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Influence of Planting Density on Citrus Yield and Tree Vigor

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Abstract This study analyzes the mechanisms by which different planting densities affect citrus yield and tree vigor, and compares low-, medium-, and high-density cultivation systems in terms of yield formation, tree structure, and resource use efficiency. Increasing planting density can significantly improve early yield per unit area and accelerate canopy closure and light interception efficiency. However, it also reduces yield per tree and intensifies competition for light, water, and nutrients, which may lead to excessive canopy shading, increased pests and diseases, and a decline in long-term productivity. In long-term production, medium-density systems often perform better in terms of yield stability and economic returns. Rootstock type and cultivar characteristics play a decisive role in adaptability to dense planting. Dwarfing or semi-dwarfing rootstocks can effectively control tree vigor and improve fruiting efficiency, serving as an important foundation for high-density cultivation. Proper pruning, water and fertilizer management, and mechanization support can help mitigate the negative effects of high-density planting. In the future, combining precision agriculture technologies with breeding innovations will enable dynamic optimization of planting density and sustainable orchard design.

Keywords Planting density; Citrus; Yield formation; Tree vigor regulation; High-density cultivation

1 Introduction

Citrus is one of the most economically important and widely grown fruit crops in the world. It includes sweet orange, mandarin, grapefruit, lemon, and lime. Citrus fruits are also an important part of the human diet, as they are rich in vitamin C, dietary fiber, and various phytochemicals.

Traditional citrus orchards usually use low planting density and wide spacing. This allows trees to develop large canopies and makes mechanized operations easier. However, it also leads to slow canopy closure and low land and resource use efficiency during the early fruiting stage (Wheaton et al., 1995). In contrast, high-density planting systems aim to speed up canopy development, improve light interception, and increase yield per unit area in the early growth and early bearing stages. At the same time, high density can increase competition for light, water, and nutrients, raise the risk of pests and diseases, and make management practices such as pruning, spraying, and harvesting more complex. It may even shorten orchard lifespan or reduce long-term economic returns (Vidalakis et al., 2011).

In low-density systems, the number of trees per hectare is small and spacing is large. This usually supports vigorous growth, larger canopy size, and easy machine movement, but it may delay canopy closure and the achievement of maximum yield. Medium-density systems try to balance faster canopy formation with higher early yield, while controlling tree vigor, reducing shading, and lowering management costs. High-density and super-high-density systems can reach or exceed 1 000~2 000 trees per hectare. In some citrus studies, these systems have shown clear advantages in improving early yield and land use efficiency, especially when combined with dwarfing or semi-dwarfing rootstocks (Haque and Sakimin, 2022). In citrus production, the development of semi-dwarfing and dwarfing rootstocks, dwarfing viroids, precision irrigation and fertilization, and improved pruning and training practices has further supported the use of high-density planting systems (Azevedo et al., 2020).