small, efficient rootstocks (such as dwarf citrandarins or some tetraploid rootstocks) can stabilize yield per area, improve water use efficiency, and reduce the risk caused by individual tree loss.

6 Agronomic Management Practices Supporting Optimal Planting Density

6.1 Pruning and canopy management

In a study on 35-year-old 'Valencia' sweet orange trees, four pruning treatments were applied every year in mid-February, removing 0%, 25%, 50%, and 75% of the main branches. As pruning intensity increased, overall canopy volume decreased, but vegetative growth was stimulated, with longer shoots and larger leaves. At the same time, light penetration inside the canopy improved (Al-Saif et al., 2023). Heavy pruning (75% branch removal) resulted in the highest fruit yield, increasing by nearly 20% compared with the unpruned control. It also significantly improved fruit size, juice content, total soluble solids (TSS), TSS/acid ratio, and vitamin C content. Even in older and larger trees, strong pruning can renew the canopy, restore internal light conditions, and improve both yield and fruit quality.

Mechanical pruning is widely used in high-density orchards to control canopy size and reduce labor costs. It is especially suitable for hedgerow systems combined with topping and side hedging. In 'Finn 95' lemon, a 4-year comparison of five pruning strategies showed that alternating full mechanical pruning (topping, skirting, and double-sided hedging) with manual pruning, or using only mechanical pruning, significantly reduced pruning time and increased net profit compared with continuous manual pruning. These approaches did not show clear long-term yield reduction (Martin-Gorriz et al., 2021). Similarly, in 'Clemenules' mandarin, a 4-year experiment comparing 12 pruning strategies showed that alternating mechanical pruning (topping plus one-sided hedging) with manual pruning maintained stable tree size and canopy vitality. Yield was comparable to fully manual pruning, while costs were lower (Fonte et al., 2022).

In China, new labor-saving cultivation systems further highlight the link between canopy structure and light use. In Hubei, a comparison among traditional planting, wide-row–narrow-spacing planting, and a "fence-type" system showed clear differences in vertical canopy structure measured by UAV LiDAR. The point cloud density above half tree height was 64.85% in the wide-row system and 71.94% in the fence-type system, compared with only 50.02% in the traditional system (Dian et al., 2023). The fence-type system forms a vertical hedgerow canopy using support structures and pruning. This improves light distribution and increases photosynthetic rates in all canopy layers. The average photosynthetic rate of lower canopy leaves in the fence system was 1.74 times that of the traditional system and 1.66 times that of the wide-row system.

6.2 Nutrient and water management

Under high planting density, competition for soil resources becomes stronger. Therefore, precise water and nutrient management is essential to maintain tree vigor, yield, and root health. In semi-arid orange orchards, a 5-year study on deficit irrigation showed that compared with full irrigation (100% ETc), sustained subsurface deficit irrigation (SSDI), regulated deficit irrigation (RDI), and partial root-zone drying (PRD) reduced water use by 25%, 33%, and 49%, respectively, without significant yield loss (Stagno et al., 2024). At the same time, water use efficiency increased and some fruit quality traits improved. Vitamin C content was higher under RDI (62.7 vs 58.5 mg 100 mL^{-1}). SSDI and PRD increased pulp color index to around 10, compared with 8.44 in the control. Leaf nutrient levels remained generally adequate, although potassium was slightly low, suggesting that K monitoring is important under deficit irrigation.

In high-density young 'Valencia' orchards (955 trees ha^{-1}) under Huanglongbing (HLB) conditions in Florida, drip or microsprinkler irrigation combined with fertigation was compared with standard-density orchards (358 trees ha^{-1}) using controlled-release fertilizers (Ferrarezi et al., 2020). Nitrogen application followed UF/IFAS recommendations: 0.11-0.34 kg N per tree annually for non-bearing trees, and 224 kg N ha^{-1} annually for bearing trees, adjusted based on leaf analysis. After seven years, leaf nutrient concentrations were generally within or above recommended levels. High-density fertigation treatments produced the highest yield per unit area and total soluble solids. In some years, yields were 86%~300% higher than standard density, even though individual tree canopy volume was smaller (4.3~5.9 m^3 vs 6.2~7.2 m^3).