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Effects of Different Irrigation and Fertilization Regimes on Growth Characteristics and Yield Performance of 'Taishuu' Sweet Persimmon (*Diospyros kaki* Thunb.)

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Abstract This article analyzes the effects of different water and fertilizer management regimes on the growth characteristics and yield performance of 'Taishuu' sweet persimmon, analyzes its water and nutrient requirements at different developmental stages, and focuses on the regulatory effects of irrigation levels, fertilization intensity, and water–fertilizer coupling on vegetative growth, leaf photosynthetic physiology, dry matter allocation, fruit enlargement, and yield components. Available evidence indicates that appropriate irrigation promoted shoot and canopy growth and supported fruit enlargement, whereas the yield-increasing effect of excessive irrigation gradually diminished. Moderate deficit irrigation at specific developmental stages could reduce fruit drop and improve water-use efficiency, but might decrease individual fruit weight. Fertilization similarly showed a pronounced nonlinear effect on tree growth and yield. Moderate and balanced nutrient supply was beneficial for maintaining leaf nutritional status and supporting fruit development, whereas excessive fertilization could induce excessive shoot growth, nutrient imbalance, and deterioration in fruit quality. Compared with conventional high-water and high-fertilizer management, water- and fertilizer-saving practices and precision integrated fertigation were more effective in coordinating vegetative and reproductive growth and improving water–fertilizer use efficiency and marketable yield. Future research should consider the phenological stage, tree age, crop load, soil conditions, and climatic characteristics of 'Taishuu' sweet persimmon to establish region-specific water-fertilizer response models and integrate drip fertigation, soil moisture monitoring, sensor technologies, and intelligent decision-support systems to achieve dynamic and precise regulation of water and nutrient supply. These approaches could provide a theoretical basis and management reference for improving fruit quality, yield, and resource-use efficiency in 'Taishuu' sweet persimmon production.
Keywords 'Taishuu' sweet persimmon; Water and fertilizer management; Water-fertilizer coupling; Yield formation; Integrated fertigation

1 Introduction

'Taishuu' sweet persimmon is a pollination-constant non-astringent cultivar introduced from Japan to China in the 1990s, and it has become attractive to producers because of its fragrant aroma, favorable flavor, and strong commercial value (Yang et al., 2025). In China, its average market price has been reported at 40~50 yuan/kg, with potential output value reaching 450 000~750 000 yuan/ha, and the planted area in southern China has expanded to nearly 2 000 ha with continued growth (Yang et al., 2025). 'Taishuu' is also an important breeding parent in sweet persimmon improvement, having contributed to newer cultivars such as 'Dannuri', 'Wonchu', and 'Yeonsu', which were selected for combinations of early maturity, large fruit size, high soluble solids, and good eating quality (Kim et al., 2021). Existing comparisons also indicate that 'Taishuu' itself has commercially desirable fruit traits, including medium-to-large fruit size around 265 g and soluble solids around 17.2 °Brix in cultivar comparison trials, supporting its value in fresh-fruit markets (Kim et al., 2021). More broadly, persimmon breeding and evaluation increasingly emphasize fruit weight, shape, skin color, texture, soluble solids, flavor, productivity, and marketability, which places 'Taishuu' squarely within the category of premium sweet persimmon cultivars whose cultivation performance must be matched with high-quality orchard management (Yang et al., 2022).

Despite this high market potential, the production performance of ‘Taishuu’ is highly sensitive to ecological conditions and orchard management. Regional studies show that fruit quality varies substantially among orchards because China’s wide climatic diversity creates differences in precipitation, temperature, and growing-season heat conditions, which in turn affect fruit size, texture, and flavor expression. The suitable production zone of ‘Taishuu’ appears narrower than that of some other sweet persimmon cultivars, and excessive rainfall, unbalanced heat-water conditions, summer drought, and high temperatures can reduce fruit quality or cause undesirable flesh characteristics (Yang et al., 2025). Large-scale sensory and metabolomic work on more than 2 500 ‘Taishuu’ fruits from 35 orchards further showed that flavor is the principal contributor to overall eating quality and that richness is the dominant component of flavor, indicating that cultivation practices influencing water and nutrient status are likely to affect market acceptance through changes in taste-related metabolites (Yue et al., 2024). For fruit trees more generally, mismatched irrigation and fertilization often lead to low output efficiency, nutritional imbalance, and quality decline, whereas strategic water-fertilizer coupling provides a more favorable environment for vegetative growth, reproductive development, and fruit formation (Li et al., 2024).

Water and fertilizer management is especially important because it directly regulates the root-zone environment, nutrient uptake, canopy growth, photosynthesis, fruit set, fruit expansion, and final yield formation. A meta-analysis in China found that drip fertigation increased crop yield by 12.0%, water productivity by 26.4%, and nitrogen use efficiency by 34.3% while decreasing evapotranspiration by 11.3% relative to traditional irrigation and fertilization, with fruit crops showing the greatest increase in nitrogen use efficiency. A later meta-analysis similarly showed that water-fertilizer integration with drip irrigation improved yield by 12.5%, water use efficiency by 34.5%, and nitrogen use efficiency by 31.3%, and recommended moderate nitrogen reduction relative to conventional farmer practice for fruit trees in suitable soils (Yang et al., 2024). Mechanistically, drip irrigation and fertigation can promote root development, increase root activity and microbial biomass, expand root distribution within the main soil layer, reduce nitrate leaching, and improve the synchronization of water and nutrient supply with crop demand (Yang et al., 2023). In fruit trees, moderate rather than excessive inputs are often optimal: mango achieved the best comprehensive benefit under 75% *ET*c with stage-specific fertilization (Sun et al., 2022), wine grape performed best under moderate irrigation and fertilizer quotas (Han et al., 2023), pear reached superior growth, fruit quality, and yield under a specific water-nitrogen-phosphorus coupling treatment, and capsicum likewise showed optimal growth, quality, and efficiency under 90% irrigation water requirement with 90% recommended nitrogen (Sharma et al., 2025). Apple studies further show that mild deficit irrigation can restrain excessive vegetative growth, improve water-use efficiency, and maintain or increase yield, while severe deficit during fruit expansion is harmful (Wen et al., 2025).

For persimmon, the need for precise water and fertilizer regulation is also supported by crop-specific evidence. Foliar phosphatic fertilization in sweet persimmon increased vegetative growth, the number of effective flowering buds, fruit number, yield, soluble solids, and fruit firmness while reducing acidity and fruit drop, confirming that nutrient management directly influences both source growth and sink retention. In young persimmon orchards, improved tree water and nutrient status increased vegetative growth and enhanced fruit yield or fruit weight, and adequate irrigation system design and fertigation strategy were considered essential to meet tree requirements at different physiological stages. Additional work in persimmon indicates that shallow root distribution requires frequent low-rate irrigation under some soil conditions, while long-term orchard floor and soil fertility management can alter soil organic matter, phosphorus, potassium, microbial communities, and enzyme activity in ways that are strongly associated with fruit yield and quality. However, persimmon responses can vary with tree age and irrigation configuration, since in juvenile orchards changes in emitter number may slightly improve trunk growth without consistently changing yield. Against this background, studying different water and fertilizer management regimes in ‘Taishuu’ sweet persimmon is necessary to clarify how irrigation and fertilization combinations affect vegetative growth, yield components, and overall productivity under local cultivation conditions. Such work can provide a scientific basis for developing efficient orchard management models that

balance high yield, fruit quality, and resource-use efficiency, while supporting the stable expansion of a high-value sweet persimmon industry.

2 Water and Nutrient Requirements of 'Taishuu' Sweet Persimmon and Their Regulatory Basis

2.1 Water requirements

'Taishuu' sweet persimmon should be managed with stage-specific water supply because persimmon water demand and sensitivity change markedly across dormancy, shoot growth, fruit set, enlargement, and ripening. Bud swelling marks the transition from dormancy to active growth, when buds begin absorbing water and nutrients, while shoot growth proceeds from early spring into midsummer and flowering and fruit set follow shortly thereafter. Correct identification of these phenological stages is important because flowering is sensitive to water and nutritional stress (Shahid et al., 2024). At the orchard scale, persimmon yield and vegetative growth both increase with irrigation, but the benefit of extra water declines once irrigation becomes high, indicating that full productivity requires adequate rather than excessive water supply. Persimmon water demand is especially high in summer, when crop coefficients can approach or exceed 1.0, so this period requires close irrigation control to sustain transpiration and fruit growth.

Water stress during fruit development must be managed cautiously because persimmon fruit growth is highly sensitive to deficit irrigation, especially when stress occurs in spring and summer (Porras-Jorge et al., 2025). Deficit irrigation can save about 20% of irrigation water and improve water-use efficiency without always reducing total yield, but it often lowers final fruit weight and therefore may reduce commercial value (Porras-Jorge et al., 2025). Several studies also show that irrigation affects fruit number through early-stage processes: higher irrigation increased fruit number by as much as threefold in one trial, whereas spring deficit irrigation reduced June fruit drop and sometimes increased harvested fruit number. Late-season water restriction can accelerate color development and advance ripening, but this benefit is usually accompanied by lower fruit weight, so irrigation scheduling for 'Taishuu' should prioritize adequate supply from shoot growth through fruit enlargement and use deficit only strategically during less sensitive periods.

2.2 Nutrient requirements

The nutrient requirement of 'Taishuu' sweet persimmon is governed by rapid vegetative growth early in the season and by strong assimilate and mineral demand from developing fruit later in the cycle. Persimmon nutrition should therefore be synchronized with phenology and crop load rather than applied uniformly, because adequate management depends on knowing tree needs at specific developmental stages (Quartieri et al., 2023; Shahid et al., 2024). In 'Rojo Brillante', fruit enlargement was identified as the period of greatest nutritional balance across sprout origin and irrigation type, which makes it a key stage for diagnosis and adjustment of nutrient programs (Morales et al., 2022). Estimated fruit nutrient removal is substantial, at about 0.85 kg·N, 0.39 kg P_2O_5, and 1.42 kg K_2O per ton of production, highlighting the particularly high demand for potassium during cropping (Morales et al., 2022). Mature orchards also show annual macronutrient demands near 90 kg·N·ha^{-1}, 10 kg·P·ha^{-1}, 80~90 kg·K·ha^{-1}, 130~160 kg·Ca·ha^{-1}, and about 25 kg·Mg·ha^{-1}, confirming that Ca and K are major components of total seasonal nutrient requirement (Quartieri et al., 2023).

Nutrient partitioning changes during fruiting, so balanced fertilization is more important than simply increasing fertilizer rates. In pot-grown 'Fuyu', medium N and K fertigation improved fruit size under heavy crop load, whereas high fertigation was not superior and reduced skin color, showing that excessive supply can impair fruit quality. Fruit also becomes a strong sink for N and especially K; when leaf:fruit ratio declined, the proportion of total tree N and K allocated to fruit increased sharply. Across persimmon studies, leaf N tends to decline while fruit flesh N increases during maturation, whereas leaf P and K decrease without necessarily producing parallel fruit changes, indicating active internal redistribution among organs (Vilhena et al., 2022). Calcium and magnesium are particularly important for quality, because Ca and Mg concentrations and the N/Ca and Ca/(K+Mg) ratios are closely related to firmness, color, soluble solids, and tannin status, and Ca deficiency has been associated with physiological disorders such as top rot and blossom-end browning (Vilhena et al., 2022).

2.3 Water-nutrient synergy

Water and nutrient uptake in 'Taishuu' sweet persimmon should be viewed as a coupled process, because soil water availability controls nutrient mass flow to roots, while nutrient status affects canopy growth, transpiration, and sink activity. Nutrient imbalance reduces uptake of other elements and increases plant sensitivity to stress (Morales et al., 2022). In fruit trees, improving irrigation and fertilization together is more effective than managing either factor alone, and this is especially relevant in persimmon, where sustainable irrigation and fertilization are both considered essential for a salinity-sensitive crop (Li et al., 2024). General fertigation evidence shows that synchronizing water and nitrogen supply with crop demand increases yield, water productivity, and nitrogen-use efficiency while reducing evapotranspiration relative to conventional practice. In fruit crops specifically, drip fertigation produces the largest NUE gains among crop groups in one meta-analysis, supporting its relevance for persimmon orchards.

Mechanistically, water-nutrient coupling improves performance by maintaining suitable root-zone moisture, promoting fine-root development, and matching nutrient release to periods of maximum uptake. Intelligent fertigation studies showed that stage-based control of irrigation and fertilization improved water and nutrient use efficiency by tailoring inputs to uptake dynamics (Bao et al., 2023). In tomato and watermelon, these strategies increased root length, surface area, and uptake capacity, and the resulting improvements in root traits were strongly associated with higher N, P, and K use efficiency and irrigation water productivity (Bao et al., 2023; Wang et al., 2024). Similar coupling responses were reported in mango, where moderate fertilization combined with localized micro-irrigation maximized dry matter production and water–fertilizer use efficiency, while excessive fertilizer reduced agronomic efficiency. For 'Taishuu' sweet persimmon, this evidence supports a regulatory basis centered on drip or localized fertigation, moderate nutrient rates, and phenology-based scheduling so that water and nutrient supply remain synchronized with shoot growth, fruit set, enlargement, and ripening (Morales et al., 2022; Sneha et al., 2025).

3 Effects of Different Water Management Regimes on the Growth and Yield of 'Taishuu' Sweet Persimmon

3.1 Effects of water supply on shoot, leaf, and overall tree growth

Water supply has a clear regulatory effect on vegetative growth in persimmon, and the available evidence indicates that shoot extension, trunk enlargement, canopy development, and overall tree vigor all increase as irrigation approaches non-limiting levels. In a three-year trial, higher irrigation increased both yield and vegetative growth, although the response diminished at the highest water inputs, suggesting that tree growth benefits from adequate water but not from unlimited irrigation. This pattern is consistent with the view that persimmon has relatively high seasonal water demand, especially in summer, when crop coefficients can approach or exceed 1.0 and canopy transpiration rises with increasing atmospheric demand and canopy light interception (Ballester et al., 2022). For orchard management, this means that insufficient irrigation during periods of active canopy expansion is likely to restrict vegetative growth and reduce the framework needed to support stable cropping in later stages.

Deficit irrigation can moderate excessive vigor, but its effect on tree growth depends on intensity, timing, and irrigation system design. In young persimmon orchards, increasing the number of emitters per tree increased relative trunk growth by 15%~18%, and trees irrigated with double lines showed slightly less negative stem water potential in midsummer, indicating that better wetting of the active root zone can improve early vegetative performance (Parra et al., 2021). However, within the tested range of wetted area, irrigation design had little consistent effect on canopy volume or yield in two of three seasons, so hydraulic layout refinement appears to have subtler effects than irrigation dose itself. Additional regional evidence indicates that persimmon often develops a shallow root distribution and performs well under frequent, low-volume irrigation, a pattern that supports localized drip supply for maintaining leaf turgor and sustained shoot growth (Abdullaeva, 2024). For 'Taishuu', these findings support a strategy of maintaining relatively stable soil moisture during vigorous spring and early summer growth while avoiding prolonged deficits that suppress trunk and shoot development (Qiang et al., 2025).

3.2 Effects of water management on photosynthetic physiology and plant water status

Water management strongly affects photosynthetic physiology in persimmon through its control over stomatal behavior, transpiration, and plant water status. As soil moisture declines, stem water potential and leaf conductance also decline, showing that water deficit rapidly constrains gas exchange (Porras-Jorge et al., 2025). Under mild stress, persimmon trees respond mainly through stomatal regulation, reducing transpiration and maintaining stem water potential within a relatively narrow range, which reflects a drought-avoidance rather than dehydration-tolerance strategy. Persimmon also shows some xeromorphic adjustment, including high leaf relative apoplastic water content, which likely helps retain water when leaf water potential becomes more negative. At the whole-canopy level, transpiration increases from April to June–July and is positively related to reference evapotranspiration and solar radiation, while its response to vapor pressure deficit is nonlinear, indicating that atmospheric demand interacts with soil water supply to determine actual water use (Ballester et al., 2022).

These physiological responses also explain why plant-based indicators are useful for irrigation scheduling in persimmon. Sap flow provided a strong real-time signal for estimating persimmon water status in mild deficit conditions, while leaf turgor measurements with the Yara ZIM-probe were highly correlated with midday stem water potential (Martínez-Gimeno et al., 2017). Well-watered trees generally maintained stem water potential above about −0.8 MPa, and rootstock differences affected drought sensitivity, with *D. lotus* often appearing more sensitive than *D. virginiana* in turgor- and water-potential-based monitoring (Martínez-Gimeno et al., 2017). Even so, water-stressed trees typically recovered stem water potential and leaf conductance after rewatering, suggesting that moderate, short-term deficit irrigation does not necessarily cause lasting physiological injury (Porras-Jorge et al., 2025; Qiang et al., 2025). Evidence from other fruit trees reinforces this point: mild deficit can limit transpiration more than photosynthesis and improve instantaneous water-use efficiency, whereas severe deficit causes poorer photosynthetic recovery and more persistent physiological damage (Chen et al., 2025).

3.3 Effects of water management on fruit enlargement and yield formation

Water management has particularly strong effects on fruit enlargement and yield formation because persimmon fruit growth is highly sensitive to water deficit. Across multiple studies, regulated deficit irrigation reduced final fruit weight, with the strongest decreases observed when water restriction occurred during spring or especially summer fruit growth. Higher irrigation generally increased mean fruit size and reduced rejection up to about an irrigation-to-ET_0 ratio of 0.8, while total yield rose with irrigation before approaching a plateau at high application rates. This indicates that adequate water supply is essential for marketable fruit enlargement, even when total tonnage does not always respond proportionally to additional water (Ballester et al., 2022). For ‘Taishuu’, which is valued for large, high-quality fruit, this tradeoff is especially important because even modest reductions in individual fruit weight can reduce commercial performance despite stable total yield (Martínez-Gimeno et al., 2017).

At the same time, moderate water restriction at specific stages can alter fruit set and increase irrigation water productivity. Spring deficit irrigation consistently reduced June or physiological fruit drop, increasing harvested fruit number by about 30% in *D. lotus* and 42% in *D. virginiana* in one study, and lowering overall fruit drop by 31% under early deficit in another. Recent trials likewise found that regulated or sustained deficit irrigation saved 11%~30% of irrigation water, maintained marketable yield, and in some cases improved water productivity, mainly because lower fruit drop offset smaller fruit size. However, late-season deficit also accelerated ripening, increased red-orange coloration, and reduced firmness, which may allow earlier harvest but usually at the cost of lower fruit weight (Porras-Jorge et al., 2025). The evidence suggests that in ‘Taishuu’ sweet persimmon, full or near-full irrigation is preferable during fruit enlargement, while carefully controlled spring or late-season deficit may be used strategically to regulate fruit retention, ripening time, and water-use efficiency (Qiang et al., 2025).

4 Fertilizer Management Effects in ‘Taishuu’ Persimmon

4.1 Effects of different fertilization levels on vegetative growth

Different fertilization levels clearly regulate vegetative growth in persimmon, but the response is nonlinear and depends strongly on nutrient source, timing, and crop load. Moderate-to-adequate fertilization generally increases

shoot growth, leaf area, trunk or stem thickening, and total dry matter production, whereas insufficient nutrition suppresses canopy development and excessive nitrogen can induce overly vigorous secondary shoot growth (Enab and Mikhael, 2018; Guo et al., 2022). In young 'Fuyu' trees, high summer fertilization increased shoot length but did not improve next-spring flower bud number, showing that stronger vegetative growth does not necessarily translate into better reproductive potential. Similarly, oil-cake application at 50~100% of the recommended rate increased dry matter production by more than 1 500 kg ha^{-1}, but also increased water sprouts and reduced light interception in the inner canopy as vigor rose. These findings indicate that fertilization should aim to maintain balanced tree vigor rather than maximize vegetative growth alone (Bayram and Büyük, 2021).

Nutrient source also changes the pattern of vegetative response. In young 'Fuyu' trees, chemical fertilizer triggered secondary shoot growth within two weeks, whereas liquid pig manure released nitrogen more slowly and produced no such flush over the same period, indicating that fast-acting nitrogen sources stimulate more immediate canopy expansion (Choi et al., 2017). In 'Costata', combining mineral nitrogen with organic nitrogen and biofertilizer improved shoot number, shoot length, leaf number, and leaf area more than organic nitrogen alone and performed similarly to or better than 100% mineral nitrogen (Enab and Mikhael, 2018). Organic and biologically mediated inputs can also strengthen early vegetative establishment: arbuscular mycorrhizal inoculation increased seedling height, leaf area, stem diameter, shoot dry mass, root dry mass, and nutrient accumulation in persimmon seedlings, while green-manure row management and combined manure plus NPK improved growth in field orchards (Machineski et al., 2018; Abdullaeva, 2024). For 'Taishuu', the most defensible inference is that moderate fertilization supplied in forms that avoid abrupt nitrogen release will better support stable shoot and leaf growth than either nutrient deficiency or excessive mineral nitrogen.

4.2 Effects of fertilizer ratios on leaf nutritional status and photosynthetic capacity

Fertilizer ratios affect leaf nutritional status by changing both the absolute concentration of nutrients in leaves and the balance among nutrients, and this balance appears more important than simply raising fertilizer dose. Persimmon leaf nutrient levels vary with management and sampling time, so fertilization programs should be guided by leaf analysis across phenological stages rather than by fixed annual inputs alone (Figure 1) (Bayram and Büyük, 2021; Acosta et al., 2023). In 'Rojo Brillante', management altered leaf K and Mg concentrations, and fruit quality correlated closely with Ca and Mg status and with the N/Ca and Ca/(K+Mg) ratios, indicating that nutrient balance within the canopy has direct physiological and quality consequences (Vilhena et al., 2022). High nitrogen supply tends to delay maturation and weaken color development, because leaf N is negatively related to fruit color and soluble solids and positively related to firmness (Vilhena et al., 2022). In addition, increasing Mg fertilization raised leaf N, P, K, Mg, and total chlorophyll in 'Costata', supporting the view that targeted nutrient balancing can enhance photosynthetic apparatus as well as mineral status.

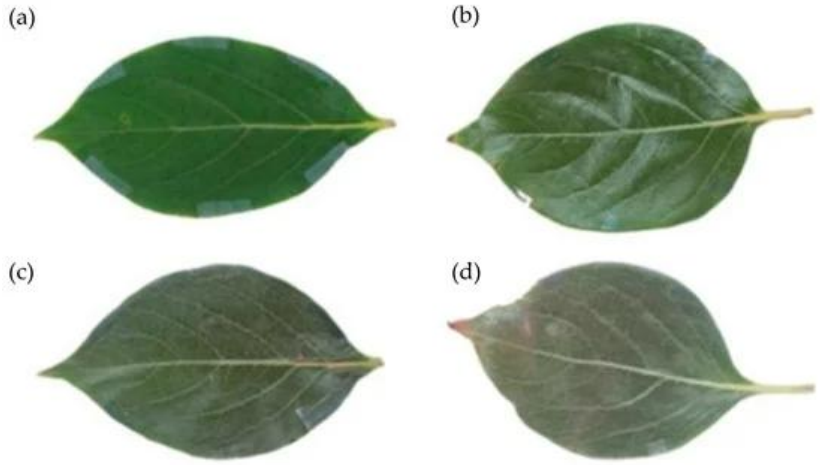


Figure 1 Persimmon leaves collected (Adopted from Acosta et al., 2023)

Image caption: (a) April (after flowering), (b) July (70% fruit size), (c) October (fruit at harvest) and (d) November (lethargy) (Adopted from Acosta et al., 2023)

The available evidence also suggests that optimal nutrient ratios, not maximal inputs, best sustain photosynthetic capacity. In Chinese cherry, an intermediate NPK combination improved leaf NPK concentration and mean daily photosynthetic rate more than higher or less balanced treatments, while also improving fruit set and fruit size, which is consistent with a source–sink mechanism relevant to persimmon (Guo et al., 2022). In persimmon, high fertilization increased N and K concentrations in leaves, fruits, and shoots, but it also decreased skin color and reduced soluble sugars in dormant shoots, showing that surplus nutrition can shift carbon allocation away from desirable quality and reserve formation. Mixed organic-mineral-biofertilizer regimes increased leaf chlorophyll and leaf N, P, K, Ca, Fe, Mn, and Zn compared with mineral nitrogen alone in 'Costata', and foliar micronutrient sprays improved leaf Zn, Fe, and B while producing greener leaves (Enab and Mikhael, 2018). For 'Taishuu', these results support fertilization strategies that maintain balanced N:K supply while preventing relative Ca or Mg dilution, because photosynthetic performance and subsequent fruit quality appear to depend on nutrient balance more than on high fertilizer intensity (Vilhena et al., 2022; Acosta et al., 2023).

4.3 Effects of fertilizer management on fruit set, individual fruit weight, and yield

Fertilizer management influences fruit set, individual fruit weight, and total yield mainly by regulating crop load support and nutrient partitioning to fruit. In container-grown 'Fuyu', lower leaf-to-fruit ratios increased yield but reduced individual fruit weight, soluble solids, and color, while medium N and K fertigation increased fruit size under high crop load more effectively than no fertigation or high fertigation. High fertigation was not superior to medium fertigation for total dry matter or K accumulation and decreased fruit skin color, indicating diminishing returns and quality penalties at excessive input levels. Related studies in 'Uenishiwase' and young 'Fuyu' showed that as crop load increased, more N and especially K were partitioned into fruit and less remained in woody organs and roots, which explains why fertilization in heavy-bearing trees must replace nutrients exported by harvest without overstimulating vigor (Choi et al., 2010).

Field studies support the same balance principle. In mature 'Fuyu', all oil-cake rates increased mean fruit weight and firmness, but the highest three-year average yield occurred at 50% of the recommended rate rather than at higher rates, suggesting that moderate organic fertilization optimized both productivity and profitability. In 'Costata', the combination of 50% mineral nitrogen, 25% organic nitrogen, and biofertilizer produced the highest yield and improved fruit quality, while magnesium fertilization increased fruit set, fruit number, fruit weight, and soluble solids when rates reached 125~150 g tree^{-1} year^{-1} (Enab and Mikhael, 2018). Organic orchard floor management and foliar micronutrient supply also improved reproductive performance: more frequent mowing in organic orchards increased average fruit yield and fruit fresh weight, and combined Zn, B, and Fe sprays increased fruit number, fruit weight, fruit diameter, and yield per tree. Evidence from persimmon bioregulator studies is directionally similar, with GA_3 or BA treatments increasing fruit set, fruit weight, and yield, but these results are better viewed as complementary to nutrient management than as substitutes for it (Darwesh, 2020; Chu et al., 2025; Thakur et al., 2025).

5 Effects of Integrated Water and Fertilizer Management on Growth and Yield Formation of 'Taishuu' Sweet Persimmon

5.1 Synergistic regulation of tree vigor under different water-fertilizer combinations

Different water-fertilizer combinations regulate tree vigor through a clear synergistic effect on root-zone resource availability, root growth, and canopy expansion. In fruit trees, integrated drip irrigation and fertilization is widely recognized as an efficient approach for improving water and fertilizer use while supporting healthy vegetative growth (Liu et al., 2023; Zhang et al., 2024). Appropriate coupling treatments promoted root area and root density in pear, and the same treatments maintained a higher leaf area index through the growing season, indicating that balanced water and nutrient supply supports both belowground and aboveground vigor (Li et al., 2024). Similar responses were reported in young apple trees, where moderate increases in fertilizer under the same irrigation level enhanced plant growth, basal stem growth, leaf area, SPAD, and dry matter, and mild deficit irrigation under high fertilization produced the best overall growth condition (Zhou et al., 2023). In mango, localized micro-irrigation with a moderate fertilization rate maximized total dry matter and water-fertilizer use efficiency, again showing that vigor is highest under coordinated rather than maximal input levels.

The evidence also shows that the vigor response is nonlinear, with clear thresholds beyond which additional water or fertilizer no longer improve growth and may reduce efficiency. Pear studies identified a critical threshold in water-fertilizer coupling, below which increased inputs promoted vegetative growth, but above which production gains became insignificant or even negative. In mature pear orchards, higher irrigation combined with higher nitrogen increased spring shoot length, shoot base diameter, and leaf chlorophyll, but the recommended scheme was still a medium-irrigation, high-fertilizer combination rather than the maximum water input (Liu et al., 2023). Evidence from fruit-tree systems points in the same direction: irrigation is a major determinant of vegetative growth, yet deficit strategies can be useful only when stress is moderate and carefully timed, because persimmon is sensitive to water shortage and excessive restriction can suppress canopy development or shift vigor–cropping balance unfavorably. For 'Taishuu', this supports a management principle of maintaining stable spring and early summer soil moisture together with moderate, well-timed fertilization to sustain shoot growth and leaf area without inducing wasteful vegetative excess (Zhou et al., 2023; Chaurasia et al., 2025).

5.2 Effects of water-fertilizer coupling on photosynthetic production and dry matter allocation

Water-fertilizer coupling affects photosynthetic production mainly by coordinating stomatal behavior, leaf nutritional status, chlorophyll maintenance, and root hydraulic supply. In young apple, coupling treatments significantly increased SPAD, net photosynthetic rate, stomatal conductance, and water-use efficiency, and dry matter showed a positive linear relationship with SPAD, photosynthesis, and stomatal conductance (Zhou et al., 2023). In mango, drip and micro-moistening irrigation increased net photosynthetic rate, root and shoot hydraulic conductivity, and total dry mass while reducing total water consumption, and moderate fertilization gave the highest photosynthetic and dry matter responses. Pear experiments further indicate that suitable water-fertilizer treatments improve stomatal conductance and leaf area index, thereby helping maintain photosynthesis during periods of rapid fruit-tree growth (Li et al., 2024). Meta-analytic evidence is consistent with these single-crop studies: water-fertilizer integration with drip irrigation increased nitrogen-use efficiency by 31.3%, water-use efficiency by 34.5%, and yield by 12.5%, partly through lower crop evapotranspiration and improved soil physical and chemical properties (Yang et al., 2024).

Dry matter allocation also shifts under different water-fertilizer regimes, and the best yield does not necessarily occur at the treatment with the highest instantaneous gas exchange. In strawberry, irrigation-fertilizer interaction significantly affected photosynthetic rate and final fruit dry matter accumulation, and intermediate irrigation combined with moderate-to-high fertilization ranked highest overall because fruit dry matter accumulation had the greatest direct effect on yield (Du et al., 2024). In Chinese dwarf cherry, a medium water-medium fertilizer treatment gave the best overall balance among photosynthesis, soluble sugar, soluble protein, yield, and water-fertilizer use efficiency, while a higher fertilizer treatment improved some quality traits but not overall performance (Liu et al., 2026). Mechanistic work in tomato shows that irrigation amount strongly affects fruit fresh weight, dry weight, carbon allocation, and sugar-metabolism enzymes under potassium supply, indicating that nutrient effects on dry matter partitioning depend on water status and that water stress can redirect carbon between soluble sugars, starch, and other compounds (Wu et al., 2023). For 'Taishuu', this implies that integrated fertigation should target not only high leaf photosynthesis but also stable allocation of assimilates to shoots, reserve tissues, and developing fruit, especially during fruit enlargement when sink demand rises sharply (Liu et al., 2023; Li et al., 2024).

5.3 Effects of integrated water and fertilizer management on fruit development and yield components

Integrated water and fertilizer management affects fruit development through combined effects on fruit set, fruit retention, fruit enlargement, and final yield composition. In pear, suitable coupling treatments increased yield, single-fruit weight, and primary fruit rate, and the best-performing treatment also showed the best overall fruit growth and development (Li et al., 2024). In pomegranate, the interaction between irrigation and fertilizer regime significantly affected fruit set, fruit retention, marketable fruit, and yield, and 80% ET_0 combined with 75% mineral fertilizer plus 25% organic manure increased yield by 18.23% relative to full irrigation with 100% mineral fertilizer while maximizing water-use efficiency (Abdel-Sattar et al., 2021). In jujube, water, nitrogen, and phosphorus applied together significantly changed fruit quality and yield, and increases in irrigation and

nitrogen significantly increased yield, again supporting the need for coordinated rather than isolated input management (Zhang et al., 2024). Across fruit trees more broadly, water-fertilizer integration tends to improve average fruit weight, yield, and nutrient-use efficiency, particularly under drip systems and moderate nitrogen reduction relative to conventional farmer practice (Yang et al., 2024).

Persimmon evidence indicates that integrated management must also account for the crop's sensitivity to water stress during fruit enlargement and its distinctive fruit-drop behavior. In 'Rojo Brillante', regulated deficit irrigation reduced fruit drop and increased harvested fruit number, improving irrigation water productivity, but it also reduced unit fruit weight, so higher fruit counts did not always translate into better economic returns (Porras-Jorge et al., 2025). Spring RDI in mature persimmon improved irrigation water productivity by up to 21% on *D. lotus* and 31% on *D. virginiana* and increased harvested fruit number by 30% and 42%, respectively, mainly through reduced fruit drop rather than larger fruit size. Fertilization also interacts with fruiting intensity in persimmon: high crop load weakens tree vigor, and appropriate fertilization is needed to sustain yield components without promoting excessive vegetative competition, while high fertilization alone can increase shoot growth without improving fruit yield or color. Based on evidence from persimmon and related fruit-tree systems that maintains adequate water and nutrient supply through fruit set and enlargement, uses deficit only in carefully selected periods, and prioritizes the balance among fruit number, individual fruit weight, and marketable yield rather than maximizing any single component (Zhou et al., 2019).

6 Comparison and Optimization of Different Water and Fertilizer Management Regimes for 'Taishuu' Sweet Persimmon

6.1 Conventional High-Water and High-Fertilizer Management and Its Limitations

Conventional high-water and high-fertilizer management in fruit orchards is limited first by its poor match with actual crop demand. Traditional practice often applies irrigation and fertilizer by habit or generalized experience rather than by plant water requirement, soil evapotranspiration, or nutrient demand, which commonly results in inputs that are too high for efficient crop use (Li et al., 2018). High-input management is increasingly described as super-optimal input, meaning application beyond the agronomic optimum, and this is associated with resource waste, lower use efficiency, and environmental degradation (Ding et al., 2025). In apple, inappropriate water and nitrogen strategies reduced yield, quality, water productivity, and NUE while increasing environmental risk (Wen et al., 2024). In pear, unreasonable irrigation and fertilization dosages were linked to poor vegetative growth and fruit quality, and the response to added inputs followed a threshold pattern rather than a linear one (Liu et al., 2023).

The second limitation is that excessive irrigation and fertilization can directly impair root-zone conditions, fruit performance, and environmental safety. In kiwifruit, excessive irrigation had a stronger negative effect on yield and WUE, and excessive irrigation combined with high fertilization aggravated nutrient leaching (Ding et al., 2025). In pear, excess irrigation promoted nutrient leaching below the active root zone, while excess nitrogen caused waste and nonpoint-source pollution without increasing individual fruit volume or weight; excessive water could also increase fruit drop and reduce irrigation water productivity (Liu et al., 2023). In vegetable soils already under excessive fertilization, irrigation had a stronger effect than fertilization on leachate quality, and conventional irrigation plus conventional nitrogen represented the poorest baseline compared with optimized combinations (Li et al., 2018). Persimmon-specific orchard evidence also shows that higher irrigation does not indefinitely increase output, because the marginal yield response declines at high irrigation levels, and moderate early-season water stress can sometimes improve the commercial outcome by reducing fruit drop and increasing fruit number rather than maximizing fruit size (Puerto et al., 2021).

6.2 Water- and fertilizer-saving management and its applicability

Water- and fertilizer-saving management is applicable to 'Taishuu' sweet persimmon when the goal is to maintain yield or marketable output while improving input efficiency. Across fruit crops, reducing above-optimal water to optimal water increased apple yield by 19.4% and water productivity by 36.1%, while reducing above-optimal nitrogen to optimal levels increased apple yield by 8.9% and NUE by 48.1% (Wen et al., 2024). The same

meta-analysis estimated average saving potentials of 20.4% less irrigation water and 37% less nitrogen without sacrificing overall production performance (Wen et al., 2024). In kiwifruit, reducing super-optimal irrigation increased yield by 16.24% and WUE by 20.06%, while reducing super-optimal nitrogen increased yield by 32.76% (Ding et al., 2025). These results indicate that input reduction is most useful not under true deficiency, but where local practice has already exceeded crop requirement (Ding et al., 2025).

Its applicability depends strongly on timing, deficit intensity, and the production target. In mango, mild deficit irrigation at 75% *ET*c combined with stage-specific fertilizer rates gave the best overall benefit for yield and water–fertilizer use efficiency, while full irrigation with a different fertilizer schedule was better for some fruit-quality traits (Sun et al., 2022). A related mango study showed that regulated deficit irrigation at maturity plus moderate fertilization maximized yield and WUE, whereas deficit at flowering or fruit expansion reduced yield (Peng et al., 2023). In pomegranate, 80% ET_0 combined with 75% mineral fertilizer and 25% organic manure increased yield by 18.23% over full irrigation plus full mineral fertilization and gave the highest water-use efficiency, while 60% ET_0 with the same fertilizer mix was more suitable where water was severely scarce or fruit was destined for processing (Abdel-Sattar et al., 2021). For persimmon, this supports water- and fertilizer-saving regimes mainly in orchards with excessive baseline inputs, moderate crop load, and careful stage selection, rather than as a blanket reduction strategy across the whole season (Puerto et al., 2021).

6.3 Precision integrated water and fertilizer management and optimization strategies

Precision integrated water and fertilizer management is the most promising direction for optimizing ‘Taishuu’ sweet persimmon because it synchronizes supply with crop demand instead of simply increasing or decreasing inputs uniformly. Drip fertigation consistently improved yield, water productivity, and NUE relative to traditional irrigation and broadcast fertilization, with meta-analytic gains of 12.0% in yield, 26.4% in water productivity, and 34.3% in NUE; among crop groups, fruit crops showed the largest NUE increase. A second meta-analysis found that water–fertilizer integration with drip irrigation improved crop yield by 12.5%, WUE by 34.5%, and NUE by 31.3%, and was suitable for fruit trees in medium-textured soils; it recommended subsurface drip with low flow rates and nitrogen inputs 10%~25% below conventional farmer rates (Yang et al., 2024). Persimmon-specific production systems likewise indicate that adequate fertigation should supply water and nutrients daily according to physiological stage and should be paired with suitable dripper layout and irrigation-system design (Parra et al., 2022).

Optimization strategies should therefore combine stage-specific quotas, moderate deficit where appropriate, and sensor- or algorithm-assisted adjustment. In grape, moderate irrigation and moderate fertilization under drip fertigation gave the best combined balance of yield, fruit quality, WUE, and fertilizer productivity (Han et al., 2023). In citrus, response-surface optimization generated explicit stage-wise irrigation and NPK thresholds, showing that precise requirements differ sharply among growth stages rather than following a constant seasonal ratio (Chen et al., 2026). Sensor-based fertigation in mandarin improved canopy growth, relative leaf water content, A-grade fruit proportion, and water and nutrient savings over conventional practice, while autonomous fertigation software in grapefruit achieved fertilizer savings of up to 40% under variable water quality (Imbernón-Mulero et al., 2023). More broadly, precision systems are most useful when they integrate soil testing, crop phenology, water-quality analysis, sensors, and decision-support tools, because fixed ratios and timings do not adequately capture soil heterogeneity or shifting crop demand (Xing and Wang, 2024). For ‘Taishuu’, the practical optimization path is a drip-fertigation regime built around phenological stages, moderate rather than maximal inputs, and dynamic adjustment from soil, plant, and weather feedback rather than conventional fixed schedules (Han et al., 2023; Meshram et al., 2025).

7 Conclusions and Perspectives

Overall, the available evidence shows that water and fertilizer management strongly regulate vegetative growth, fruit development, yield formation, and resource-use efficiency in persimmon and related fruit-tree systems. Adequate irrigation promotes vegetative growth and supports yield, but the response is not linear because the marginal benefit of additional water declines once irrigation becomes high. In persimmon, moderate spring

regulated deficit irrigation can reduce fruit drop and improve irrigation water productivity without necessarily reducing yield per tree, although it commonly reduces individual fruit weight. Late-season water restriction can accelerate color development and fruit ripening, but this benefit is usually accompanied by lower fruit weight and softer fruit. Fertilizer management shows a similarly nonlinear pattern. Excess fertilization tends to stimulate shoot growth more readily than stable yield improvement, and in persimmon it can reduce skin color, disturb vegetative–reproductive balance, and increase the risk of weak return bloom or alternate bearing under high crop load. By contrast, moderate and balanced fertilization improves leaf nutritional status, canopy performance, and fruit development, especially when nutrient supply is coordinated with crop load and developmental stage. Taken together, the most robust conclusion is that 'Taishuu' benefits not from maximum water and fertilizer input, but from moderate, coordinated supply that maintains vigor, supports fruit enlargement, and improves efficiency.

The first key principle is to synchronize water and nutrient supply with phenological demand rather than apply uniform inputs across the whole season. Persimmon water demand is especially high in summer, while sensitivity to deficit depends on stage, with spring water stress influencing fruit drop and late stress influencing color development and ripening. Research in apple and pear likewise shows that growth, photosynthesis, and fruit quality respond differently across water–nitrogen combinations and developmental periods, which means the best treatment is usually stage-specific rather than seasonally constant. The second principle is that water and fertilizer should be managed as a coupled system, because suitable coupling maintains favorable soil moisture and nutrient availability, promotes root growth, improves stomatal conductance and leaf area, and ultimately sustains photosynthesis and dry matter accumulation. The third principle is to avoid both under-supply and super-optimal input. Multiple studies show the existence of a threshold beyond which more water or fertilizer no longer improves yield and may instead reduce fruit quality, lower use efficiency, or increase nutrient loss and environmental risk. Meta-analyses in apple and broader drip-fertigation systems show that reducing above-optimal inputs can increase yield, WUE, and NUE, with estimated savings of about 20.4% irrigation water and 37% nitrogen in apple and recommended nitrogen reductions of 10%~25% under drip integration. A related principle is to balance productivity and efficiency rather than maximize either one alone, because the highest yield treatment is not always the best comprehensive treatment when water productivity, fertilizer productivity, fruit quality, and soil sustainability are considered together. For 'Taishuu', efficient management should therefore prioritize moderate soil moisture, balanced nutrient ratios, and integrated evaluation of yield, fruit quality, and input-use efficiency.

Future work should move from generalized orchard practice toward precision integrated fertigation tailored to cultivar, rootstock, soil, and climate. Current evidence already shows that drip-based water–fertilizer integration improves crop yield, WUE, and NUE, and is particularly suitable for fruit trees in medium-textured soils. Region-specific optimization is essential because optimal water and nitrogen levels vary among climates, soils, and orchard ages, and benefits from input optimization tend to weaken as trees age or as local conditions change. The same conclusion emerges from crop-specific optimization studies, which repeatedly identify intermediate irrigation and fertilizer combinations as superior to both low and high inputs, but with different numerical optima in different regions. The next step is intelligent management based on real-time monitoring and decision support. Recent smart-agriculture studies show that IoT nodes, environmental sensing, soil-moisture monitoring, and intelligent decision-support systems can support sequential irrigation and fertigation decisions that satisfy crop demand while minimizing waste. Review evidence further indicates that combining sensors, remote sensing, machine learning, variable-rate technology, and predictive modeling can improve targeted application, reduce leaching, and adapt management to soil heterogeneity and changing environmental conditions (Xing and Wang, 2024). For 'Taishuu' sweet persimmon, the main research priority is now clear: establish local water–fertilizer response curves under different soils, climates, and rootstocks, then integrate those thresholds into sensor-guided drip fertigation systems that dynamically adjust irrigation and fertilization by phenological stage.

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Conflict of Interest Disclosure

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