stage resulted in only a 3% yield reduction, while maintaining the highest yield among different deficit treatments. Another study based on stage-specific irrigation optimization demonstrated that maintaining soil water content at 70%-90% of field capacity during flowering and fruit development, and 40%-60% during ripening, achieved the highest water-use efficiency (Li et al., 2023).

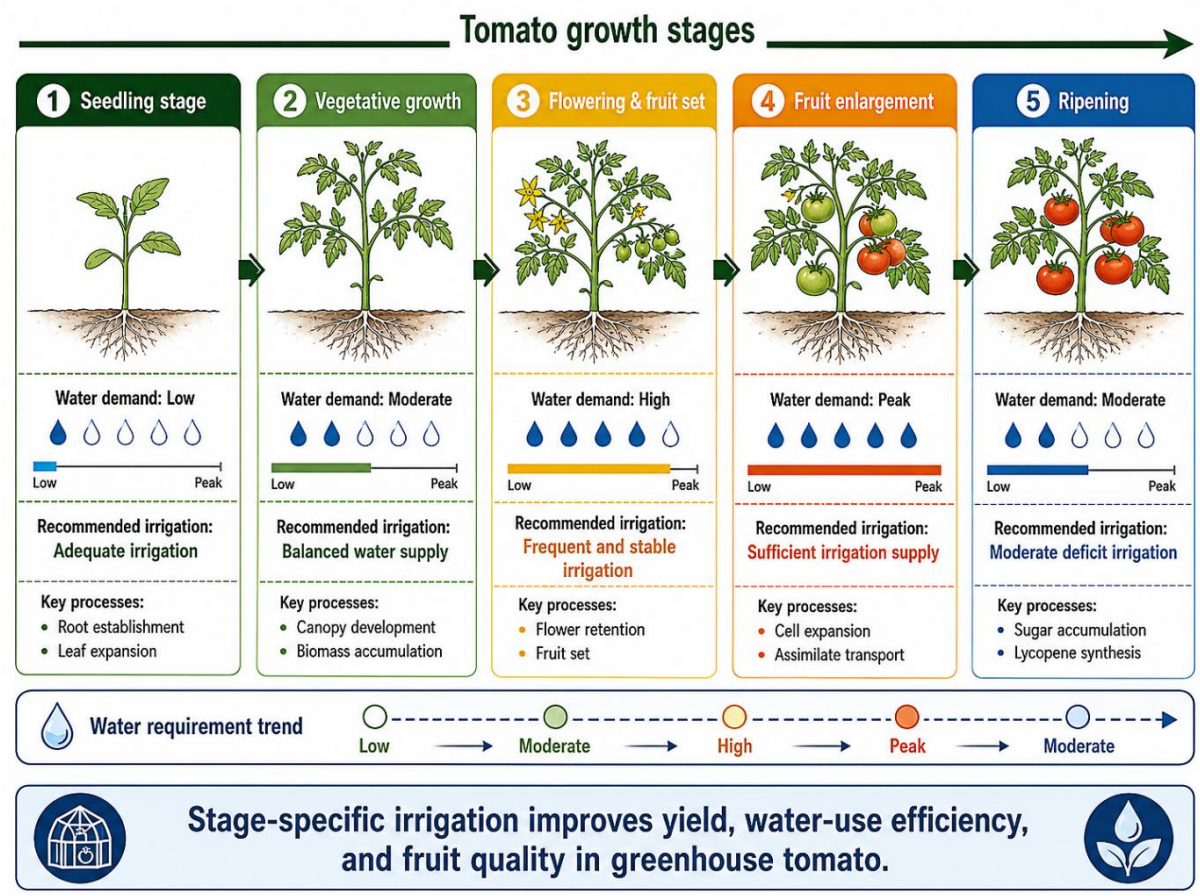


Figure 1 Stage-specific water demand characteristics and irrigation regulation strategies during greenhouse tomato growth

2.2 Effects of water status on tomato root development

Tomato root development is highly sensitive to water availability because root systems directly determine plant capacity for water uptake and nutrient acquisition. Feng et al. (2024) reported that appropriate irrigation combined with sufficient nitrogen supply increased tomato root length, root surface area, and root volume, and these root traits were positively associated with fruit yield and water-use efficiency.

Irrigation level is an important factor affecting root distribution across soil layers. Under greenhouse drip irrigation systems, tomato water uptake mainly occurs within the 0-30 cm soil layer. However, moderate deficit irrigation can increase the relative contribution of deeper roots (30-60 cm) to water absorption across the soil profile while reducing surface evaporation losses (Li et al., 2023). Excessive reduction in irrigation amount, however, inhibits increases in root length density and weakens overall plant growth capacity (Li et al., 2023; Lyu et al., 2025). In contrast, moderate water limitation can increase the root-to-shoot ratio and improve water-use efficiency, reflecting an adaptive strategy in which plants enhance root acquisition capacity under limited water availability.

The rhizosphere water environment also regulates root activity by affecting soil aeration, hydraulic conductivity, enzyme activity, and interactions with microorganisms. Excessive irrigation may cause oxygen deficiency in the root zone, promote reactive oxygen species accumulation, and reduce root absorption capacity, thereby indirectly restricting photosynthesis in aboveground tissues (Ahmad and Li, 2021). Water-saving irrigation systems can