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Development of a Meteorology-Based Irrigation Decision-Support Application for Maize in Timișoara, Romania

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ABSTRACT

This study develops a meteorology-based decision-support workflow for maize in the Timișoara area by connecting historical weather inputs, FAO-56 reference evapotranspiration (ET_0), stage-dependent crop coefficients and a root-zone water balance. Random Forest regression is designed to estimate ET_0 from a reduced set of meteorological predictors and will be evaluated using chronological training, validation and test periods. The application translates estimated crop demand and soil-water depletion into potential irrigation dates, net/gross application depths and system runtime.

2005–2025
Historical analysis window

FAO-56 ET_0
Reference water demand

Random Forest
Reduced-input modelling

3 outputs
Timing • depth • duration

INTRODUCTION

- Maize is sensitive to water deficits, particularly around flowering and grain filling.
- Rainfall alone does not show how much water remains available in the root zone.
- Scheduling should combine atmospheric demand, effective rainfall, crop stage, soil storage and system performance.
- Data-driven estimates need an agronomic reference and independent evaluation.

AIM Build a reproducible application that estimates potential irrigation timing, depth and duration by linking meteorology, crop development, soil-water accounting and system parameters.

MATERIALS AND METHODS

STUDY AREA & METEOROLOGICAL INPUTS

Timișoara reference point: 45.75° N, 21.21° E
Analysis window: 2005–2025
Daily inputs: temperature, precipitation, relative humidity, dew point, solar radiation, wind and cloud cover.
Quality checks precede ET_0, ETc and soil-water calculations.


sensor setup

DECISION-SUPPORT WORKFLOW

1. ERA5 DATA — Daily weather quality checks

2. ET_0 / ETc — FAO-56 reference; $ETc = Kc \times ET_0$

3. WATER BALANCE — Effective rain + root-zone storage

4. IRRIGATION — Date, net/gross depth and duration

KEY CALCULATIONS

Crop evapotranspiration: $ETc = Kc \times ET_0$
Total available root-zone water: $TAW = 1000(\theta FC - \theta WP) \times Zr$
Daily depletion: previous depletion + ETc − effective rainfall − net irrigation (limited by TAW)
Gross depth: $dg = dn / \eta$ | Irrigation duration: $t = dg / r$

CROP, SOIL & IRRIGATION PARAMETERS

- Maize phenology is represented through BBCH milestones; development dates are estimated from planting date and the selected schedule.
- Kc changes with growth phase: 0.5, 0.8–1.0, 1.2, then 1.0–0.8.
- Soil scenarios: sandy loam, loam and clay loam; site-specific soil properties require field testing.
- Drip-system application rate and efficiency are configurable inputs.

RANDOM FOREST DESIGN

TRAIN	VALIDATE	TEST
2005–2018	2019–2021	2022–2025

Target: FAO-56 reference ET_0; predictors: reduced daily weather features (temperature, humidity, dew point, cloud cover, sunshine and day-of-year). Training: 2005–2018; validation: 2019–2021; independent test: 2022–2025. Performance will be assessed with MAE, RMSE and R^2 and compared with Hargreaves–Samani.

IRRIGATION DECISION RULES

1 Calculate crop demand: $ETc = Kc \times ET_0$.
2 Update root-zone depletion from ETc, effective rainfall and net irrigation.
3 Trigger an irrigation alert when depletion reaches $RAW = p \times TAW$.
4 Calculate gross depth from net depth and efficiency; calculate runtime from gross depth and application rate.
5 Update the schedule when forecast rain, crop stage, soil scenario or system settings change.

ETc — Crop demand $ETc = Kc \times ET_0$

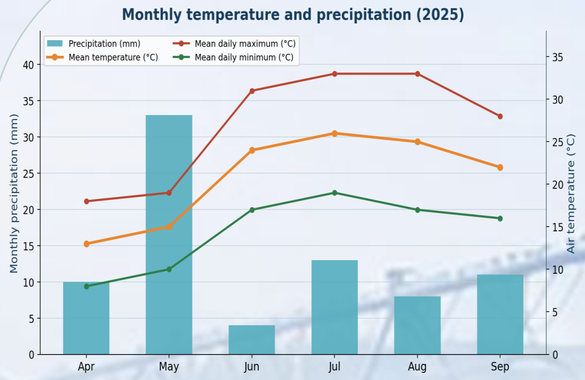
ROOT-ZONE — Water depletion ETc − effective rain

TRIGGER — Irrigate at selected RAW threshold

DURATION — Gross depth ÷ application rate

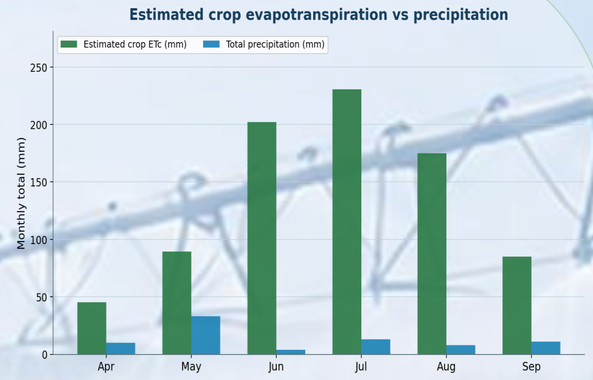
RESULTS AND DISCUSSION

Monthly temperature and precipitation (2025)



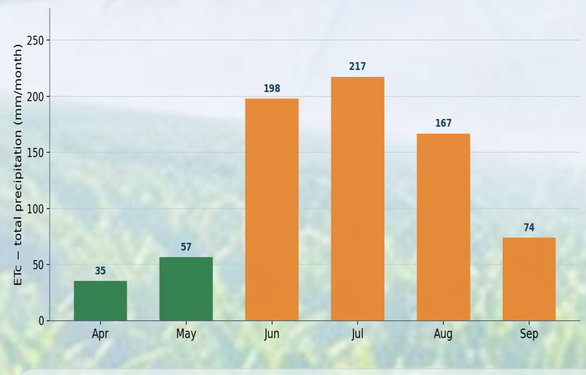
Temperature and precipitation • April–September 2025

Estimated crop evapotranspiration vs precipitation



Screening estimate: crop ETc versus rainfall

Monthly crop water-balance indicator



ILLUSTRATIVE IRRIGATION SIZING

Scenario assumptions: application efficiency η = 85%; application rate r = 4 mm h^{-1}. Durations show system sizing, not dates to irrigate.

Net depth (mm)	Gross depth (mm)	Rate (mm h^{-1})	Duration (h)
10	11.8	4	2.9
15	17.6	4	4.4
20	23.5	4	5.9
25	29.4	4	7.4

Scenario settings: η = 85%; application rate r = 4 mm h^{-1}

SEASONAL WATER-DEMAND SIGNAL

June–August was the warmest part of the 2025 screening season (mean daily maxima 31–33 °C), while reported rainfall was 4–13 mm/month from June to September. Estimated ETc exceeded rainfall in each month; the largest arithmetic gap was July (219.1 mm). Effective rainfall and root-zone storage determine the actual irrigation need.

79 mm — Reported rainfall • Apr–Sep

831.8 mm — Estimated ETc • screening

219.1 mm — July ETc − rainfall

RANDOM FOREST MODEL EVALUATION

Weather inputs — Reduced daily meteo features

RF model — Approximate reference ET_0

Independent test — Holdout years 2022–2025

Report metrics — MAE · RMSE · R^2

Planned chronological split: training 2005–2018, validation 2019–2021 and independent testing 2022–2025. Report MAE, RMSE and R^2 against FAO-56 reference ET_0 after daily-data processing.

Hargreaves–Samani provides a temperature-based benchmark. Random Forest approximates reference ET_0 from reduced inputs; it is not yet an independently field-validated predictor of actual maize water demand.

APPLICATION OUTPUT ET_0 → ETc → root-zone depletion → potential irrigation alert. Outputs include a candidate date, net/gross depth and runtime, updated with planting date, crop stage, soil scenario, forecast rainfall and irrigation-system settings.

CONCLUSIONS

- The seasonal profile indicates greater potential irrigation pressure during the warm summer period.
- Estimated ETc exceeds monthly rainfall in several months, while effective rainfall and stored root-zone water determine the actual deficit.
- Combining meteorology, crop stage, soil properties and system settings supports more structured irrigation planning.
- Random Forest predictions must be evaluated on independent years against FAO-56.
- Field validation is the next step before operational irrigation recommendations.

MAIZE DEVELOPMENT STAGES (BBCH)



EMERGENCE BBCH 10 | **STEM ELONGATION** BBCH 30 | **TASSEL EMERGENCE** BBCH 50 | **FLOWERING** BBCH 65 | **MATURITY** BBCH 89

Kc sequence from the supplied agronomic guideline: 0.5 (V3–V6) → 0.8–1.0 (V6–V10) → 1.2 (V10–R3) → 1.0–0.8 (R3–R5). Crop coefficients are linked to growth phase, while BBCH milestones organize the estimated crop schedule.

APPLICATION OUTPUTS & ACKNOWLEDGEMENT

The application links estimated crop demand to an irrigation decision: potential date, net/gross depth and runtime.

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ET — ET_0 / ETc — Atmospheric and crop demand

H_2O — SOIL WATER — Root-zone deficit estimate

IRR — IRRIGATION — Date • depth • runtime