2022). In Brazilian tropical conditions, VSP training provided higher vine water status but lower berry Brix compared with a modified Geneva Double Curtain, illustrating a trade-off between water relations and fruit exposure in a hot, seasonally dry region (Favero et al., 2010). Reviews of training systems under climate change propose re-evaluating divided and high-wire systems, particularly in warm and sub-tropical zones where VSP often requires intensive manipulation to avoid overexposure and rapid ripening (Del Zozzo and Poni, 2024).

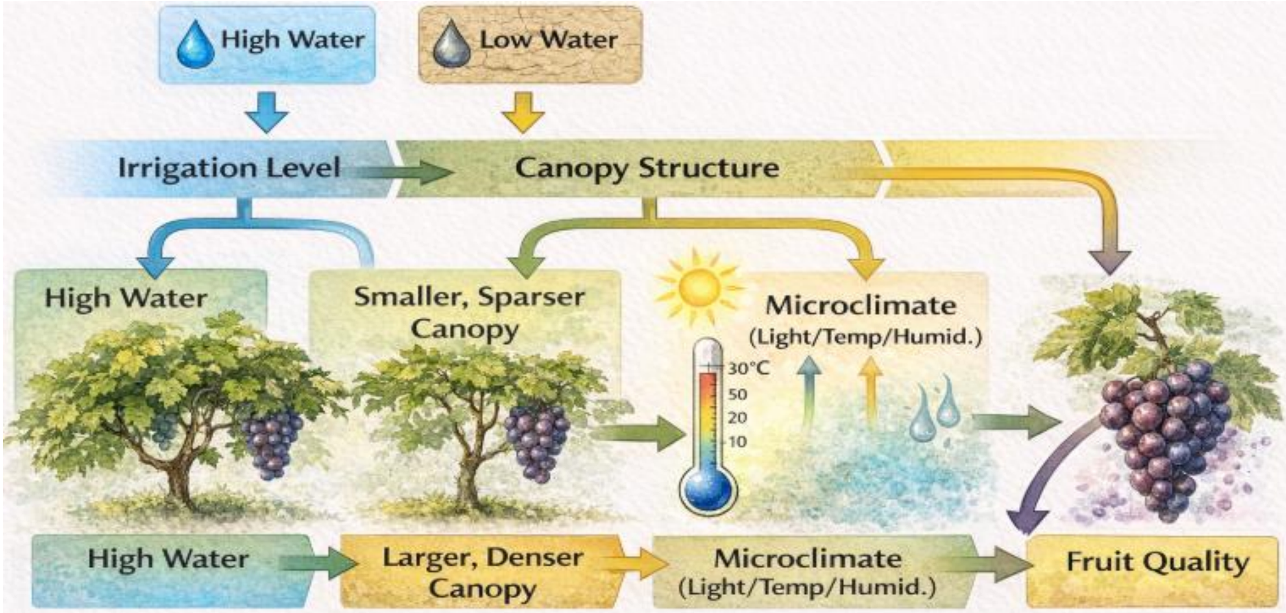


Figure 4 Conceptual model illustrating how water availability regulates canopy structure, microclimate, and physiological processes affecting grapevine performance (Adopted from Del Zozzo et al., 2024)

In humid, rainy regions, canopy structures must also address disease pressure and excess vigor. For the 'Miguang' grape in a rainy Chinese region, a single-curtain system improved cluster-zone light, leaf photosynthetic capacity, and assimilate distribution to fruit compared with a pergola, while simultaneously decreasing vegetative growth (Du et al., 2023). Systematic reviews of climate-change adaptation highlight that combining location, training system, irrigation, and canopy management at multiple scales allows region-specific compromises between water use and productivity (Naulleau et al., 2021). Across cool, temperate, and warm areas, training choices therefore need to integrate local climate, water resources, and disease risk to select canopy architectures that maintain photosynthetic efficiency and fruit quality under changing environments.

## 8 Case Study: Effects of Typical Canopy Management Systems on Grape Quality

### 8.1 Comparison of photosynthetic efficiency under different training systems

Training system geometry shapes how efficiently grape canopies convert intercepted light into carbon gain. In potted Sangiovese, whole-canopy gas exchange showed that, when expressed per unit leaf area, the single high wire (SHW) system achieved about 24% higher net $CO_2$ exchange than both VSP and pergola under well-watered conditions, highlighting superior photosynthetic efficiency of more elevated, sprawling canopies (Del Zozzo et al., 2024). Under progressive water deficit, SHW maintained higher NCER/leaf area and transpiration/leaf area, while VSP and pergola exhibited stronger declines in light saturation point and quantum yield, indicating lower drought resilience and efficiency.

Training systems also differ in how they reconcile photosynthetic efficiency with fruit ripening and composition. Despite lower NCER/leaf area than SHW, the pergola system reached the best fruit maturity at comparable yields, suggesting a favorable balance between light interception, evaporative cooling, and source–sink relations. A broader review confirms that divided or non-VSP systems (e.g., pergola, high wires, GDC) can improve overall efficiency by enhancing light distribution and balancing dry-matter partitioning, while conventional VSP often achieves good control of vigor but may require multiple canopy operations to maintain internal light and avoid excessive berry heating in warm climates (Del Zozzo and Poni, 2024).