and flavonoids. Although substandard, semi-dwarf, and dwarf rootstocks reduce yield per tree, they improve yield efficiency (kg fruit m^{-3} canopy) and allow closer spacing. In 'Lane Late' sweet orange, FA13 and FA41 produce smaller trees, and under higher density they show strong yield potential per area. FA13 also improves nutrient use efficiency under low fertilizer input, making it suitable for intensive but sustainable systems (Hervalejo et al., 2021) (Figure 1).

In 'Valencia', several low-vigor trifoliate hybrids (such as IPEACS-239, IPEACS-256, and US-802) showed about 55% higher production efficiency than the vigorous 'Rangpur' lime, making them good candidates for high-density systems (Domingues et al., 2021). In high-density systems, dwarfing citrandarin rootstocks such as IAC 1600, 1697, and 1711 maintained high productivity while improving water use efficiency and reducing HLB susceptibility, performing better than standard Swingle (Devite et al., 2025).

Figure 1 Overview of the experimental plot (Adopted from Hervalejo et al., 2021)

5.3 Matching planting density with genetic traits

The optimal planting density in citrus depends on a proper balance among scion vigor, rootstock dwarfing ability, and production goals. For traditional vigorous rootstocks, densities above 1 000 trees ha^{-1} are usually not justified. Once orchards reach full production, yield per year is often no longer strongly affected by density, while excessive density increases competition and management difficulty. When both scion and rootstock are vigorous, a moderate density (about 300~700 trees ha^{-1}) is more appropriate. When vigorous scions are grafted onto dwarf or semi-dwarf rootstocks, higher or even super-high densities can be used because tree size is controlled and efficiency is improved. Long-term trials with 'Valencia' grafted onto dwarf TSKC × TRFD citrandarins showed that adjusting spacing based on smaller tree size can increase productivity to about 40 t ha^{-1} $year^{-1}$, nearly doubling yield (Costa et al., 2021).

In Spain, 'Salustiana' grafted onto the dwarf FA517 rootstock performed well under super-high-density planting with mechanical harvesting. Proper rootstock selection can support both high-density systems and mechanization (Hervalejo et al., 2022). For 'Flying Dragon', spacing of 1.5~2.5 m within rows and 4~5 m between rows is recommended to balance early yield and canopy management (Kumar, 2024). Compact or naturally small scions (such as some mandarins and 'Murcott') can be combined with moderately dwarfing rootstocks to create "walkable" orchards, allowing ground-based harvesting and reducing pesticide use.

In 'Shamouti', weaker trifoliate-related rootstocks (such as Swingle and C-13) support higher planting densities than vigorous citrus or Rangpur rootstocks, while still maintaining good fruit quality (Carvalho et al., 2022). On the other hand, under water-limited conditions or high HLB pressure, using high-density systems together with