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A Closed-Loop Ultrasonic Framework for Detecting and Modulating Plant Water Stress in Ixora for Precision Irrigation

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Abstract

Agriculture accounts for roughly 70% of global freshwater withdrawals, creating strong demand for plant-centered irrigation methods that detect water stress earlier and use water more efficiently. Plants under drought emit airborne ultrasonic sounds, but most prior studies treat these emissions only as diagnostic outputs. This study tests a closed-loop concept in which drought-associated plant acoustics are first decoded and then reused as biologically informed ultrasonic stimulation. In Phase 1, *Ixora* plants were recorded with a SONAPHONE system at 1 h and 9 h after watering. Well-watered plants showed sparse, short pulses (~7 ms) with dominant frequencies above 50 kHz, whereas early-drought signals were denser, longer (~16 ms), and lower in frequency. Across the analyzed drought spike set (n = 12), mean pulse width was 16.36 ms, mean amplitude 27.25 dB, and mean dominant frequency was 25.86 kHz. In Phase 2, well-watered *Ixora* leaves were exposed to 22 kHz or 30 kHz ultrasound for 20 min within a 1 h trial; controls received no ultrasound. Infrared thermography measured leaf temperature change (ΔT) as a non-contact proxy consistent with stomatal-linked evaporative cooling. Mean ΔT increased from 1.00 ± 0.23°C in controls (n = 6) to 2.07 ± 0.31°C at 22 kHz (n = 3) and 1.73 ± 0.21°C at 30 kHz (n = 3). These findings support a proof-of-concept precision-irrigation framework in which plants are both sensors and responsive biological systems within an irrigation feedback loop.

Keywords
Plant Bioacoustics, Precision Irrigation, Infrared Thermography, Ultrasound Stimulation, Water Stress

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Biography
David Hsu is a student at Princeton International School of Math and Science in New Jersey, USA. His research interests include plant bioacoustics, precision irrigation, environmental engineering, and sustainable agricultural technology. His current research investigates how ultrasonic signals emitted by plants under water stress can be detected and translated into a closed-loop irrigation framework. Through acoustic recording, infrared thermography, and ultrasound stimulation, he explores how plant-centered sensing systems may improve water-use efficiency and support future sustainable agriculture.