

7 Challenges and Optimization of High-Yield Peach Production

7.1 Problems in current nutrient management

Many peach orchards still rely on uniform, empirically based fertilizer programs that ignore variability in soils and tree demand. In the southeastern United States, current N recommendations may be based on half-century-old work, with growing concern about over-fertilization, imbalanced vegetative/reproductive growth, fertilizer runoff, and inefficient use of financial resources (Casamali et al., 2021b). Excessive phosphorus use in perennial orchards can create very low P use efficiency ($\approx 15\%$) and large P surpluses, shifting soil P to more labile forms and sharply increasing the risk of P loss (Chen et al., 2022).

Low fertilizer-use efficiency is a major challenge in N management for peaches. Conventional high-N programs in China result in low N absorption, substantial N leaching and gaseous losses, and elevated greenhouse gas emissions (Xiao et al., 2019). In typical surface-broadcast systems, conventional management produced considerable NH_3 volatilization, N_2O emissions, and runoff, alongside only moderate yields (Yang et al., 2023). Spatial analyses in Brazilian orchards further show strong within-orchard variability of soil nutrients, yield, and fruit quality, meaning uniform fertilization leads to over-application in some zones and under-application in others (Oldoni et al., 2019).

7.2 Problems in current irrigation management

Integrated crop management has often been implemented only partially, with irrigation still applied empirically and usually in excess, wasting water and energy and raising greenhouse gas emissions (Maletsika et al., 2022). Energy-use analysis in Greek canning peaches identified irrigation as the single largest energy consumer and the practice with the highest impact on GHG emissions, mainly through electricity and fuel use (Maletsika et al., 2022).

Conversely, many new orchards elsewhere are not irrigated for several years after planting and depend solely on rainfall, leaving trees vulnerable to the increasingly frequent droughts (Casamali et al., 2021b). Under severe drought, non-irrigated young trees showed 56% smaller canopy volume, 39% smaller trunk cross-sectional area, 40% lower leaf photosynthesis, and reduced commercial yield compared with irrigated trees, with negative effects persisting in subsequent years. In arid Tunisia, cutting irrigation to 50% ET_c caused 20%-25% yield losses in mature orchards, underscoring the risk of unplanned, severe water cuts (Toumi et al., 2024).

7.3 Integrated optimization strategies

Precision fertigation links water and nutrient supply to tree demand in space and time. Drip irrigation, by delivering water directly to roots, provides an efficient platform for fertigation and precise matching of crop needs (Sharma et al., 2024). In perennial orchards, applying fertilizers through drip (fertigation) increased peach and apple yields and improved fruit quality compared with non-fertigated controls (Figure 3). Bag-controlled release fertilizers and super-large granular slow-release humic acid fertilizers further synchronize N release with peach growth stages, substantially increasing N use efficiency and reducing losses, while maintaining or increasing yield and net economic benefit (Xiao et al., 2019; Yang et al., 2023).

Region-specific, spatially explicit management models are another key optimization pathway. In Brazil, delineating two management zones in a 1.8-ha orchard based on soil and tree attributes creates opportunities for site-specific fertilization to correct over- and under-application (Oldoni et al., 2019). Precision irrigation protocols using thermal imagery and variable-rate drip at subfield scale in a commercial peach orchard maintained stem water potential within target ranges and improved water productivity in responsive management cells, showing the value of downscaling management within orchards (Katz et al., 2023). At a broader scale, deficit irrigation case studies in Moroccan peaches demonstrate that sustained deficit can reduce water use by 20% without affecting yield or quality and increase water productivity by 33%, though adoption is limited by conceptual ambiguity and risk perceptions (Laita et al., 2024).