A Fuzzy Decision Support System to Optimize Irrigation Practices in Trentino Region

Romeo Silvestri, Massimo Vecchio, Fabio Antonelli
OpenIoT Research Unit of Fondazione Bruno Kessler (FBK) – Italy

Introduction

The Need for Smarter Irrigation

Figure: Overhead Sprinkler Irrigation of Vineyards in Trentino, Italy

- **Sustainable water use is essential** to address climate change, water scarcity, and rising productivity demands
- High value crops require **precise soil moisture control** to protect yield and quality
- **Traditional irrigation** methods are often **inefficient** and **non-adaptive** to real field conditions

Introduction
Solution & Research Objectives

*“ A **Decision Support System** (DSS) is a system that supports decision-making by transforming data and knowledge into clear, actionable recommendations ”*

Intelligent Decisions

Provide daily, interpretable irrigation recommendations, integrating multiple sources

Optimization

Calibrate the system based on expert feedbacks, improving decision quality

Validation

Evaluate the performance using a consistent methodology

Study Overview

Use Case: Rovere della Luna consortium

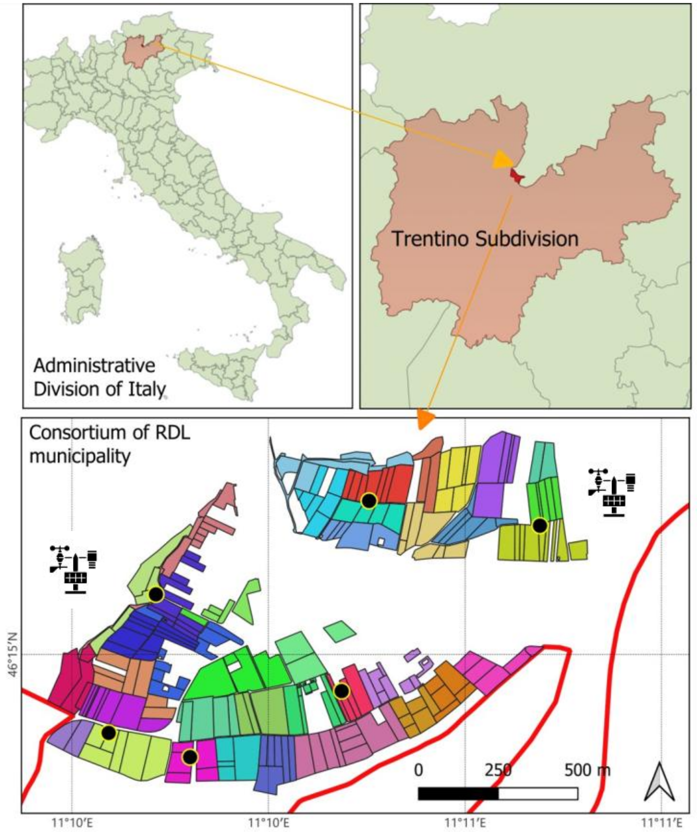
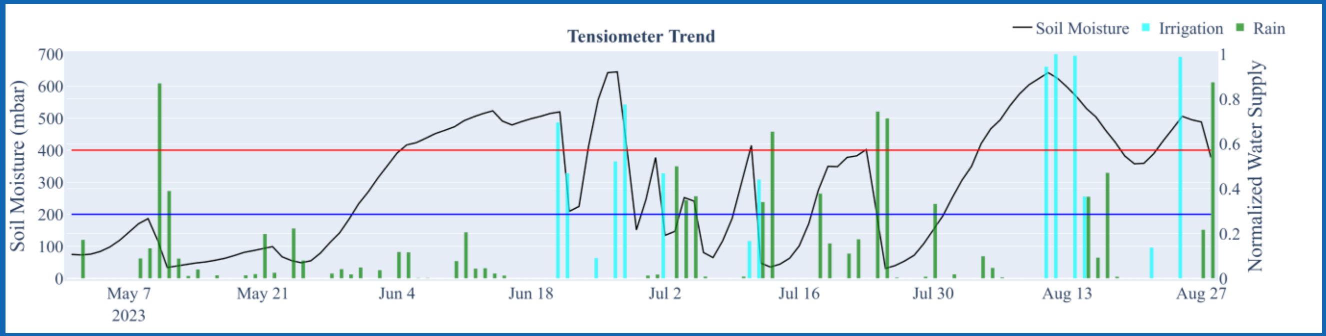


Figure: Map showing the geographical area of the Rovere della Luna consortium, with tensiometers and weather stations



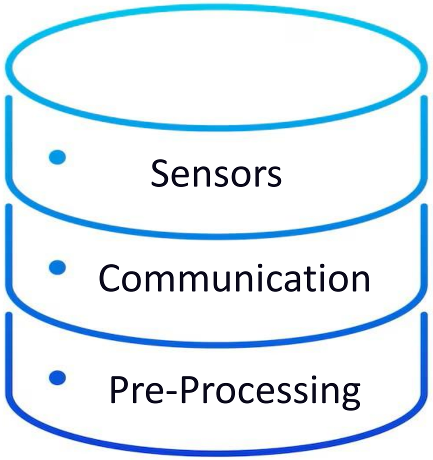
Consortium Characteristics:

- Location: Rovere della Luna consortium, Trentino, Italy
- Period: Summer 2023 (May – September)
- Crop Type: High-value vineyards
- Sensor Network:
  - 16 tensiometers placed at 30cm and 60cm depths
  - 2 weather stations (temperature, humidity, rainfall, radiation)

⇨ 5 sectors selected for the study

Study Overview
Decision Workflow

1-3



Edge & Data Ingestion

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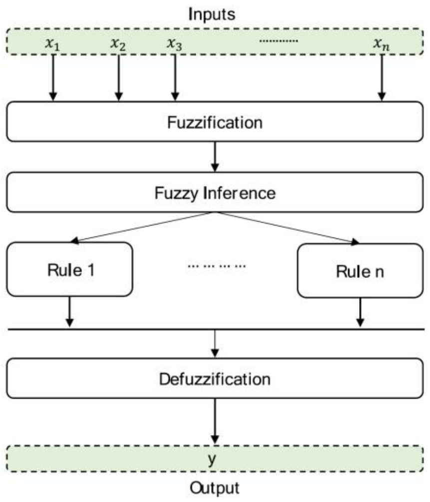

Decision Support System

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Irrigation Scheduling

DSS Architecture

Variables & Fuzzification

Input Variables:

- Last Average Tensiometer – previous day (mbar)
- Predicted Average Tensiometer – via LSTM (mbar)
- Predicted Rain Amount – 3 days (mm)
- Predicted Maximum Temperature – 3 days (°C)

3 linguistic terms (Low, Medium, High)

Output:

- Irrigation Recommendation – Decision

4 linguistic terms (Number of Irrigation Turns)

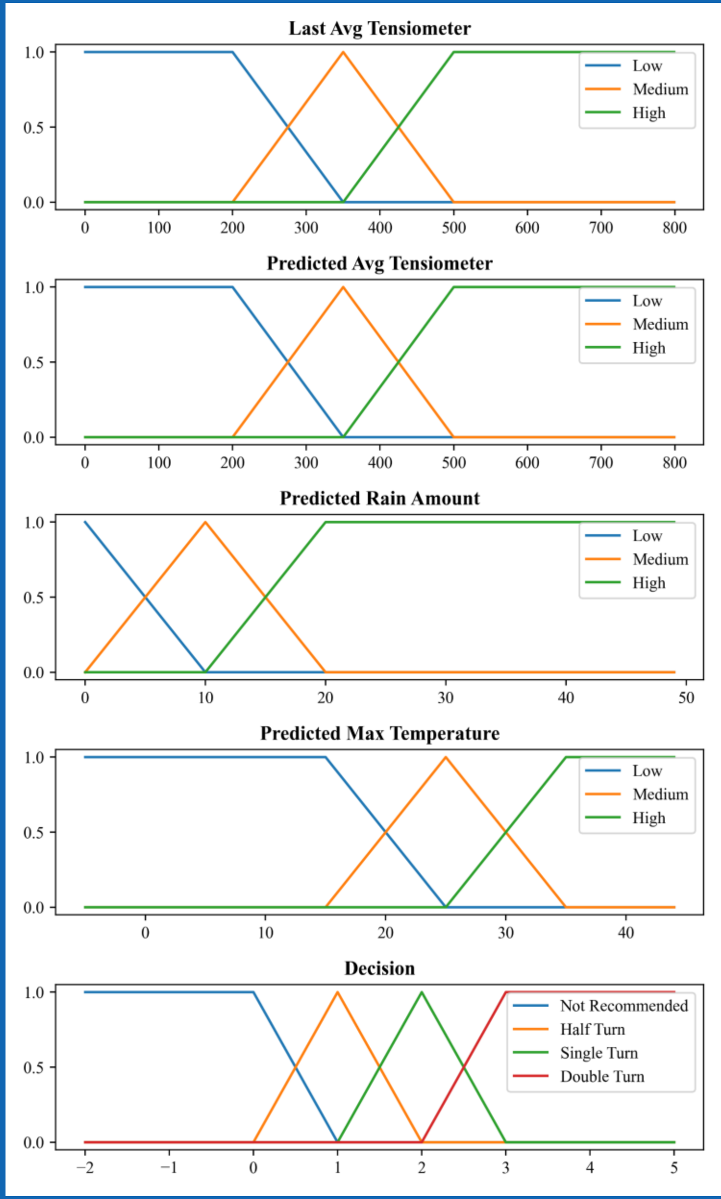


Figure: Fuzzy linguistic variables of the Fuzzy DSS

DSS Architecture

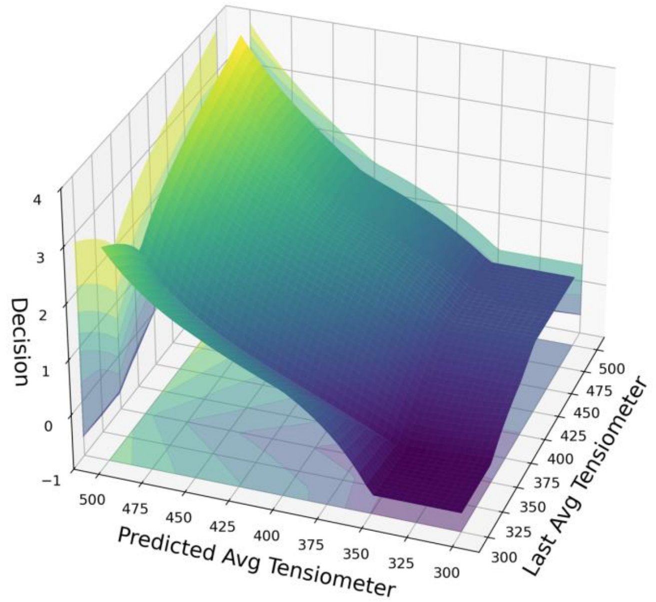
Expert Rules and Inference Logic

The Fuzzy DSS makes irrigation decisions using **21 "IF–THEN" rules** based on agronomic expertise
It uses a **Mamdani**-type inference approach with centroid defuzzification method

Example Rules:

IF Predicted Tensiometer IS High AND Predicted Rain IS Low → Double Turn

IF Predicted Tensiometer IS Low AND Max Temperature IS Low → No Irrigation



Inference Logic:

📥 Input (Fuzzified) → 🔀 Rules Evaluation → 🎯 Defuzzification

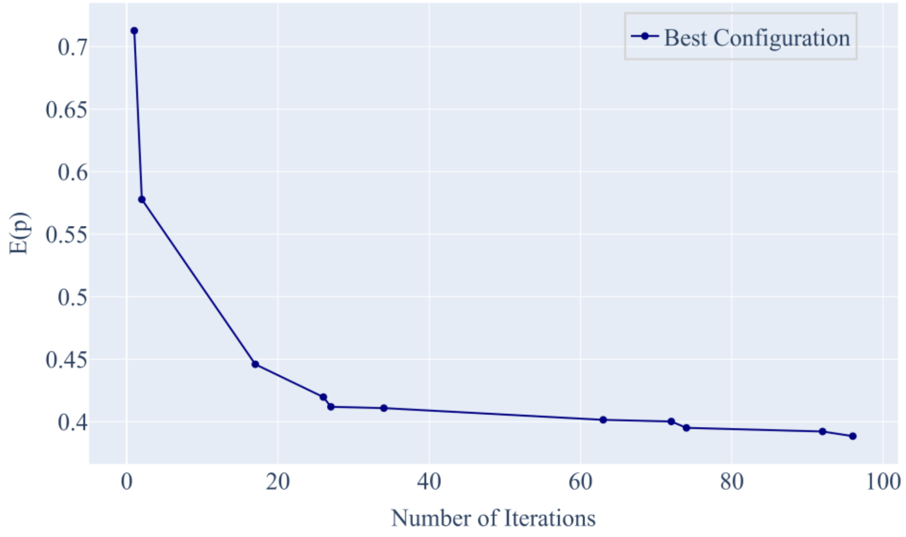
Bayesian Optimization with Feedback

The system was calibrated using expert feedback, collected via surveys, and **Bayesian optimization** to fine-tune fuzzy membership functions for improving alignment with human recommendations

Error Minimization Function (MSE)

$$E(p) = \frac{1}{N}\sum_{i=1}^{N}(y_i(p) - \hat{y}_i)^2$$

- $y_i(p)$: current DSS output for the *i*-th input
- $\hat{y}_i$: corresponding expert's recommendation
- p: fuzzy membership parameters
- N: number of evaluation scenarios



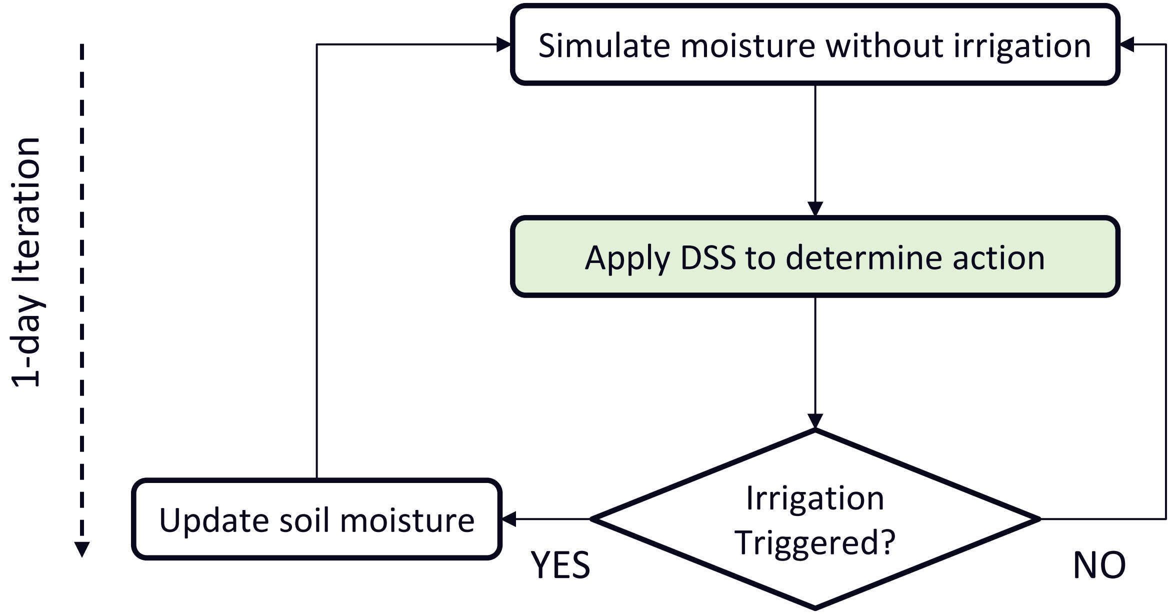
Error reduced by 45% after 100 iterations

Validation Framework

Evaluation Setup and Performance Metrics

The irrigation strategies were tested through **day by day simulation** of soil moisture over the 2023 season across 5 vineyard sectors, using **30 cm tensiometer** data as reference

Step-by-step Simulation



Evaluation Metrics

- 💧 Total water used (liters per row)
- 🔴 Critical dry days – soil above threshold (400 mBar)
- 📉 Average soil moisture value (mBar)

Results

Sector-Level Simulation: Observed vs Recommended

Figure: Comparison of actual and DSS-simulated irrigation schedules for a specific water sector in RDL during 2023

Results

Overall Impact on Water Use and Soil Moisture

Sector	Water Volume per Row (L)			Critical Days			Avg Tensiometer (mBars)		
	Real	DSS	DSS_{opt}	Real	DSS	DSS_{opt}	Real	DSS	DSS_{opt}
1	1'828	325	325	3	1	1	110	196	196
2	4'479	4'550	1'300	9	5	3	174	184	184
3	11'486	5'200	5'200	29	10	9	245	254	253
4	10'931	10'075	9'750	44	24	33	291	266	270
5	23'757	7'800	8'450	29	20	15	239	272	269
Total	52'501	27'950	25'025	114	60	61	1'059	1'172	1'172

Table: Comparison of irrigation sector performances for RDL during 2023

Conclusion

Key Takeaways & Future Directions

Water Savings

Methods

Interpretability

Scalability

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FUTURE BUILT ON KNOWLEDGE

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thank you