created by fertilizer overuse, although the exact direction of pH change depends on the starting soil condition and organic material used. Excessive chemical fertilizer application has been associated with soil compaction and acidification in medicinal-plant cultivation systems (Wang et al., 2022; Huang et al., 2024). In short-term substitution experiments, organic manure reduced soil bulk density, pH, and electrical conductivity while increasing nutrient status and enzyme activity (Ren et al., 2021). In strongly acidic soils, organic fertilizer compost ameliorated soil quality and shifted microbial communities toward structures closer to native soils. In other systems, alkaline organic inputs moved soil pH toward neutral conditions and significantly altered bacterial richness, showing that pH regulation is context dependent but agronomically important (Shang et al., 2020). For *A. macrocephala*, this matters because regional differences in organic matter, electrical conductivity, and pH are part of the soil factor set associated with quality formation and fungal network structure.

2.2 Regulation of soil nutrient supply capacity

Organic fertilizer substitution regulates soil nutrient supply by increasing organic matter inputs, broadening nutrient pools, and stimulating enzyme-mediated nutrient transformation. A three-year substitution experiment found that partial organic fertilizer replacement significantly increased alkali-hydrolyzable nitrogen, available phosphorus, available potassium, and soil organic matter, with especially strong effects at 30-50% substitution ratios (Lu et al., 2025). In tea plantations, organic-only treatments produced the highest total nitrogen, available nitrogen, organic matter, and pH, while mixed organic-chemical regimes improved overall growth and soil function more effectively than chemical fertilizer alone (Miao et al., 2024). Organic inputs in cotton also increased total nitrogen, hydrolyzed nitrogen, available phosphorus, and available potassium across the 0-40 cm soil layer while reducing salinity (Zhao et al., 2025). In degraded grassland soil, vermicompost and mushroom residue particularly increased available phosphorus and available potassium, confirming that organic materials can selectively enhance the readily available nutrient fractions most relevant to plant uptake (Shang et al., 2020).

The nutrient-regulation effect of organic substitution is not limited to nutrient stocks; it also changes nutrient form, cycling rate, and use efficiency through enzyme activity and decomposition pathways. In *Fritillaria thunbergii*, both organic and inorganic fertilization lowered the $\text{NH}_4^+/\text{NO}_3^-$ ratio by 64%, increased bulb yield 6.8-fold, and showed that a lower ratio favored yield, while organic fertilizer uniquely maintained urease activity relative to inorganic fertilizer (Du et al., 2024). In maize rhizosphere soil, partial substitution increased urease, invertase, and alkaline phosphatase activities, and path analysis showed that soil physicochemical changes influenced enzyme activity through shifts in microbial communities (Ren et al., 2021). Repeated application of organic amendments has been reported to increase microbial biomass by up to 100% and enzymatic activity by up to 30%, providing a broader mechanism for improved nutrient mineralization and cycling (Aytenew and Bore, 2020). Because the