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Short communication

Reduced frequency of soil moisture measurements for cost-effective Irrigation management in arid regions

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Climate projections indicate that expanding irrigated agriculture by more than 20% may be required to meet global food demand. To reduce pressure on freshwater, researchers are pursuing alternative sources including treated wastewater reuse and desalination (Al-Kilani and Bani-Melhem, 2025), alongside water conservation through smarter management of agricultural water (Kaur *et al.*, 2025; Abdelal *et al.*, 2024). Irrigation management using soil water content (SWC) sensors can conserve water by supplying the right amount at the right time, while reducing groundwater pollution and energy for pumping (Datta and Taghvaeian, 2023; Schattman *et al.*, 2023). The use of lab analysis is not practical for such purposes due to the time and effort involved, except to support the calibration of these sensors (Al-Khreisat *et al.*, 2025b). Researchers have mainly focused on exploring measurement principles of SWC, calibrating sensors for different soils, and lowering sensor costs (Abdelal *et al.*, 2025). These efforts have led to many reliable and affordable sensor types (Abdelal and Al-Kilani, 2024), which is important for farmers who, unlike researchers, prioritize lower costs (Al-Kilani *et al.*, 2025a; Songara and Patel, 2022). However, reducing the operational costs of SWC monitoring by adjusting operational settings has received limited attention. This study explores the effect of adjusting measurement frequency on operational costs related to energy consumption and replacement frequency and the possibility of compromised reliability.

Sensor setup and calibration

A Time Domain Transmission (TDT) SWC sensor (SMT100, Truebner, Germany) was installed within 10 cm of boxwood shrubs (*Buxus sempervirens*) in a semiarid field site in Mshagar, Jordan (annual rainfall <300 mm). The sensor, operated on factory calibration, was placed in the top 30 cm of a clay loam soil (bulk density 1.1 g cm⁻³, EC 0.1 dS m⁻¹, pH 7.9) and powered by a battery-operated Truebner100 logger with four D batteries (Fig. 1). TDT sensors operate at high frequencies (up to ~1.75 GHz), reducing interference from soil salinity compared to lower-frequency capacitance sensors (Mane *et al.*, 2024). Prior to field deployment, bench-scale tests were conducted using soil from the field, adjusted to volumetric water contents of 10, 20, and 30%. Sensor readings were compared with laboratory determinations using mean absolute error (MAE) ($|SWC_{lab} - SWC_{sensor}|$) as an evaluation metric (Al-Khreisat *et al.*, 2025b). Five replicates per level resulted in average MAE of 2.9, 5.1, and 3.6%, at 10, 20, and 30% moisture levels, respectively, consistent with ranges reported elsewhere (Bogena *et al.*, 2017). Field monitoring ran from March to June 2025 at three locations, with two measurement frequencies: 1 reading every 2 min (default) and 1 reading every 15 min, the latter was chosen to retain at least hourly data in case some readings were faulty or missing. The analysis focused on reliability of data record, energy consumption (battery voltage), and memory use.

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Fig. 1. The SMT100 sensor used in this study for SWC monitoring (left), the installation points near the plants (middle), and the internal data logger and battery-based energy supply system for the sensor (right).

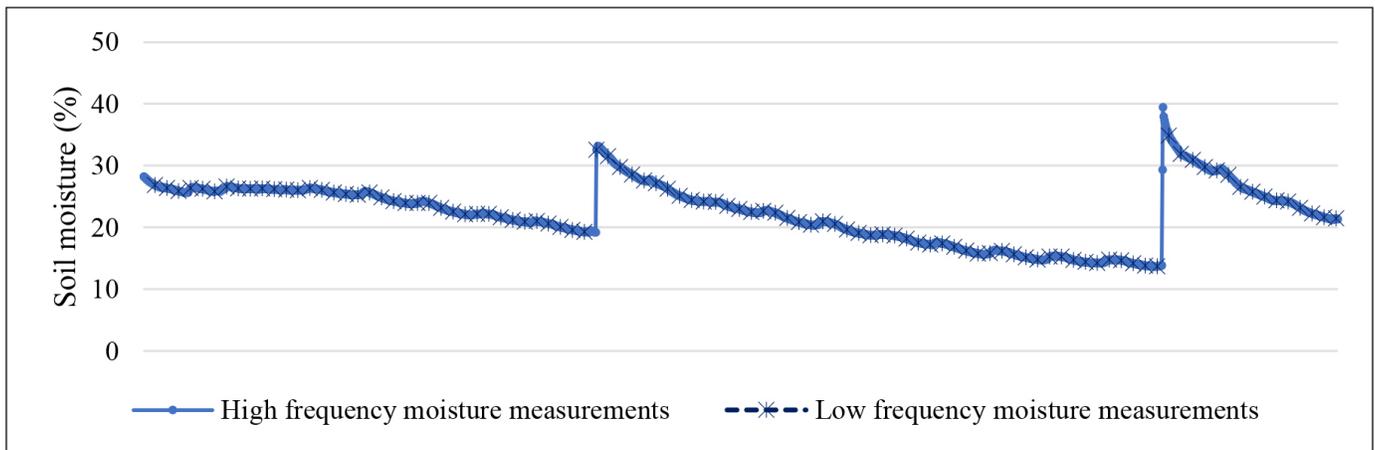


Fig. 2: SWC measurements using high and low frequency at the study site.

Reliability of reduced measurement frequency

The primary concern in this study was the sufficiency of the measurement frequency; i.e. would any significant events be missed during the sleep time. To explore this aspect, measurements at higher and lower frequencies were graphed against irrigation events (Fig. 2).

Both measurement frequencies adequately captured soil moisture dynamics, and the rate of water loss was too low to justify higher-frequency readings. Slow drainage is likely linked to the clay content and modest evaporation rates. To further verify this, evapotranspiration (ET), a main driver of moisture stress (Peethani *et al.*, 2025) and a key indicator of crop water use (Al-Omoush *et al.*, 2025; Mehta and Pandey, 2015), was examined using 9 months of daily evaporation data from a nearby station (~300 m). The maximum daily evaporation (7.7 mm; Table 1) indicates that water abstraction would generally be insufficient to cause substantial SWC decline or plant wilting during sensor sleep, even under high crop coefficients ($K_c = 1.5$) or even if most of the evaporation occurred in a short period (1-2 hours).

The impact of evaporation on SWC can be more clearly illustrated by accounting for its fraction from the soil water depth (Fig. 3). At most, evaporation would decrease SWC by 8% during a full day. Even if it reached 10%, SWC would not drop from field capacity (when irrigation was applied) to wilting point (when plant

roots can't absorb water) within the sensor's sleep time. These results conclusively indicate that a lower measurement frequency, (as low as 4 readings per hour) would not be risky. However, nearby regions have recently experience record-breaking ET levels (Al-Kilani *et al.*, 2025b), so the risk from reducing the measurement frequency should be considered on a site-by-site basis.

Impact on energy and data storage

Prior to deployment, battery voltage was 6.5 V and logger memory (16 MB) was empty. After ~3 weeks of operation, the low-frequency setting (1 reading/15 min) led to a drop to 6.1

Table 1: Summary statistics of daily ET in the study site over a period of 9 months (Sep-May)

Statistic	Value (mm)
Mean	3.152
Std. Error	0.155
Median	2.671
Std. Dev	1.682
Variance	2.829
Range	7.328
Minimum	0.4
Maximum	7.7

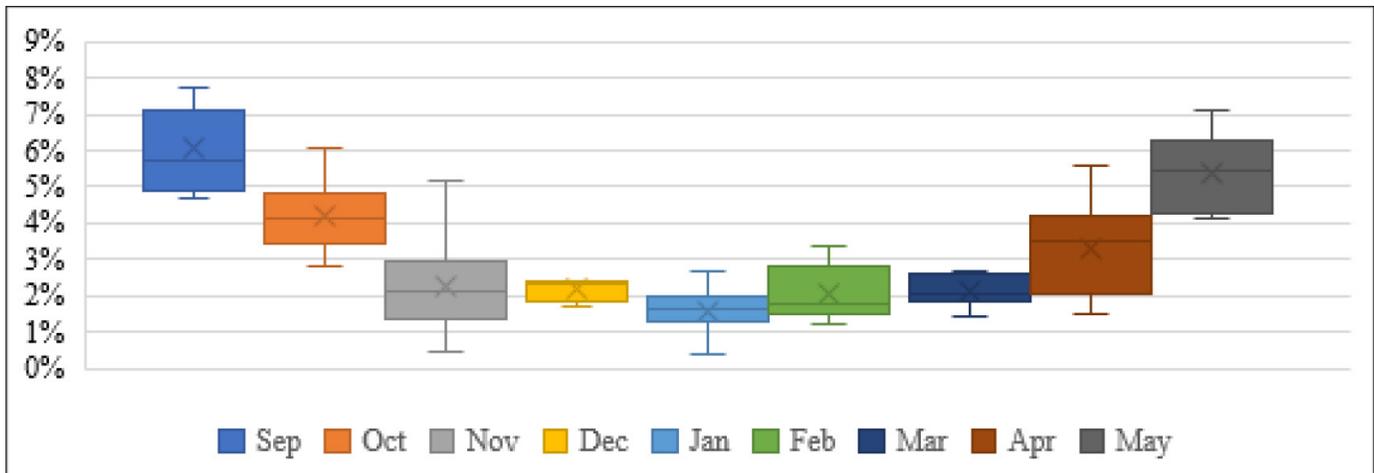


Fig. 3: Average daily ET as a percentage of available water for a period of 9 months in the study site based on a 50 cm soil depth and a 20% available water (FC-PWP)

Table 2: Impact of reducing measurement frequency on energy and memory consumption over a period of 3 weeks

Frequency	Energy consumed (%)	Memory used (%)	Est. battery life (days)	Est. memory life (days)
2-min	30%	20%	70	105
15-min	6%	3%	350	700

V ($\approx 6\%$ battery use) and 3% memory use, whereas the high-frequency setting (1 reading/2 min) consumed $\approx 30\%$ of battery life and 20% of memory (Table 2). Extrapolating these values gives an estimated battery life of ~ 70 days and memory life of ~ 105 days at high frequency, compared with ~ 350 and ~ 700 days, respectively, at low frequency. This is sufficient to cover the full growing cycle of irrigated vegetables in the study area (Al-Khreisat *et al.*, 2025a).

In practice, the gain in energy efficiency is not perfectly proportional to the reduction in measurement frequency, i.e. reducing frequency by 50% may not lead 50% energy reduction. This is because additional factors such as sensor warm-up time, idle power draw, and non-linear battery discharge also affect consumption. Meaningful energy savings are achieved when the sensor actually sleeps between readings, the active time per measurement is short, and background processes (e.g., constant communication or logging) are minimized. In this study, data were stored locally on the logger without using power-intensive communication protocols (e.g., GSM, LoRa); if such protocols are employed, lowering measurement frequency would typically yield even stronger proportional savings. Extending the interval between readings also lengthens maintenance intervals: memory capacity at low frequency is sufficient for several growing seasons, while battery life becomes the limiting factor, with an estimated ~ 350 days at low frequency versus a little over 2 months at high frequency. Assuming a labor cost of \$5 per field visit and \$8 per set of four D batteries, the high-frequency setting requires about 5.2 visits per year ($\sim \$67.6/\text{year}$), compared with roughly one visit ($\sim \$13/\text{year}$) at low frequency, saving about \$55 per sensor annually. In networks with hundreds of sensors (Bogena *et al.*, 2017), these savings can reach thousands of dollars; improving the economic feasibility of sensor-based irrigation and

supporting SDG 15 (“Life on Land”) and SDG 12 (“Responsible Consumption and Production”).

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