Abstract

Morocco is entering an era of structural water scarcity, with repeated droughts, shrinking inflows, rising demand, and groundwater depletion. The drivers are both climatic and human: drier years reduce recharge, while rising demand, especially from irrigated agriculture, pushes withdrawals beyond sustainable limits. Agriculture, which consumes most freshwater, has been reshaped by modernization policies (*Plan Maroc Vert*, *Generation Green*) that subsidized a rapid shift from gravity to drip irrigation, often without matching training or basin-level regulation. In many regions, these efficiency gains coincided with crop intensification, area expansion, and increased pumping, deepening groundwater over-exploitation rather than reversing it. Within this context, the semi-arid Tensift basin poses a central question: how do contrasting irrigation practices affect soil-plant-atmosphere (SPAC) processes and reshape irrigation efficiency and aquifer recharge? Against recurrent droughts, this thesis first benchmarks methods used to estimate SPAC-level water balance, from empirical and lumped tools to process-based and distributed models, as well as in-situ observations and isotope-based inferences, clarifying what each method delivers (evapotranspiration, soil moisture, groundwater recharge) and their uncertainties.

A model-data approach was then implemented with the EcH_2O ecohydrological model over winter wheat plots under flood and drip irrigation. A multi-objective calibration using soil water content, eddy-covariance fluxes, and percolation below the root zone yielded consistent performance and daily estimates of ET, soil moisture, energy partitioning, and recharge. Exploring calibration scenarios showed that energy balance simulations were comparatively insensitive to calibration choices, whereas realistic percolation required including percolation data. Results confirm that flood-irrigated wheat exhibits larger and more variable deep percolation than drip. However, irrigation efficiency rankings depend on the system boundary: including deep percolation as a return flow favors flood irrigation, whereas excluding it favors drip, challenging the common claim that “drip saves water.”

A second study, a year-long monitoring in paired olive orchards (surface and subsurface drip), provided a comprehensive dataset of stable isotope signatures ($\delta^{18}O$, $\delta^{2}H$) in precipitation, irrigation water, groundwater, soil, and xylem. A joint analysis of isotopic dynamics and a Bayesian mixing framework inferred seasonal and plant water uptake depths. Subsurface drip buffered root-zone dynamics compared to surface drip: isotopic ranges below ~30 cm and in xylem and leaf water remained narrow, indicating reduced evaporative exposure, while surface drip showed pronounced summer enrichment. Xylem signatures were similar in both orchards, implying olive roots mainly draw from the upper 50 cm, with shallower uptake under surface drip in dry seasons.

Taken together, these results meet the thesis objectives by (i) positioning methods and uncertainties to motivate combined observation-model workflows, (ii) delivering a calibrated modeling baseline to quantify irrigation impacts, and (iii) demonstrating that isotope monitoring provides diagnostics for water mixing and partitioning in the SPAC.

Although conducted on different crops, the practical message is twofold: subsurface drip (in olives) enhances drought resilience and water-use performance, while model-based evaluations of irrigation efficiency must clarify whether deep percolation is valued as recharge or considered a loss. Looking forward, integrating isotopic constraints into tracer-enabled modelling at sites combining isotopic, hydrometric, and energy monitoring would tighten recharge and partitioning estimates, and extending analyses from plot to landscape scales would reveal how soils, layouts, and groundwater connectivity modulate trade-offs across the basin.