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"Reconcile land system changes
with planetary health"

Transpiration-driven water and nutrient recovery: role of vpd and root-zone temperature in hydroponics

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Abstract

Future agricultural systems must reconcile productivity with resource efficiency, as climate change and water scarcity threaten global food production. Hydroponic systems using marginal water sources offer a promising solution by enabling simultaneous water recycling, nutrient recovery, and crop production. When embedded in controlled environments, these systems allow tightly regulated closed-loop operations with minimal inputs and losses.

A key component of this internal water cycle is plant transpiration, driving water from the root to the shoot into the atmosphere. In this context, transpiration can be transformed from a physiological necessity into a functional tool for water purification. Water vapour captured via condensation can be reused within the system or safely returned to the environment. To maximise the water flux, dry air conditions are required, typically achieved by increasing vapour pressure deficit (VPD). However, elevated VPD also affects physiological processes including stomatal regulation, photosynthesis, and biomass partitioning. When combined with variable nutrient composition commonly found in treated wastewater, maintaining stable system performance becomes even more challenging.

To assess the feasibility of transpiration-driven water purification, we set environmental conditions to increase water flux and studied their effects on nutrient uptake and plant growth. Tomato plants were grown hydroponically under two VPD levels (low: 0.6 kPa; high: 2.0 kPa) and three nutrient concentrations (15, 30, 60 $\mathrm{mg\,N\,l^{-1}}$), mimicking the fluctuations in treated wastewater. Root-zone temperature (24 °C vs. 28 °C) was additionally varied at 30 $\mathrm{mg\,N\,l^{-1}}$ to test interactions with root activity.

High VPD nearly doubled cumulative water uptake across all nutrient treatments. This was accompanied by a significant increase in leaf area, likely further promoting transpirative water loss and solute flow. However, despite a higher cumulative nitrogen uptake under high VPD, the nitrogen uptake per liter of water was on average 35 % lower compared to low VPD, indicating a decoupling of transpiration and nutrient acquisition. Root-zone heating reduced biomass (12 %) and total nitrogen uptake (6 %) but increased water uptake by 24 %.

Our findings provide a foundation for developing predictive models that integrate environmental parameters to optimise water flow and nutrient uptake. Such models will support the design of controlled environments that balance transpiration-driven water recovery with efficient nutrient use.

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