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## Postprint: Review of Water Transport Processes in *Populus euphratica* in the Lower Tarim River

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### Abstract

*Populus euphratica* is an important forest genetic resource globally and possesses significant ecological functions. With the lower reaches of the Tarim River as the study area, this paper reviews and analyzes the water transport processes of *Populus euphratica*—including water acquisition, conduction, and dissipation—based on field monitoring data and literature. Adult *Populus euphratica* primarily utilizes groundwater and deep soil water, whereas seedlings exhibit varying water sources depending on their type and local soil-water conditions. Under drought conditions, leaf water transport efficiency increases, albeit with a concomitant rise in the risk of hydraulic dysfunction; adult trees reduce transpiration by down-regulating xylem hydraulic conductivity, while seedlings enhance hydraulic conductance to acquire more water. The root system exhibits hydraulic lift, with lifted water generally accounting for 10%~39% of transpiration demand. Sap flow flux density typically ranges between 0.005~0.040 L • cm<sup>-2</sup> • h<sup>-1</sup>, decreasing with increasing groundwater depth, while annual evapotranspiration of *Populus euphratica* forests ranges from 296.7~750.0 mm. Future research should focus on elucidating interactive mechanisms of water transport among root-stem-leaf systems, further quantifying water sources with greater precision, and scaling up evapotranspiration estimation to the forest ecosystem level.

### Full Text

#### A Review of Water Transport Processes in *Populus euphratica* in the Lower Reaches of the Tarim River

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## Abstract

*Populus euphratica* is an important forest genetic resource worldwide with significant ecological functions. Taking the lower reaches of the Tarim River as the study area, this paper reviews and analyzes water transport processes—including water uptake, conduction, and dissipation—based on field monitoring data and literature review. Mature *P. euphratica* primarily utilizes groundwater and deep soil water, whereas seedlings have different water sources depending on their type and local soil-water conditions. Under drought conditions, leaf water transport efficiency increases but is accompanied by elevated risk of hydraulic dysfunction. Mature trees reduce transpiration by downregulating xylem hydraulic conductivity, while seedlings enhance hydraulic conductivity to acquire more water. The root system exhibits hydraulic lift, providing 10%-39% of transpiration water use. Sap flux density ranges from 0.005 to 0.040 L · cm<sup>-1</sup> · h<sup>-1</sup>, decreasing with groundwater depth, while annual stand evapotranspiration varies between 296.7 and 750.0 mm. Future research should strengthen studies on root-leaf hydraulic interactions, further quantify water sources precisely, and scale evapotranspiration estimation to the forest ecosystem level.

**Keywords:** *Populus euphratica*; water transport; drought; lower reaches of Tarim River

Plants serve as a “bridge” between the atmosphere and soil, and their water transport processes constitute a critical component of the soil-plant-atmosphere continuum (SPAC), representing a key focus for plant physiologists and ecohydrologists. Plant growth inevitably encounters environmental stresses such as drought and salinity, which affect water physiological processes and consequently influence growth. To adapt to these adversities, plants enhance their stress tolerance through changes in morphological structure, physiological and biochemical traits, and gene expression. Water is the primary limiting factor for plant growth, and plants regulate internal water balance through root uptake, water conduction, and transpiration to improve adaptability under stress. Therefore, studying plant water acquisition, conduction, and dissipation not only clarifies adaptive mechanisms to stress but also provides scientific support for understanding water cycling. In recent years, numerous studies have investigated water physiological processes in *P. euphratica* from various perspectives. This paper focuses on the lower reaches of the Tarim River, reviewing and analyzing water transport processes—including root water uptake, stem water conduction, and transpiration dissipation—under extreme drought conditions, aiming to provide a theoretical basis for the conservation and restoration of *P. euphratica* forest ecosystems in arid desert regions.

### 1.1 Water Sources of *Populus euphratica*

*Populus euphratica* forests are desert riparian forests influenced by river water, distributed across Asia, Africa, and other regions. Except for some xerophytic and halophytic plants, stable isotopes generally do not fractionate during water

absorption and transport. Consequently, many researchers have used isotope techniques combined with mixing models to estimate water sources for *P. euphratica* in the Tarim River basin. Studies show that water sources vary with habitat. In the upper Tarim River, riparian *P. euphratica* primarily absorbs shallow soil water, with river water contributing only 14.2%, while trees far from the river mainly utilize deep soil water and groundwater. Research indicates that water sources change significantly with groundwater depth. For instance, at shallow groundwater depths (1.8 m), *P. euphratica* barely uses shallow soil water (0–75 cm) but relies on a mixture of river water, deep soil water, and groundwater. When depth increases to 3.8 m, deep soil water (below 150 cm) becomes the main source, and at 7.2 m, trees primarily use water from below 220 cm and groundwater. In extremely arid environments, groundwater is the most fundamental water source sustaining natural vegetation. Seasonal differences in water sources are pronounced in arid regions. For example, in Nevada, USA, *Populus trichocarpa* and *Populus fremontii* mainly use shallow soil water early in the growing season but shift to groundwater during drought periods. However, in the lower Tarim River, *P. euphratica* uses relatively stable proportions of various water sources throughout the growing season, primarily relying on deep soil water or a mixture with groundwater. Due to scarce rainfall and strong evaporation, surface soil moisture is low, making groundwater and deep soil water the most stable sources.

Differences in root system depth and distribution among *P. euphratica* stands of different ages also lead to variations in water sources. In the upper Tarim River, seedlings absorb shallow soil water at average depths of 0–60 cm, while mature trees mainly use 30–100 cm soil water and groundwater. In the lower Tarim River, seedlings primarily use 80 cm deep soil water, mature trees use 140 cm deep soil water and groundwater, and over-mature trees use water below 220 cm. However, Wang et al. found that seedlings in the lower Tarim River do not use shallow soil water but, like adult trees, mainly absorb deep soil water and groundwater. Research shows that hydrogen and oxygen isotopes in xylem water of root-suckering seedlings differ significantly from those of seed-origin seedlings but match their mother trees, indicating water primarily comes from the mother tree's root system. Thus, different seedling types have distinct water sources: seed-origin seedlings mainly use shallow soil water, while root-suckering seedlings rely on deep soil water and groundwater. In the upper Tarim River with shallow groundwater, both seedlings and mature trees tend to use upper soil water, whereas in the lower reaches with deep groundwater, both prefer deep soil water. Water sources of different-aged *P. euphratica* depend on root characteristics, seedling type, and groundwater depth, with groundwater always being the primary water source for mature trees.

## 1.2 Simulation of Root Water Uptake

Root water uptake models provide deep insights into root water acquisition processes and serve as important tools for predicting uptake. Researchers have

constructed various models across scales, among which the multidimensional root water uptake model established by Javaux et al. best reflects actual root water uptake processes. The empirical model developed by Feddes et al., implemented through Hydrus software, is widely applied. Many scholars have built *P. euphratica* root water uptake models based on measured soil moisture and root length density parameters, achieving good simulation results for root zone soil water dynamics. However, in arid and semi-arid regions, root water uptake is closely related to both soil moisture and groundwater level. Current models linking *P. euphratica* root water uptake with soil moisture ignore groundwater utilization, necessitating understanding of root-groundwater interactions to provide a basis for quantitative simulation.

In recent years, isotope techniques have gained increasing attention in root water uptake research, primarily using statistical models (e.g., IsoSource, MixSIAR) for simulation. Chen et al. combined stable isotope techniques with plant water physiological characteristics to construct a quantitative model for estimating *P. euphratica* water sources in the lower Tarim River. However, hydrogen isotope fractionation during water transport in *P. euphratica* and limitations on water source numbers in models increase uncertainty in simulation results. Moreover, root water uptake is a dynamic physical process. Therefore, continuous in-situ and online isotope measurements combined with *P. euphratica* eco-physiological characteristics are needed to construct process-based root water uptake models for accurately identifying and quantifying water sources under drought conditions.

## 2.1 Leaf Water Conduction

Leaves are important components of the plant water transport system (root-stem-leaf) and the terminal of water transport. Leaf hydraulic conductance reflects internal resistance and indicates water transport efficiency. Studies show that maximum leaf hydraulic conductance in *P. euphratica* is sensitive to groundwater depth, increasing with depth. This suggests that water transport efficiency improves as drought intensifies. In well-watered environments, plants increase hydraulic conductance to compete for light, heat, and nutrients. However, in the lower Tarim River, *P. euphratica* increases water transport efficiency to resist drought as groundwater depth increases.

Both leaf water transport efficiency and safety are essential for plant growth, but they are incompatible under drought conditions. In the lower Tarim River, hydraulic safety ranges diverge among *P. euphratica* populations: trees at shallow groundwater depths have the largest safety ranges but lowest hydraulic conductance, while those at deep depths have smaller safety ranges but higher conductance. This indicates different leaf water transport strategies under varying groundwater depths. When groundwater depth increases, *P. euphratica* leaves enhance water acquisition by improving transport efficiency but simultaneously increase the risk of hydraulic dysfunction.

## 2.2 Root and Stem Water Conduction

Through water control experiments, Xu et al. compared stem hydraulic characteristics of *P. euphratica* seedlings under irrigation and drought treatments, finding that drought stress increased stem hydraulic conductivity and embolism. However, comparative analysis between *P. euphratica* in the lower Tarim River and lower Heihe River showed that trees in the more severely drought-stressed Tarim River had higher root and branch xylem embolism and 35% lower maximum specific conductivity than those in the Heihe River. Natural embolism in lateral roots of mature trees far from the river was also significantly higher than in riverside trees.

In the lower Tarim River, *P. euphratica* experiences both drought and salt stress. Studies show that salt stress of varying degrees exacerbates embolism in root and stem xylem, with roots being more susceptible. Salt stress also reduces root water transport efficiency, with greater reductions under higher stress. Stem water transport efficiency is less sensitive to salt stress; under light and moderate stress, *P. euphratica* stems maintain transport efficiency and safety by increasing vessel density, wall thickness, and mechanical strength. However, under severe salt stress, stem water transport is significantly inhibited, affecting photosynthetic physiology.

## 2.3 Hydraulic Lift

Hydraulic lift has been observed across different species, ecosystems, and climate conditions, being particularly common in arid and semi-arid regions. Field monitoring and control experiments have confirmed hydraulic lift in both mature *P. euphratica* and seedlings. In the lower Tarim River, hydraulic lift is most evident within 60–120 cm horizontally from the trunk, primarily mediated by lateral roots, with a duration of about 7 days. The lifted water volume accounts for 10%–39% of daily stand evapotranspiration and can provide 22%–41% of the transpiration water consumption for surrounding herbaceous plants. Yu et al. studied water redistribution in *P. euphratica* in the lower Heihe River, finding that hydraulic lift occurred throughout the growing season, with daily water lift of  $0.21 \text{ kg} \cdot \text{d}^{-1}$  per root system, providing 14.60%–39.33% of transpiration water. The magnitude of hydraulic lift is influenced by plant characteristics and environmental factors, but how tree size and groundwater depth variations affect hydraulic lift and water redistribution in the lower Tarim River remains unclear. Hydraulic lift in *P. euphratica* is crucial for improving stand water conditions and maintaining species diversity in desert riparian forests.

## 3.1 Leaf Scale

*Populus euphratica* leaf transpiration is influenced by meteorological factors such as air temperature and photosynthetically active radiation, as well as environmental factors like groundwater depth. High temperatures reduce stomatal conductance but increase transpiration rates; however, as drought intensifies, the

magnitude of transpiration rate increase diminishes. Under different groundwater depths, leaf transpiration rate responses to vapor pressure deficit (VPD) vary. When VPD reaches 3.5 kPa, transpiration rate peaks, decreasing as a power function when VPD exceeds 3.5 kPa. Studies show that increasing drought significantly increases stomatal resistance, thereby reducing leaf transpiration. In the lower Tarim River, groundwater depth is a key limiting factor for gas exchange, with deeper groundwater exacerbating drought stress. Thus, the effect of groundwater depth on transpiration essentially reflects how varying drought stress degrees influence transpiration.

### 3.2 Individual Scale (Stem Sap Flow)

Many scholars have used heat pulse technology combined with meteorological observations to analyze diurnal and seasonal variations in *P. euphratica* sap flow and relationships between meteorological factors and sap flow. Studies show that diurnal sap flow variation is influenced by photosynthetically active radiation, air temperature, relative humidity, wind speed, and soil temperature, with radiation being the primary factor, followed by wind speed and temperature. *Populus euphratica* sap flow shows similar patterns across regions, but daily cumulative flow varies even with the same xylem diameter. In the same region, sap flux density also differs significantly under varying groundwater depths (2.75–7.82 m), averaging 0.005–0.040 L · cm<sup>-2</sup> · h<sup>-1</sup> and decreasing with depth. Additionally, sap flow velocity and daily cumulative volume vary greatly with tree age and vigor. Overall, sap flow is influenced by meteorological factors, tree physiological and morphological characteristics, and groundwater depth, decreasing as groundwater depth increases.

### 3.3 Community Scale (Stand Evapotranspiration)

Accurate estimation of *P. euphratica* stand evapotranspiration is crucial for understanding water cycling in inland river basins and for forest conservation and restoration. Evapotranspiration is primarily controlled by meteorological factors, with seasonal variation mainly affected by phenology. Some researchers have used mathematical models to simulate evapotranspiration, such as the Penman-Monteith, Shuttleworth-Wallace, and other canopy transpiration models, which have been compared with eddy covariance data. The Shuttleworth-Wallace model is suitable for large-scale sparse vegetation systems in extremely arid areas. Sulitan et al. improved simulation accuracy by incorporating groundwater level factors into the model. Yuan et al. developed a species-specific and spatially explicit model using remote sensing data, vegetation parameters, meteorological data, and eddy covariance measurements to simulate evapotranspiration for different vegetation types and cover scenarios in the lower Tarim River. This model considers physiological characteristics and spatial distribution patterns, enabling dynamic prediction of spatiotemporal water demand variations and showing good application prospects for estimating water consumption and ecological water requirements of desert vegetation in extremely arid regions.

Average daily evapotranspiration during the growing season in the lower Tarim River, estimated by eddy covariance and water table fluctuation methods, was 3.12 mm. In the lower Heihe River, these methods yielded evapotranspiration estimates differing by about 2.05 mm, likely due to differences in forest cover (49.0% vs. 28.9%). Annual stand evapotranspiration in the Tarim and Heihe Rivers ranges from 296.7 to 750.0 mm, with differences likely caused by varying groundwater depths between the two regions. Due to soil and vegetation heterogeneity, annual evapotranspiration varies among *P. euphratica* stands.

#### 4 Research Prospects

- 1) For desert riparian forest plants, groundwater-plant root interactions are significant. Quantitative analysis of *P. euphratica* water sources must consider dynamic groundwater depth effects on root water uptake. Current quantification using hydrogen and oxygen isotopes has considerable uncertainty due to method limitations and constraints in arid region applications. Future research should link isotope techniques, root morphology, groundwater depth variations, and water uptake processes to construct quantitative models with mechanistic processes for fine-scale quantification of water sources.
- 2) Water regulation mechanisms play important roles in water acquisition, conduction, and dissipation. While characteristics and patterns of *P. euphratica* water transport under different water conditions are relatively well understood, regulatory mechanism research remains exploratory. Studies are urgently needed to understand how aquaporins, osmotic adjustment, water storage, and embolism regulate water transport under drought, and the adaptive mechanisms of water transport to environmental conditions.
- 3) Extensive research has been conducted on *P. euphratica* water physiology, including root water uptake, stem water transport, and canopy transpiration, yielding valuable results. However, interrelationships among water acquisition, conduction, and dissipation remain unresolved. Integrated studies of water transport processes should be strengthened to deeply reveal the complex physiological processes and regulatory mechanisms of *P. euphratica*.
- 4) Water dissipation has been studied at different scales (leaf, individual, community), but linkages among scales have not been established. Understanding cross-scale relationships is fundamental for estimating ecosystem evapotranspiration. High-precision observations combined with remote sensing, meteorological, and soil data are needed to scale up evapotranspiration estimation to the forest ecosystem level, providing scientific support for regional ecological water consumption and demand assessments.

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