

At the whole-tree level, simple carbon balance models in water-stressed peach show that sinks (fruits and shoots) demand carbon for growth and maintenance respiration, and once daily carbon assimilation falls below this demand, net carbon gain becomes negative and carbohydrate reserves in the trunk decline (Rahmati et al., 2015). This illustrates that fruit set and final yield are constrained not only by local fruit sink strength but also by whole-tree carbon balance under the prevailing irrigation regime.

2.3 Root growth and resource uptake

Root distribution and nutrient absorption capacity strongly influence how trees exploit soil water and nutrients. Peach rootstocks differ in their efficiency for N, P, and K uptake, transport, and use; rootstocks with greater efficiency in nutrient transport and use show superior growth parameters, indicating better adaptation to low nutrient availability (Menegatti et al., 2021). In ‘Okinawa Roxo’ rootstock, complete nutrient solutions that optimize N, P, and K contents promote strong root growth, better dry-weight partitioning, and morphophysiological characteristics suitable for grafting within three months (Souza et al., 2019).

Root system architecture (depth and angle) varies among peach × (peach × almond) backcross populations; deeper, more vigorous root systems with narrower angles are better able to explore and exploit water and nutrients in deep sandy soils (Lesmes-Vesga et al., 2023). Soil moisture and root-zone conditions directly affect root activity and water/nutrient uptake. Increasing soil water content and N supply raises leaf area and leaf, shoot, and root hydraulic conductivities in peach seedlings, improving water transport and growth under low soil moisture (Zhang et al., 2014). Conversely, severe water deficit in orchards reduces root length density by about 73% compared with well-irrigated trees, while partial rootzone drying reduces root length by about 42%, indicating that continuous deficit irrigation imposes stronger constraints on root system development than alternated wet–dry zones (Abrisqueta et al., 2008).

Roots are concentrated mainly in the upper 0.55 m of soil, especially at 0.40-0.55 m depth, with more than 88% of roots being very thin (<0.5 mm), highlighting the importance of maintaining moisture and nutrients in this zone (Abrisqueta et al., 2008). Root-zone aeration can further enhance root activity and nutrient availability. In a peach orchard, aeration increased soil oxygen, raised the abundances of N-fixing and K-solubilizing microorganisms, and increased soil alkaline N, available K, organic matter, and numbers and thickness of new white roots (Sun et al., 2022b). These changes also altered plant N and K status and increased the shoot K:N ratio, which was associated with improved fruit quality (Sun et al., 2022a). Soil management practices, including cover crops and bare soil strips, influence root growth, tree water use, and NO₃-N availability in adjacent soil; tree growth is allometrically related to root growth under these heterogeneous soil conditions.

3 Nutritional Strategies for High-Yield Peach Production

3.1 Macronutrient management

Nitrogen is the primary driver of shoot growth, leaf area development, and fruit sink strength. In peach, an annual N supply is required due to its mobility and leaching risk, with early-season soil applications commonly recommended to stimulate spring shoot growth and blossom development and to support ovary growth and fruit set (Tsoumanis et al., 2025). Nitrogen fertilization directly affects yield and fruit quality, but both deficiency and excess are detrimental: low N reduces flower bud quality, root growth, and fruiting capacity, whereas excessive N promotes vegetative overgrowth, lowers fruit quality, and increases disease incidence (Nava et al., 2022).

Field studies show that moderate N rates (around 200 kg N/ha) can maximize yield without sacrificing quality, and that the timing of N application (e.g., pit hardening vs. fruit expansion) significantly influences yield, leaf N status, and quality traits (Zhang et al., 2022). Integrated omics analyses further indicate that pre-harvest N modifies carbon and amino-acid metabolism and flavonoid biosynthesis, helping to explain stage-specific effects on fruit growth and quality.

Phosphorus and potassium act mainly on flowering, fruit growth, and sugar accumulation. P, N, and K together are essential macronutrients for Rosaceae fruit yield and quality, affecting fruit development and postharvest