Different training and trellis systems express canopy density in distinct spatial patterns, altering light interception and transmission. Shoot-positioned systems tend to concentrate higher leaf area density near the fruit zone, yet can maintain relatively higher fruit-zone light at a given density by reducing leaf layer number and improving exposure geometry (Figure 1) (Gladstone and Dokoozlian, 2003). Divided canopies, such as lyre or Geneva double curtain, achieve more even light penetration by splitting the foliage wall, lowering leaf layer number and slowing the decline of PPFD with rising density. Indices such as leaf layer number, exposed leaf area, and porosity integrate these effects and correlate closely with interior PPFD, making them useful tools to assess functional canopy density (Shtirbu et al., 2022).

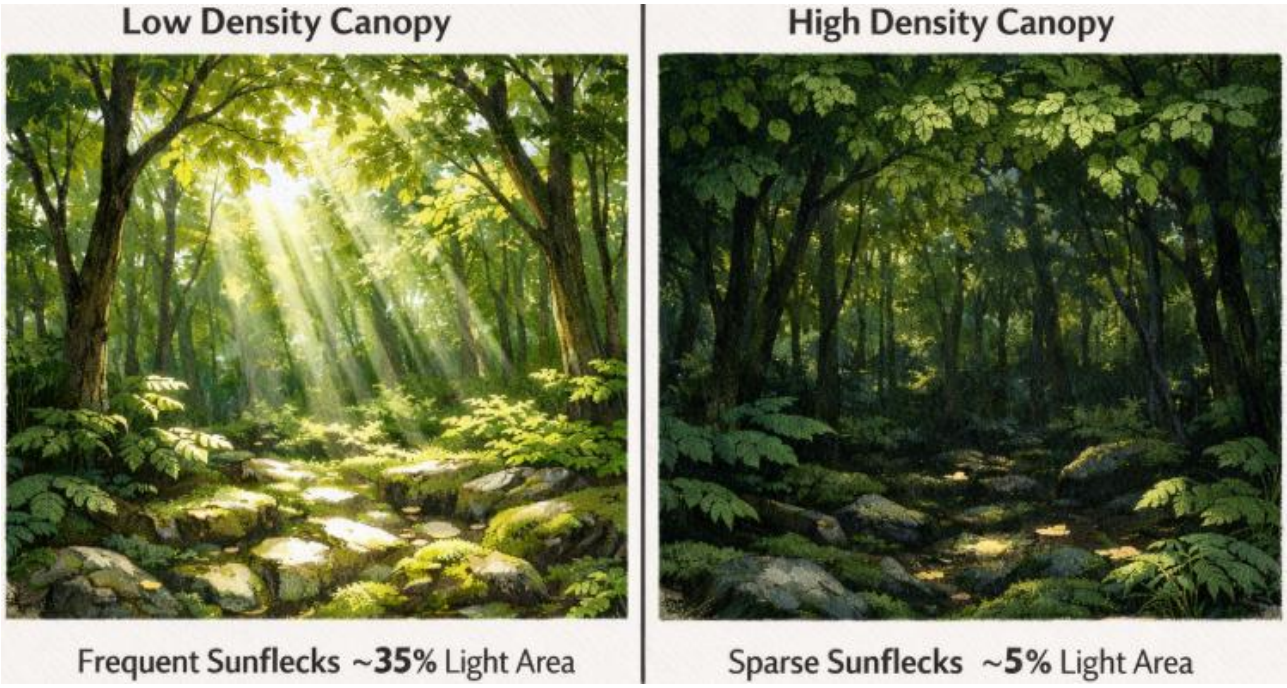

Figure 1 Comparison of sunfleck distribution under low and high canopy density, illustrating reduced light penetration with increased leaf area density (Adopted from Gladstone and Dokoozlian, 2003)

3.3 Improvement of light use efficiency through canopy optimization

Optimizing canopy architecture aims to balance total light interception with its distribution to maximize light use efficiency (LUE) at leaf and canopy scales. Three-dimensional and functional-structural models show that a relatively small proportion of leaves (20%-30%) can intercept roughly 80% of absorbed light, implying substantial scope to reduce unproductive shaded leaf area without sacrificing total interception (Iandolino et al., 2013; Prieto et al., 2019). Simulated and measured canopies with more favorable leaf area density and leaf orientation achieve similar or higher absorbed light with less total leaf area, thus improving radiation use efficiency and whole-canopy carbon gain.

Structural adjustments through training system choice, row orientation, and targeted canopy management can enhance LUE. Divided or high-wire systems, and single-curtain compared with pergola in humid climates, have been shown to increase light in the cluster zone, raise leaf photosynthetic rates in key canopy strata, and promote assimilate allocation to fruit. Opening dense canopies by shoot thinning or leaf removal increases porosity and fruit-zone light, often improving berry soluble solids and phenolic traits, although excessive exposure may risk flavonoid degradation in warm climates (Martínez-Lüscher et al., 2019; Torres et al., 2020). Functional-structural modeling further indicates that allowing non-uniform nitrogen and light distribution among leaves increases whole-canopy photosynthesis relative to uniform distributions, underscoring that canopy optimization should consider both geometry and physiological acclimation to heterogeneous light (Prieto et al., 2019).

Light distribution in grapevine canopies is highly heterogeneous, shaped by canopy density, geometry, and orientation. Dense canopies intercept large amounts of radiation but transmit little to the fruit zone and interior,