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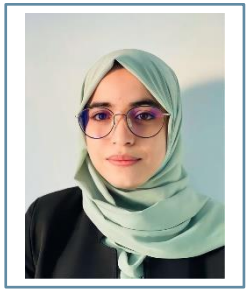
Early Multi-Year Cereal Yield Prediction Using Machine Learning Based on Satellite Drought Indices in Semi-Arid Regions



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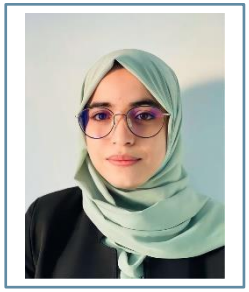

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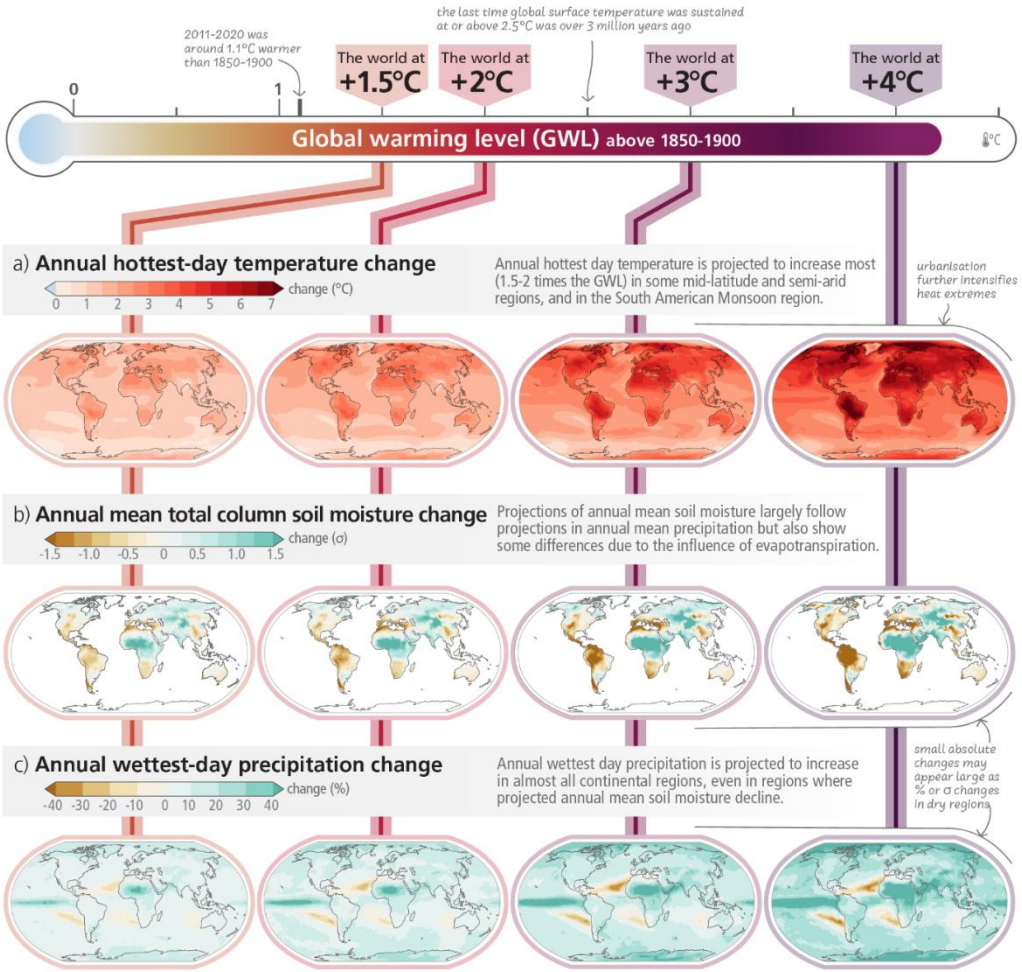
Plan

1. Introduction
2. Study area
3. Methodology
4. Results
5. Conclusions

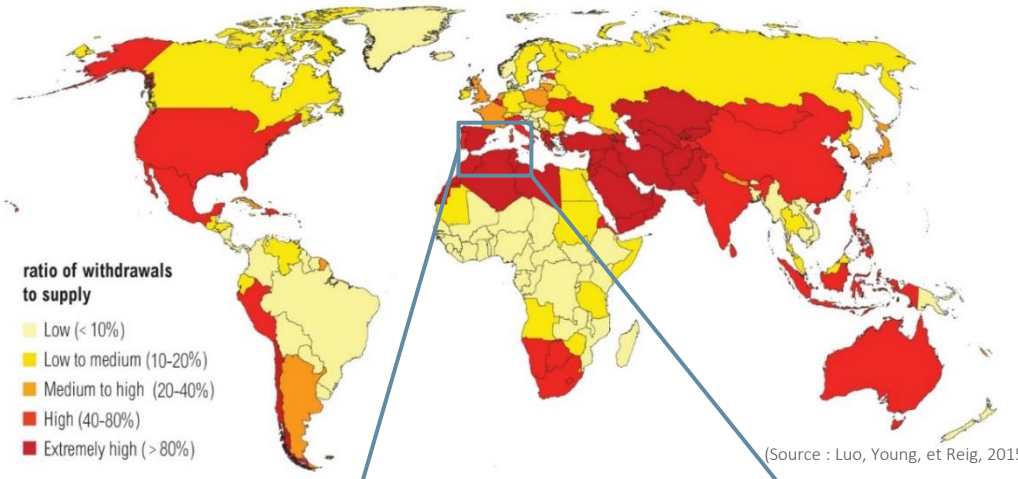
1. Introduction

With every increment of global warming, regional changes in mean climate and extremes become more widespread and pronounced



(Source : Calvin et al., 2023)

Water Stress by Country: 2040



(Source : Luo, Young, et Reig, 2015)

Ebre dam, Spain, 2017

El Houareb dam, Tunisia, 2017

In light of increasing water stress and successive droughts, a critical question arises:

How can we ensure **food security** under these challenging conditions?

Objective

- **Early** estimation of cereal yields (wheat and barley) in semi-arid regions at regional and plot levels.

Several approaches and models

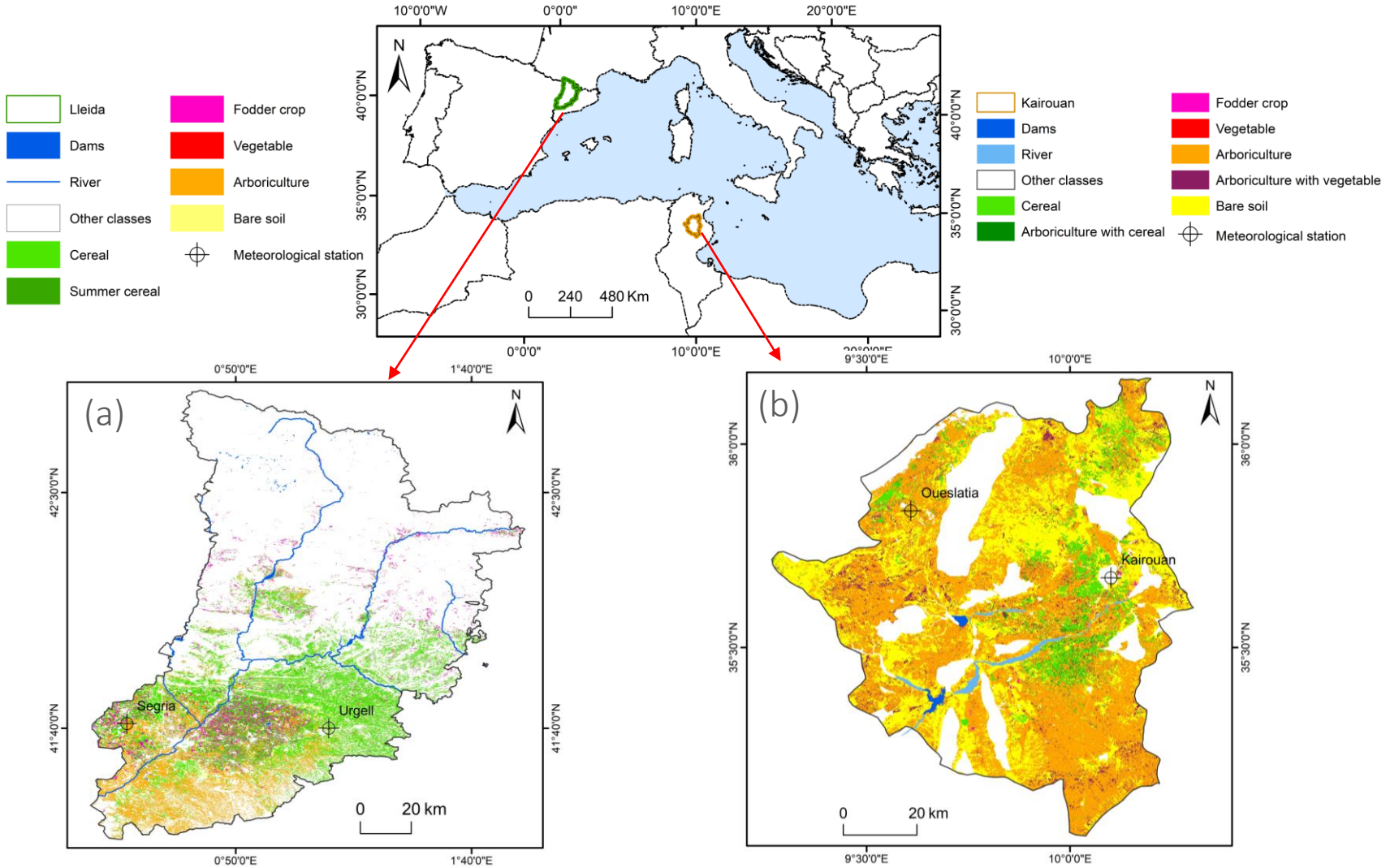
Machine Learning is a robust method that enables models to analyze complex data patterns and make accurate predictions.

Model? Data? Prediction time?

1- Which **Machine Learning model** performs best for **early** estimation of cereal yields, and from which period?

2- Which **drought index** is best for **early** estimation of cereal yields, and from which period?

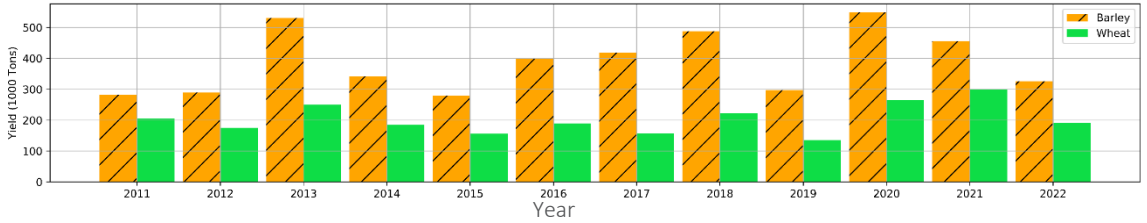
2. Study area



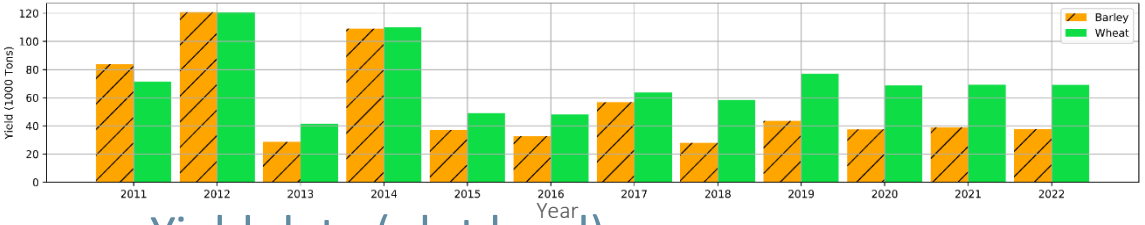
Land cover maps for the 2021/2022 agricultural year for (a) **Lleida in Catalonia** and (b) **Kairouan in Tunisia**

3. Methodology

- Yield data (Regional level)

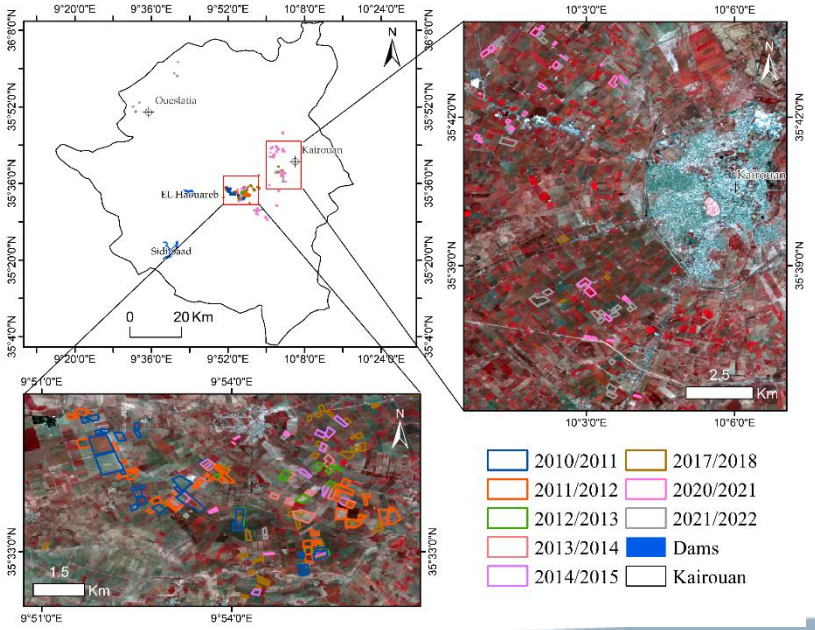


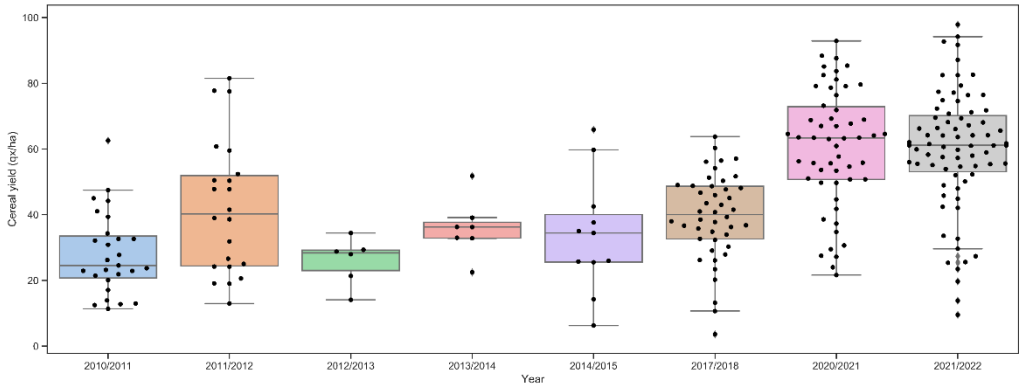
Wheat and barley regional yield data in mille Tons (1000 Tons) from 2010/2011 to 2021/2022 in **Lleida**



Wheat and barley regional yield data in mille Tons (1000 Tons) from 2010/2011 to 2021/2022 in **Kairouan**

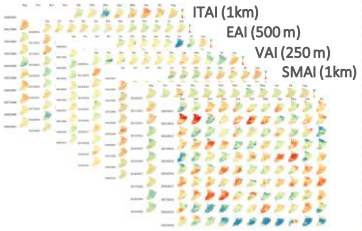
- Yield data (plot level)

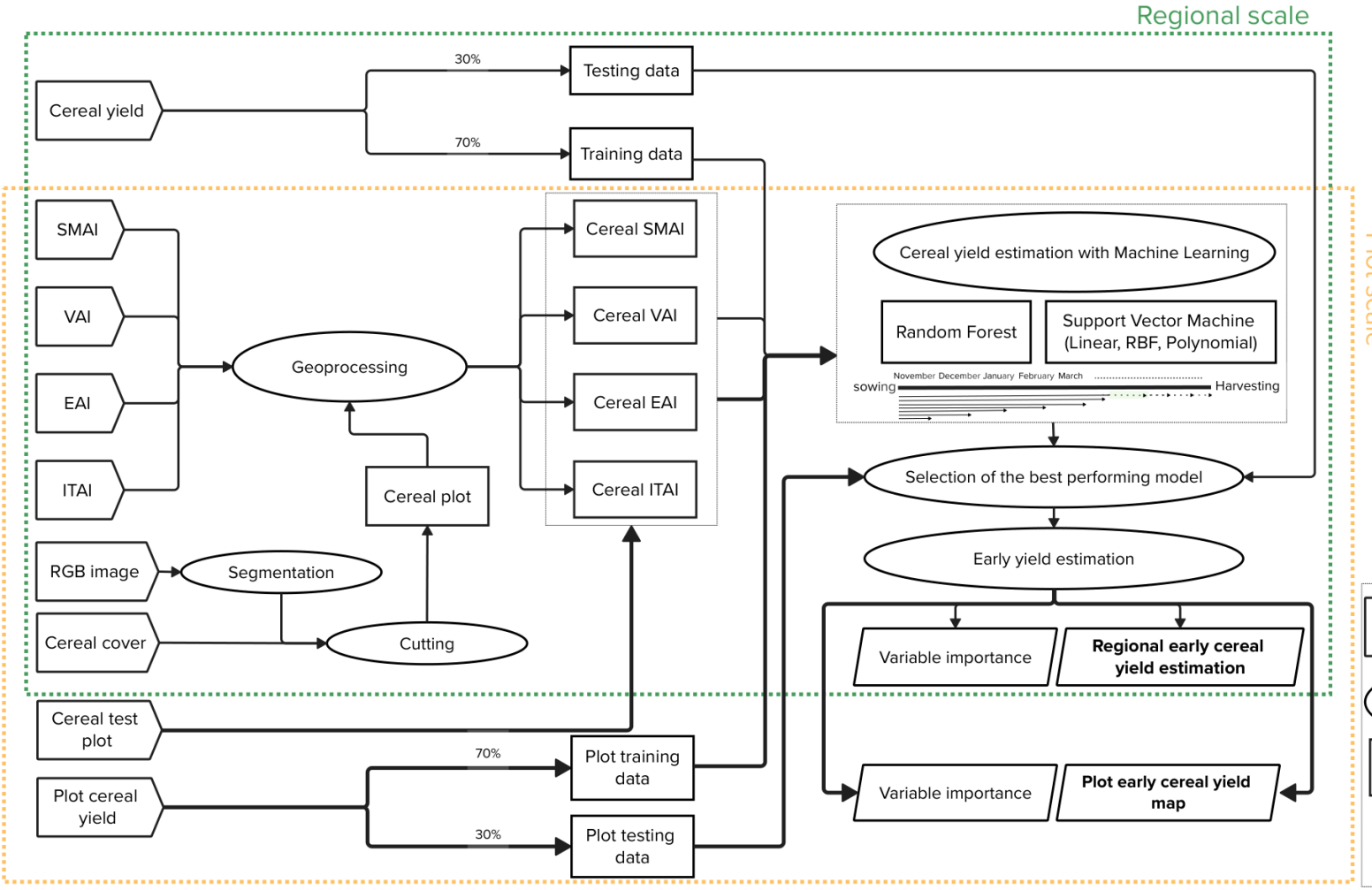




Cereal plot yield statistical data in quintals per hectare (qx/ha) in **Kairouan** from 2010/2011 to 2021/2022

3. Methodology



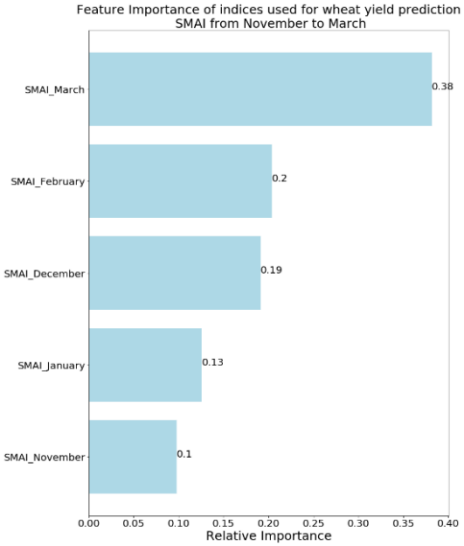


Flow chart of methodological framework steps for regional and plot cereal yield prediction.

4. Results at regional scale

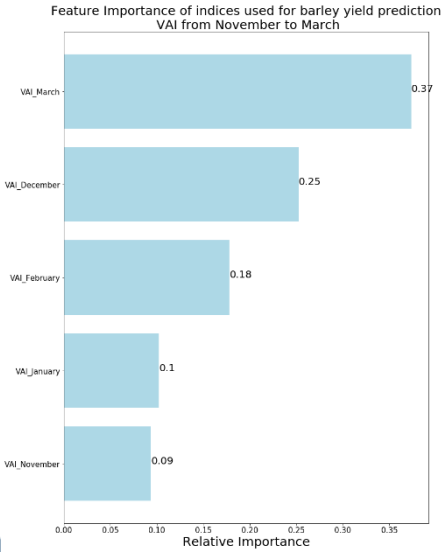
Selection of the best results for **wheat yield prediction for Lleida** using Machine Learning models with drought indices.

	From November to March	From November to May	From November to June	From November to August
Indices	SMAI	SMAI	SMAI	SMAI, VAI, EAI and ITAI
Model	RF	RF	RF	RF
R^2	0.71	0.67	0.76	0.91
RMSE (Milles Tones)	22.68	24.48	20.72	12.96
nRMSE (%)	11.19	12.08	10.23	6.40
Bias (Milles Tones)	-3.95	-2.66	-2.57	1.73

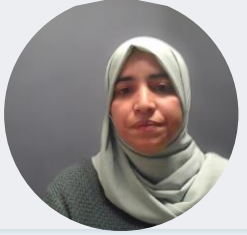


Selection of the best results for **barley yield prediction for Lleida** using Machine Learning models with drought indices.

	From November to March	From November to May	From November to June	From November to June	From November to July
Indices	VAI	VAI	VAI	SMAI, VAI, EAI and ITAI	VAI
Model	RF	SVM, Linear	SVM, Linear	RF	SVM, Linear
R^2	0.76	0.81	0.83	0.81	0.87
RMSE (Milles Tones)	30.62	26.95	25.58	27.26	22.25
nRMSE (%)	7.89	6.94	6.59	7.02	5.73
Bias (Milles Tones)	16.50	-17.60	-18.90	-7.10	-13.31



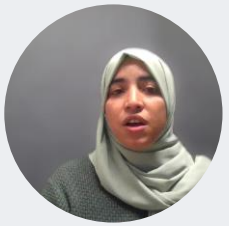
4. Results at plot scale

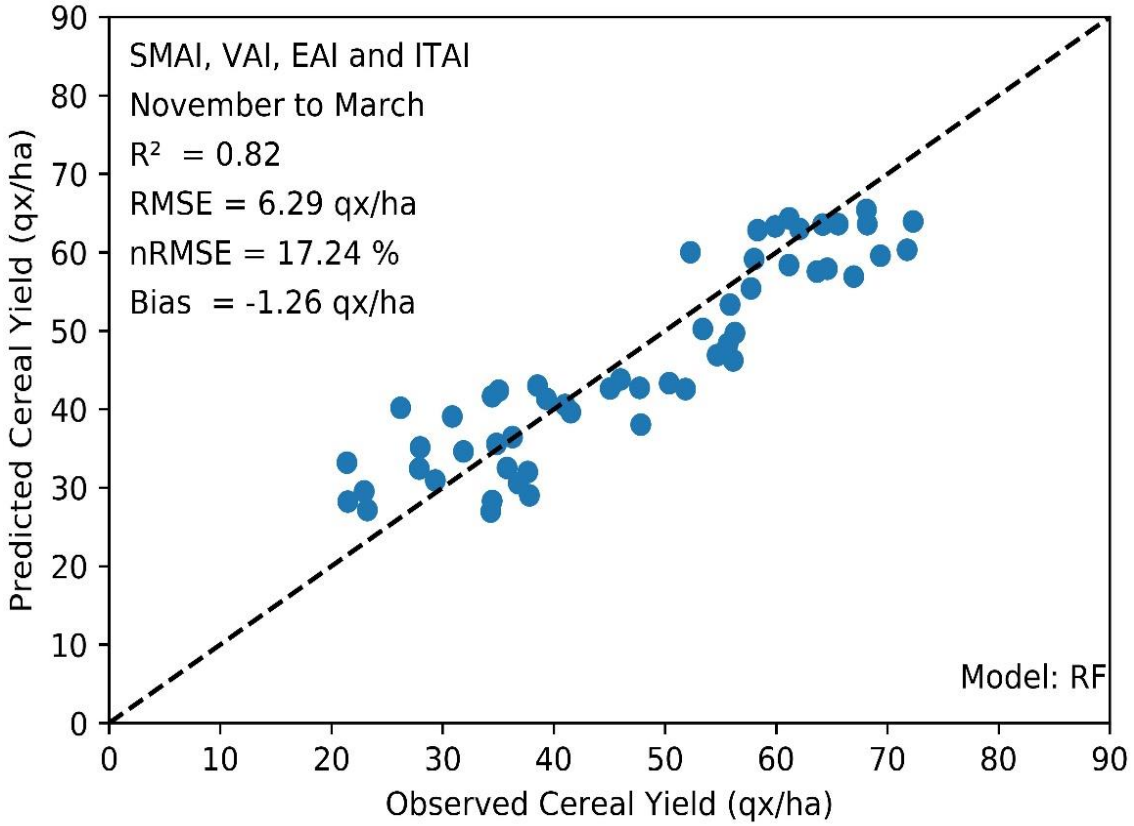


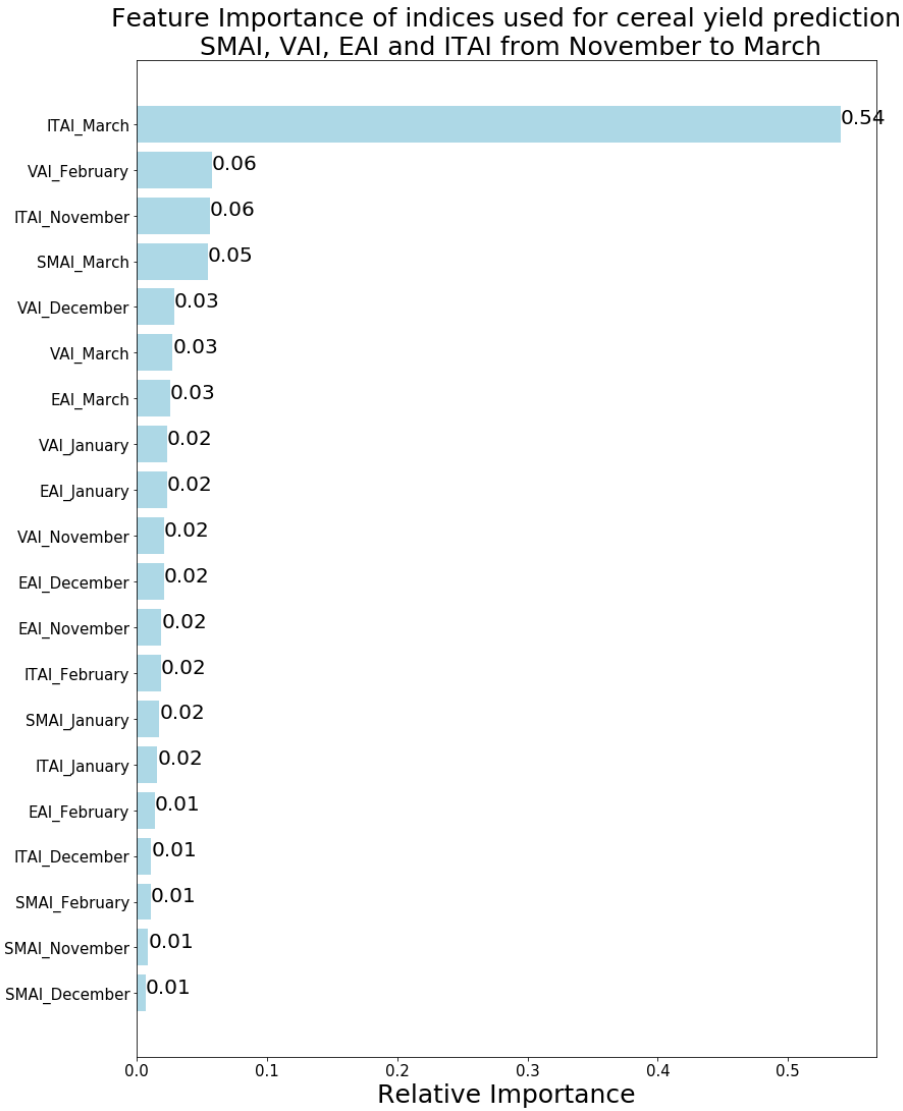
Selection of the best results for **cereal yield prediction for Kairouan** using ML models with drought indices.

	November	From November to December	From November to January	From November to February	From November to March	From November to April	From November to May	From November to June
Indices				SMAI, VAI, EAI and ITAI				ITAI
Model	RF	RF	RF	RF	RF	RF	RF	RF
R^2	0.63	0.74	0.70	0.62	0.82	0.83	0.80	0.79
RMSE (qx/ha)	8.99	7.54	8.09	9.14	6.29	6.17	6.58	6.80
nRMSE(%)	22.79	19.11	20.51	23.17	15.94	15.64	16.68	17.24
Bias (qx/ha)	0.37	0.26	0.43	1.03	-1.26	-1.58	-1.21	0.10

4. Results at plot scale



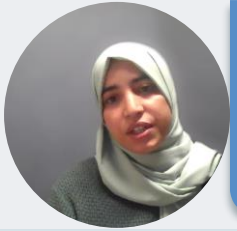


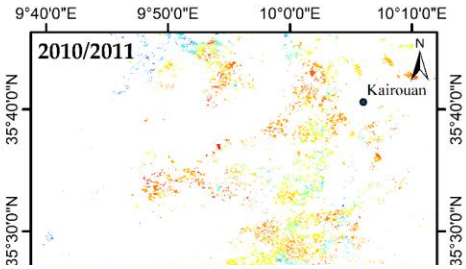


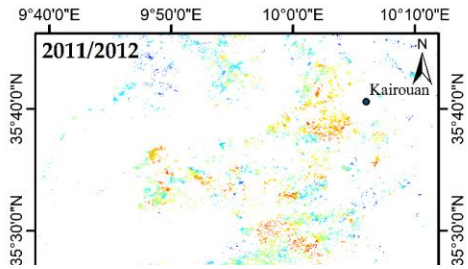
The best result in **early predicting** cereal yields for Kairouan

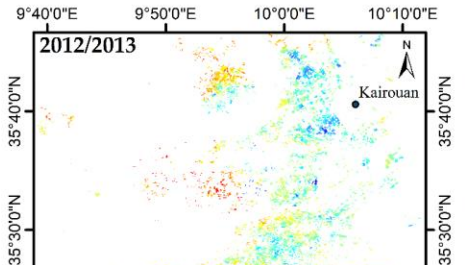
4. Results

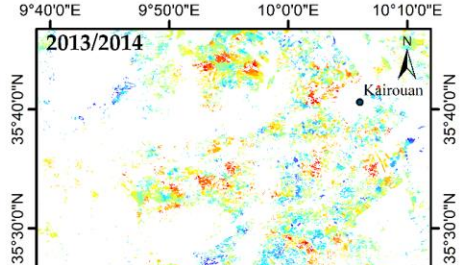
Spatialization of cereal yields in Kairouan from 2010/2011 to 2021/2022

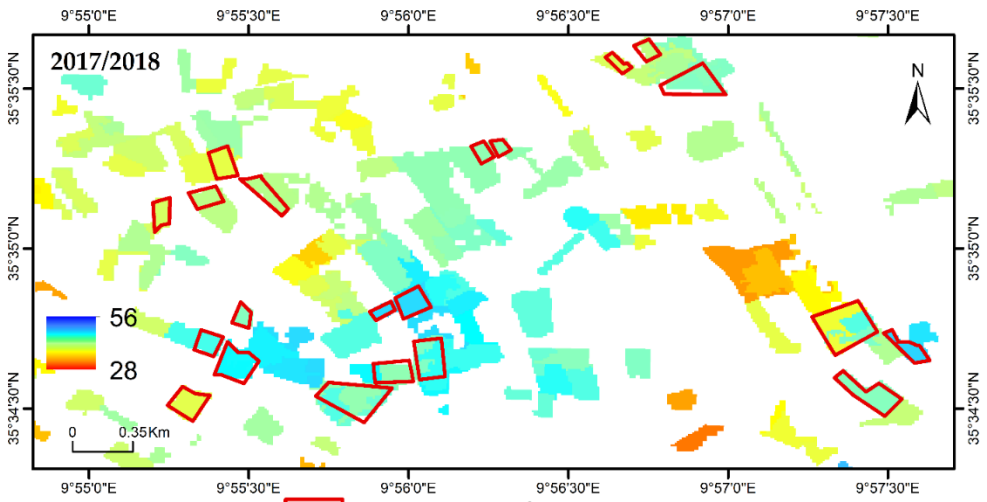


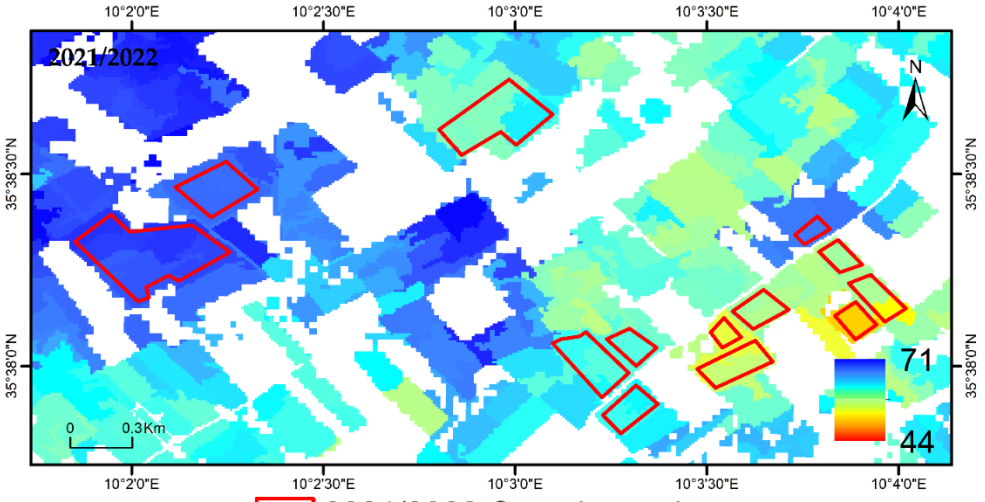






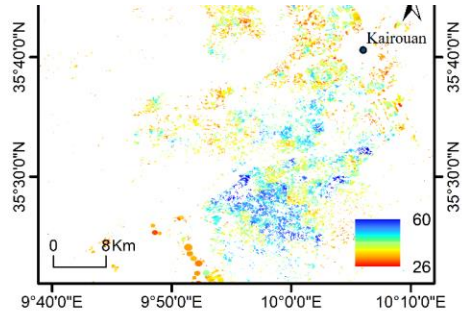


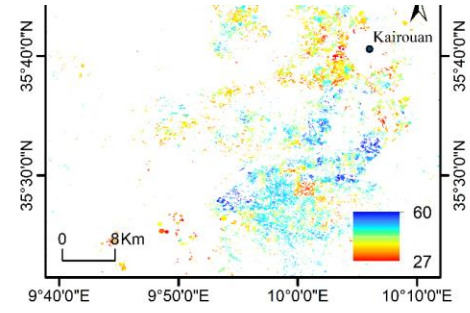


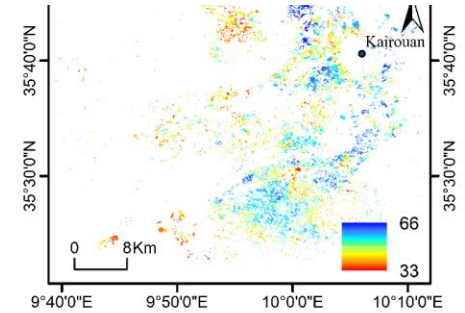


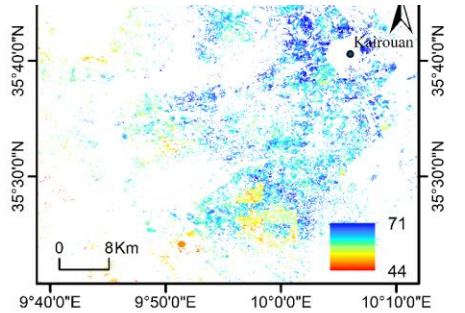
2017/2018 Cereal test plots

2021/2022 Cereal test plots









5. Conclusions

- The aim of this study was to develop an advanced model to **predict winter cereal yields** (wheat and barley) in semi-arid regions (Kairouan in Tunisia and Lleida in Catalonia) using machine learning models and **drought** indices.
- The results show that the **RF** model outperforms the **SVM** model in predicting early cereal yields.
- At the regional level, **SMAI** and **VAI** are significant predictors in **March** and **February** for Lleida and Kairouan, respectively, **four months before harvest**.
- At the plot level in Kairouan, the RF model was found to provide the best early results for the **spatial distribution** of cereal yields in **March**.
- Importantly, SMAI and VAI emerged as key factors for yield prediction at critical growth stages, emphasizing the importance of water availability during germination and tillering.
- Our study provides valuable insights for **yield prediction** and decision making in **crop management** (**food security**).

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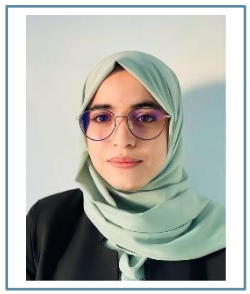

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