modify root architecture around drip lines and influence rhizosphere enzyme activity, microbial nitrogen cycling genes, and mycorrhizal colonization, indicating that irrigation strategies regulate both the physical environment and biological processes in the rhizosphere (Li et al., 2021). Giovanna et al. (2024) found that under water deficit conditions, rhizosphere microorganisms could partially alleviate plant water stress by improving soil water-holding capacity and increasing root surface area. Other microbial-based approaches can also enhance soil nutrient availability, urease and protease activities, and plant stress tolerance, thereby supporting tomato root function under greenhouse conditions (Zhao et al., 2026).

2.3 Physiological responses to water availability

Water availability directly regulates tomato photosynthetic performance and stomatal behavior. Across different growth stages, water stress generally decreases stomatal conductance, net photosynthetic rate, transpiration rate, chlorophyll content, PSII photochemical efficiency, and electron transport capacity, while increasing non-photochemical quenching and dark respiration (Yuan et al., 2016). A greenhouse irrigation experiment conducted by Zhang et al. (2025) further showed that both insufficient and excessive irrigation reduced gas exchange capacity, whereas appropriate irrigation levels and shorter irrigation intervals improved stomatal conductance and photosynthetic activity. Stomatal closure is a rapid adaptive response to declining plant water status, mainly regulated by reduced leaf turgor and enhanced root-derived abscisic acid (ABA) signaling. This response reduces water loss but simultaneously restricts carbon dioxide uptake and carbon assimilation (Ahmad and Li, 2021; Xue et al., 2021). Under water deficit conditions, changes in stomatal morphology and stomatal conductance are often coordinated with variations in leaf water potential, ABA concentration, and chlorophyll status (Chen et al., 2021).

Tomato plants also respond to water limitation through osmotic adjustment and antioxidant defense systems. Under drought conditions, plants redistribute assimilates toward roots, reduce aboveground growth, and accumulate osmolytes and stress-related metabolites to maintain cellular water balance (He et al., 2024). Potassium plays an important role in this process by regulating stomatal movement, osmotic balance, and the activity of various enzymes involved in stress responses (Sahoo et al., 2025).

At the biochemical level, drought stress increases the activities of antioxidant enzymes, including superoxide dismutase (SOD), peroxidase (POD), and catalase (CAT). However, severe stress can also enhance lipid peroxidation and cause membrane damage (Yuan et al., 2016). Seed priming, salicylic acid application, biostimulants, and beneficial microorganisms can further strengthen these protective mechanisms by improving PSII stability, reducing water loss, enhancing antioxidant enzyme activity, and alleviating drought-induced damage, thereby increasing plant stress tolerance (Fregonezi et al., 2024; Sahoo et al., 2025; Zhao et al., 2026).

3 Effects of Irrigation Strategies on Greenhouse Tomato Growth

3.1 Effects of conventional irrigation on vegetative growth

Under conventional or full irrigation conditions, tomato plant height, stem diameter, and leaf area generally increase with increasing irrigation amount. A greenhouse experiment conducted by Lyu et al. (2025) showed that increasing irrigation levels enhanced plant height, stem diameter, leaf area, SPAD value, and yield, with overall growth performance following the order of I1 > I2 > I3. Similar results were observed under drip fertigation conditions, where Zhang et al. (2025) reported that moderate increases in irrigation promoted plant height, stem diameter, leaf area index, root development, and aboveground biomass accumulation. In a pot-based greenhouse tomato experiment, maintaining soil water content at 100% field capacity resulted in the highest plant height and stem diameter, reaching 186.0 cm and 23.40 mm, respectively (Chand et al., 2020). Alshami et al. (2023) further confirmed a significant positive relationship between irrigation amount and leaf area under saline irrigation conditions. When the irrigation level was reduced to 40% of full irrigation, tomato plant length, stem diameter, stem dry weight, and stem fresh weight decreased by 33.06%, 29.7%, 28%, and 43.1%, respectively, compared with fully irrigated plants. Comparative studies of irrigation methods also showed that drip irrigation combined with suitable soil moisture conditions was more beneficial for tomato growth than furrow irrigation. Under a soil