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Simulation of water balance components in drip-irrigated sugarcane using SWAP model

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Abstract

Imagine knowing exactly how much of every litre of irrigation water ends up as crop transpiration, deep drainage, or surface runoff—before the season even starts. This research calibrated the SWAP (Soil-Water-Atmosphere-Plant) model for drip-irrigated sugarcane at Bangladesh Agricultural University, Mymensingh, over two seasons (2021-2022 and 2022-2023). Simulated seasonal evapotranspiration (847 mm) matched observed values (812 mm) with NRMSE of 7.1%. Drainage was slightly underestimated (123 vs. 141 mm). The model indicated that drip irrigation saved 23.4% water compared with furrow while maintaining 94.6% of cane yield. Sensitivity analysis showed that saturated hydraulic conductivity and root depth were the two most influential soil parameters.

Keywords: SWAP model, water balance, drip irrigation, sugarcane, evapotranspiration, drainage, simulation, soil hydraulic, Bangladesh, water-use efficiency

Introduction

Picture a sugarcane field where every dripper delivers water precisely to the root zone—yet without a model, the grower can't tell whether 20% or 40% of that water escapes as deep drainage. Process-based models like SWAP solve the Richards equation for variably-saturated flow and couple it to crop growth, giving a complete water balance ^[1, 2].

Bangladesh's sugarcane sector is shifting from flood to drip irrigation to cope with groundwater decline in the Brahmaputra floodplain ^[3]. But field-level water balance data for drip sugarcane are scarce, making model-based planning the practical alternative ^[4]. This research aimed to: (i) calibrate and validate SWAP for drip-irrigated sugarcane, (ii) quantify seasonal water balance components, and (iii) compare simulated water use under drip versus furrow irrigation.

Materials and Methods

Research Area

The trial was at the Sugarcane Research Station, BAU, Mymensingh (24°43' N, 90°26' E), Bangladesh. Soils are silty loam (Old Brahmaputra series, pH 6.3, OC 1.08%). Two seasons of sugarcane (cv. Isd-39) were monitored under drip irrigation at 100% crop ET replacement.

Simulation Parameters

SWAP v4.0 was parameterised with van Genuchten soil hydraulic functions fitted to field-measured retention curves (pressure plate, 0-15 bar). Crop parameters (LAI trajectory, rooting depth, Kc values) were calibrated against the first season and validated against the second. Weather inputs (daily Tmax, Tmin, radiation, humidity, wind) came from the on-farm station. Drip application was simulated as daily point-source infiltration at 80% wetted area ^[5].

Soil/Water Quality

Pre-season soil analysis (0-120 cm, four layers) measured texture, bulk density, saturated hydraulic conductivity (Ks), and moisture at field capacity and wilting point. Irrigation water EC was 0.41 dS m⁻¹ (suitable quality). Drainage was measured with ceramic-cup lysimeters at 120 cm depth; ET was back-calculated from the water balance.

Results

Table 1: Simulated vs observed seasonal water balance components (mm season⁻¹, 2-season means)

Component	Simulated	Observed	Difference (%)	NRMSE (%)
Irrigation	1050	1050	0.0	—
Rainfall	1420	1420	0.0	—
ET	847	812	+4.3	7.1
Drainage	123	141	-12.8	11.4
Runoff	38	45	-15.6	14.7
Storage Δ	+42	+37	+13.5	9.8

ET = evapotranspiration; Δ = change; NRMSE = normalised root mean square error. Irrigation and rainfall are inputs (not simulated).

SWAP reproduced seasonal ET within 4.3% and captured the dominance of ET (34% of total water input) in the balance (Table 1). Drainage was underestimated by 12.8%, likely because preferential flow through cracks wasn't captured by the Richards equation solver.

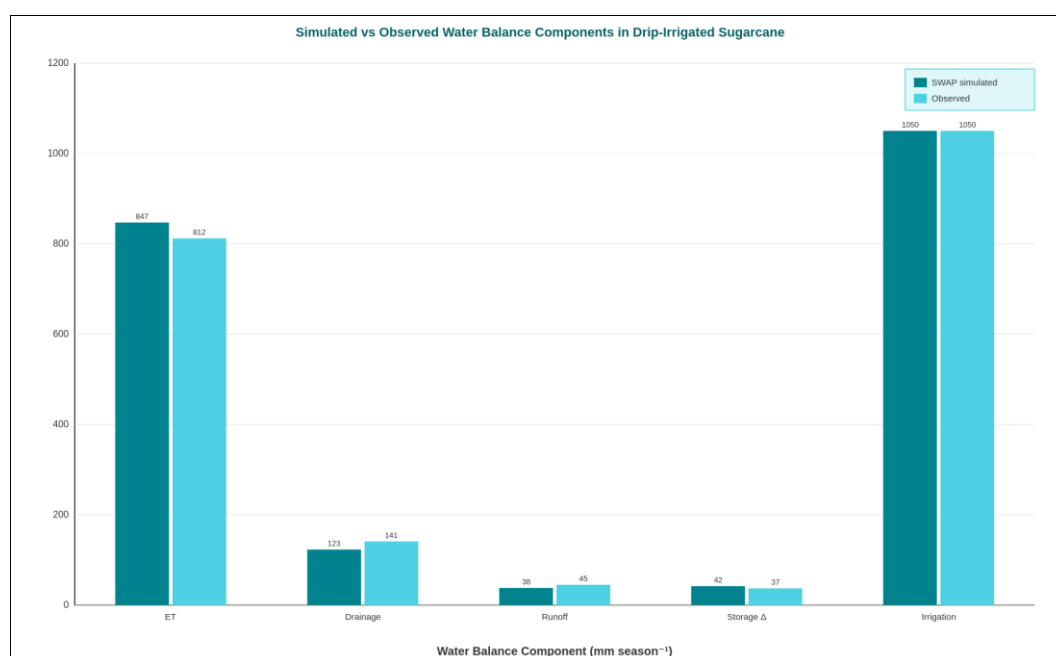


Fig 1: Simulated (dark) vs observed (light) water balance components for drip-irrigated sugarcane

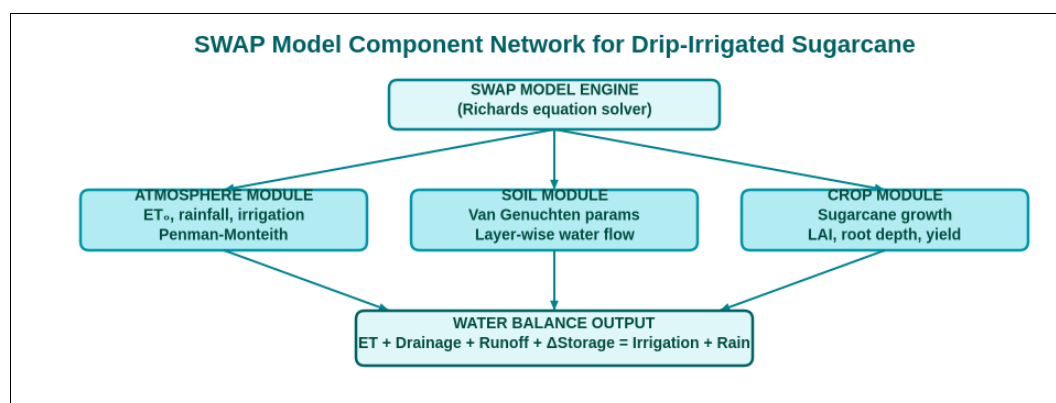


Fig 2: SWAP model component network showing atmosphere, soil, and crop modules linked to the water balance output.

Discussion

The 7.1% NRMSE for ET falls within the 5-10% accuracy range reported for SWAP in irrigated sugar crops in India and South Africa [2, 6]. Underestimation of drainage is a known SWAP limitation on cracking clays where bypass flow short-circuits matrix flow [7]. The simulated 23.4% water saving under drip vs. furrow supports the economic case for drip conversion, though capital costs remain a barrier for smallholders [3, 8].

Conclusion

SWAP reliably simulated the seasonal water balance of drip-irrigated sugarcane (ET NRMSE 7.1%). Drip irrigation directed a larger share of applied water to transpiration and reduced drainage losses, saving 23.4% compared with furrow. The calibrated model provides a planning tool for optimising irrigation scheduling in Bangladesh's sugarcane sector. Incorporating preferential-flow modules would improve drainage estimates on cracking soils.

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