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Characterization of cereals yields using different models based on remote sensing indicators from the Sentinel-1 and Sentinel-2 images in a semi-arid region

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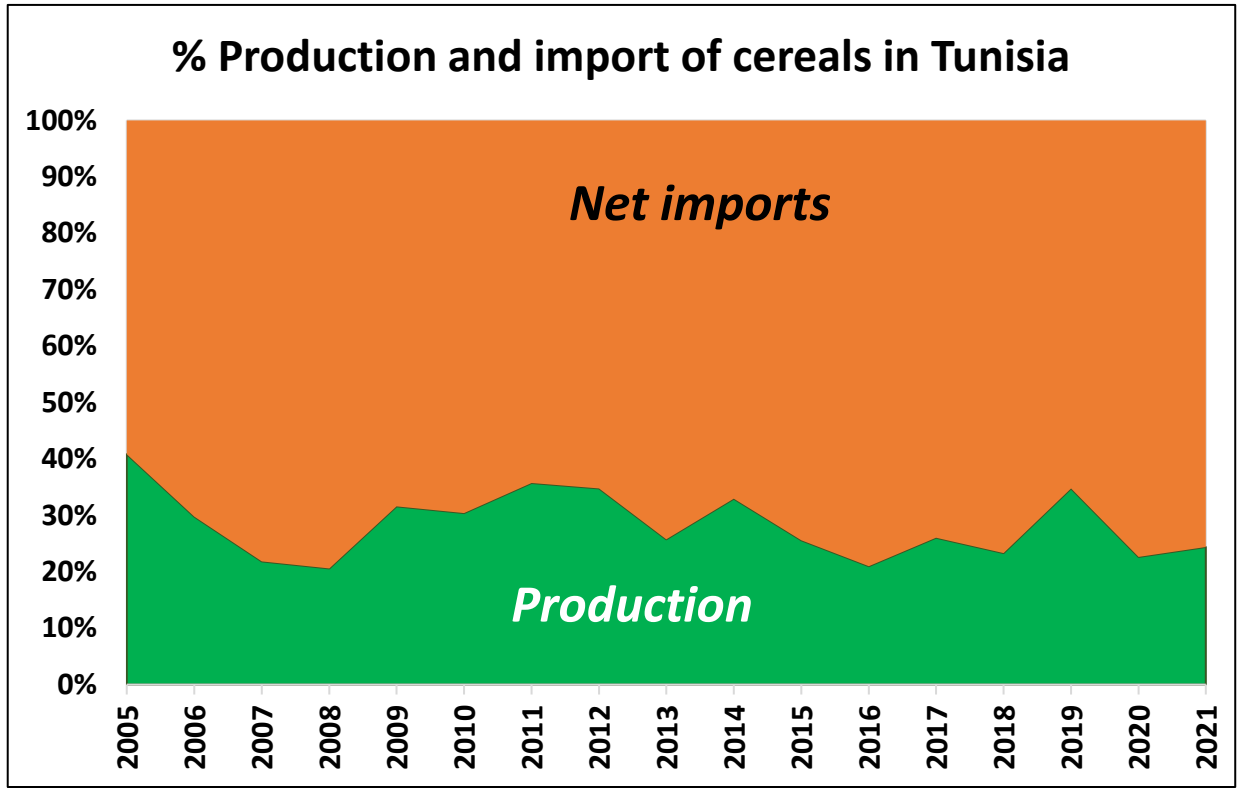
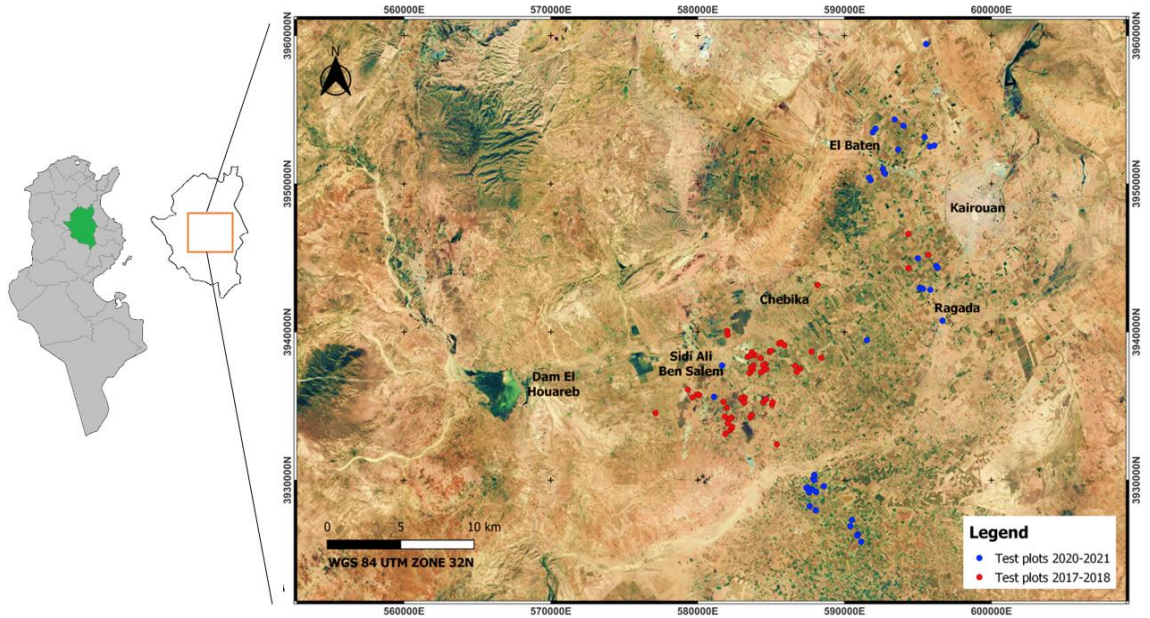
Problematic and context



Source: Office des Céréales https://www.oc.com.tn/

- For Tunisia, net cereal imports between 2005 - 2021 amounted on average to 72% of annual consumption.
- An operational early grain yield prediction system has been needed to assist policy makers in making initial assessments and planning for annual grain imports.



Objectives

Different methodologies have been proposed over the last decades, for the early grain yield prediction using specific multi- and hyper-spectral sensors.

The main objective of this study is to develop empirical models for early prediction of cereal yields at a provincial scale :

- Evaluating the performance of combining several vegetation indices to improve yield prediction results.

- Developing early forecasting models using multisource data as predictors (Sentinel-2 and Sentinel-1 images), and experimental measurements made on cereal test plots over two agriculture years (2017-2018 and 2020-2021) : → Regression model

  → Machine learning algorithms

Data base

Sentinel 2

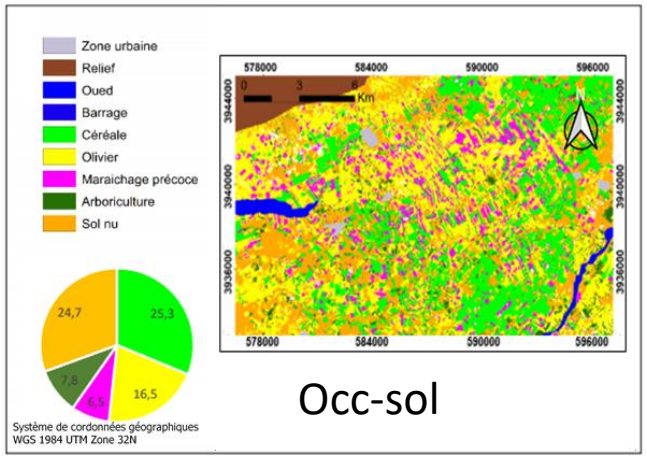
217-2018 : 28 images
2020-2021 : 38 images

Sentinel 1

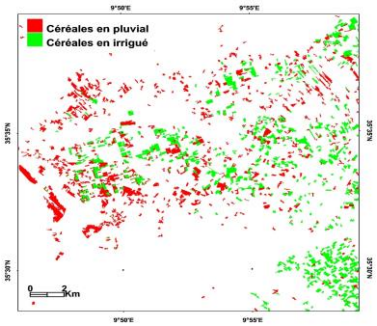
217-2018 : 27 images
2020-2021 : 32 images

Number and type of test plots for the three agricultural years.

Agriculture year	species	irrigated	rainfed	Average yield (qx/ha)	
				Grains	Straw
2017-2018	Wheat	32	2	41.93	43.99
	Barley	10	3	32.24	34.41
2020-2021	Wheat	34	1	63.71	70.46

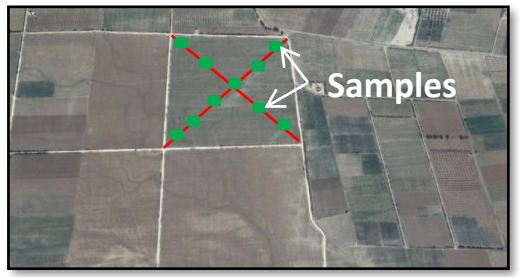


Occ-sol



Cereals mask

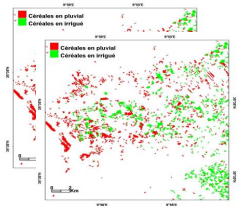
(Khlif et al, 2023)*



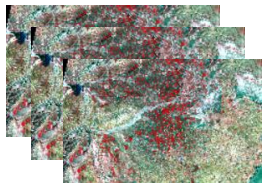
A total of **82 farms** were sampled, which covered nearly **280 ha**.

* Khlif, M.; Escorihuela, M.J.; Chahbi Bellakanji, A.; Paolini, G.; Kassouk, Z.; Lili Chabaane, Z. Multi-Year Cereal Crop Classification Model in a Semi-Arid Region Using Sentinel-2 and Landsat 7–8 Data. Agriculture 2023, 13, 1633. https://doi.org/10.3390/agriculture13081633

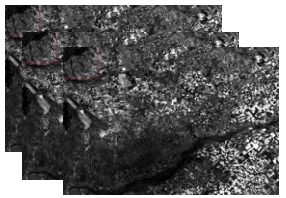
Methods

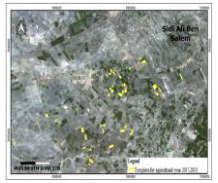


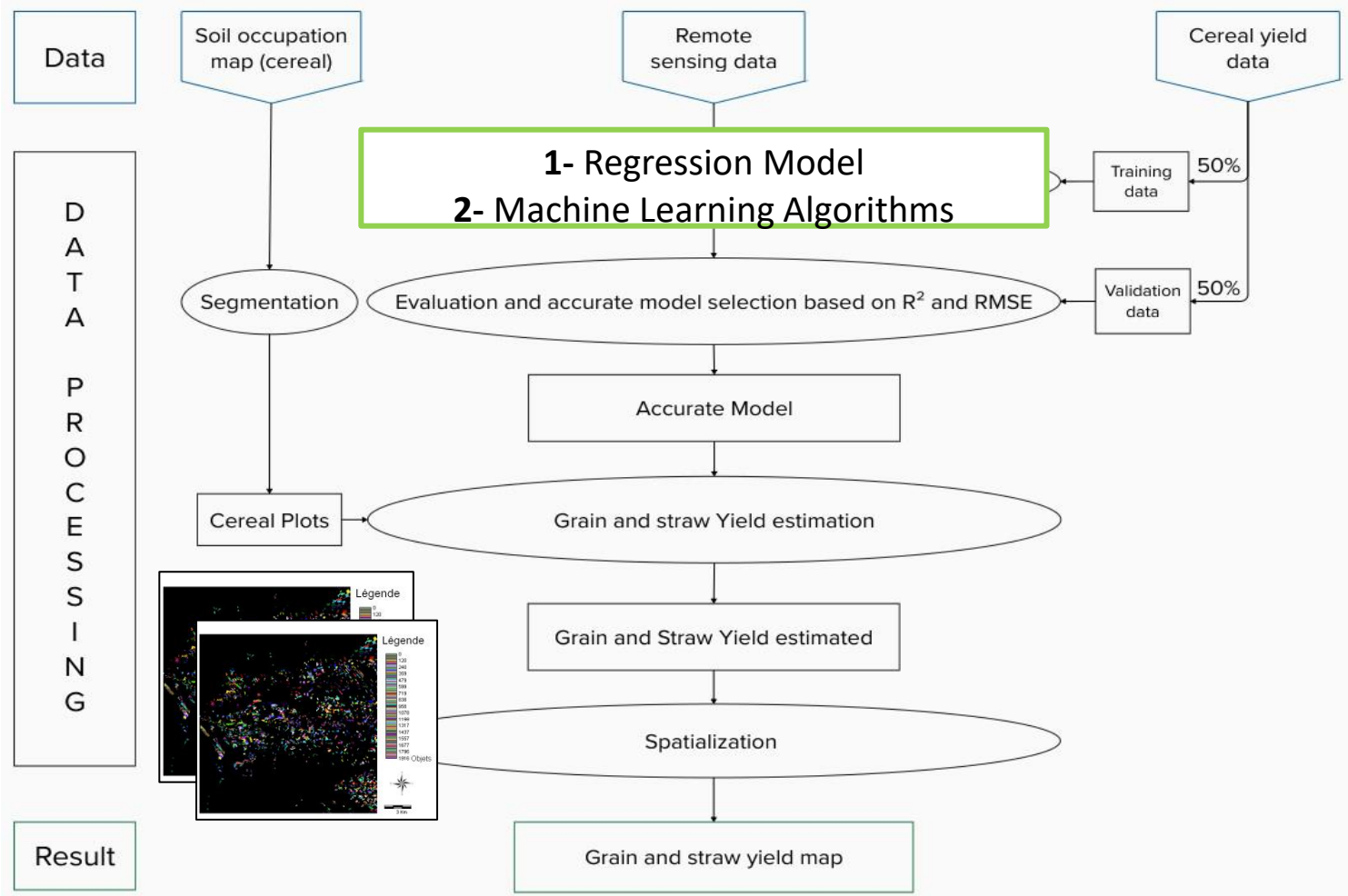
Sentinel 2



Sentinel 1



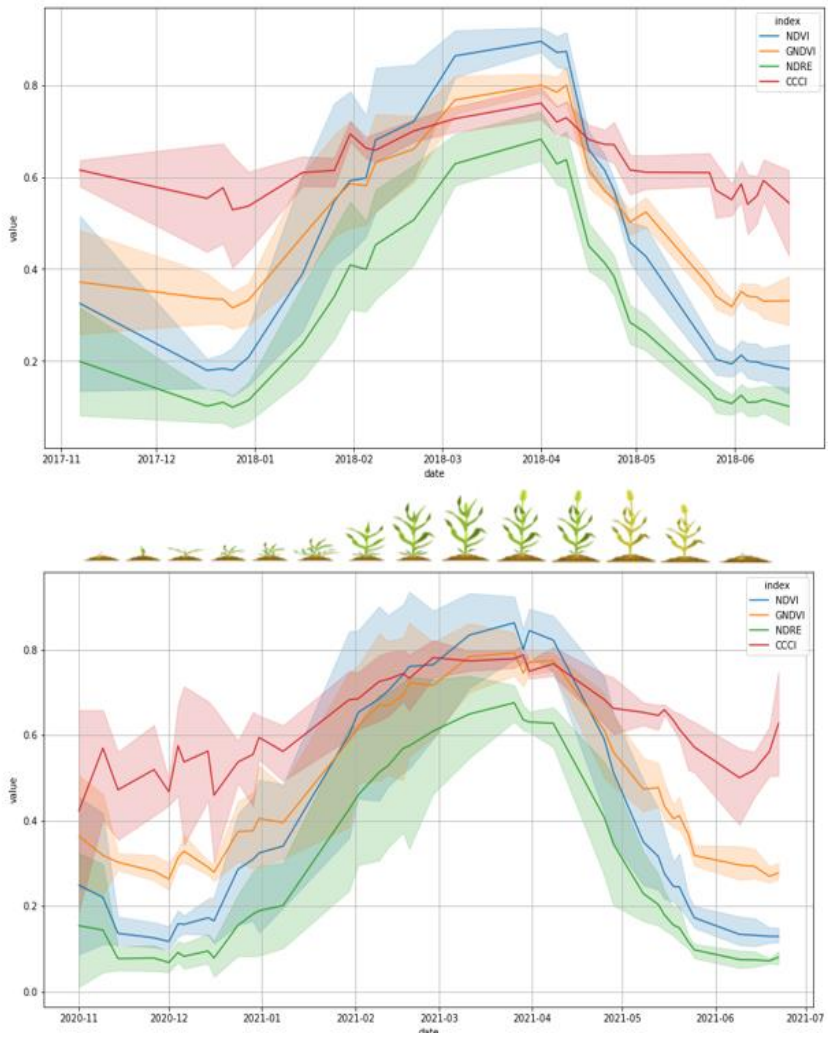




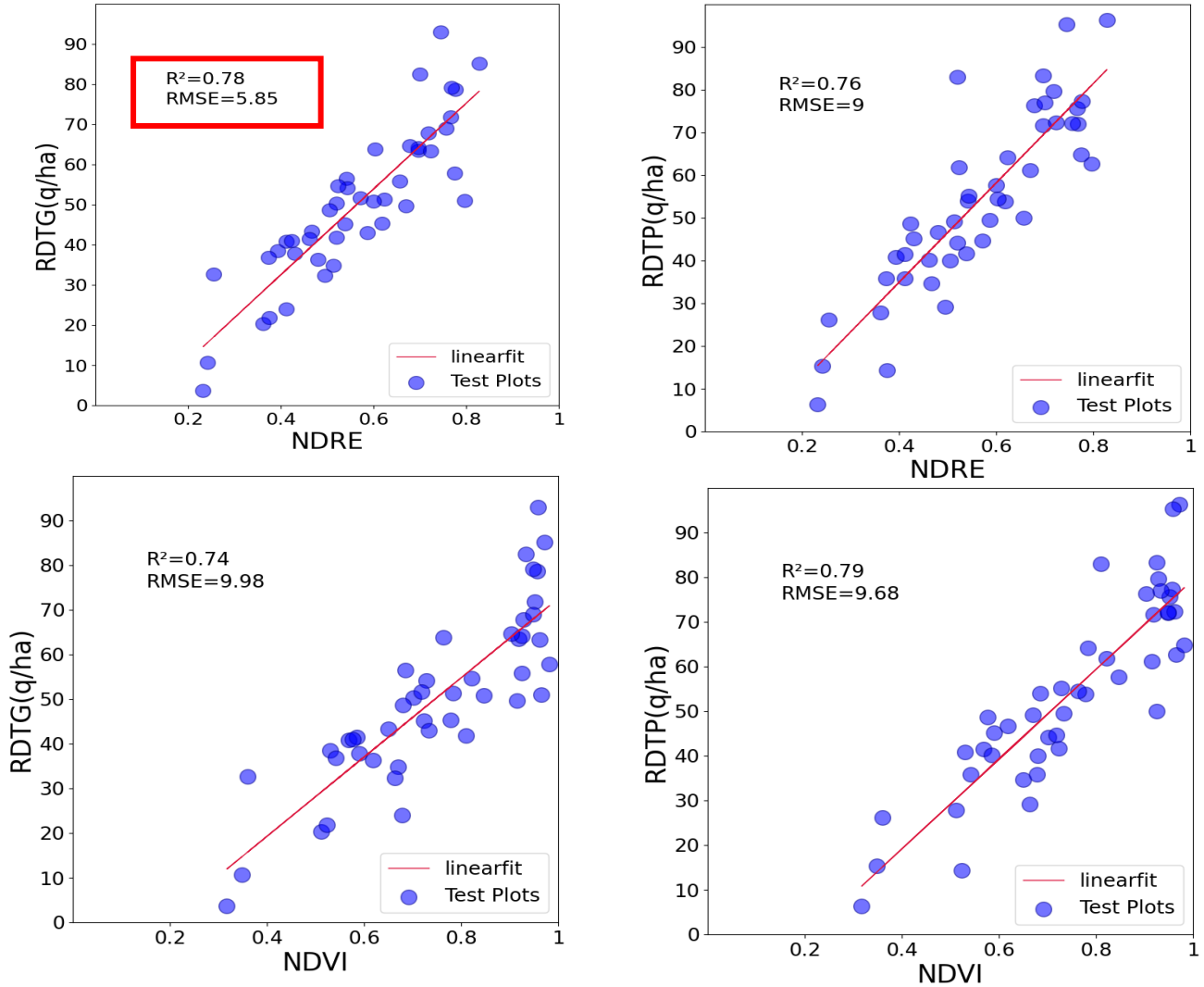
Index	Index name	Formula
NDVI	Normalized Difference Vegetation Index	$\frac{\mathrm{NIR}-\mathrm{RED}}{\mathrm{NIR}+\mathrm{RED}}$
GNDVI	Green Normalized Difference Vegetation Index	$\frac{\mathrm{NIR}-\mathrm{GREEN}}{\mathrm{NIR}+\mathrm{GREEN}}$
EVI	Enhanced Vegetation Index	$2.5*\frac{(\mathrm{PIR}-\mathrm{RED})}{(\mathrm{PIR}+6*\mathrm{RED}-7.5*\mathrm{BLUE}+1)}$
EVI2	Enhanced Vegetation index 2 bands	$2.5*\frac{(\mathrm{PIR}-\mathrm{RED})}{(\mathrm{PIR}+6*\mathrm{RED}-7.5*\mathrm{BLUE}+1)}$
NGRDI	Normalized Green Red Difference Index	$\frac{\mathrm{GREEN}-\mathrm{RED}}{\mathrm{GREEN}+\mathrm{RED}}$
NDRE	Normalized Difference Red Edge	$\frac{NIR-REDedge}{NIR+REDedge}$
CCCI	Canopy Chlorophyll Content Index	$\frac{\frac{NIR-REDedge}{NIR+REDedge}}{\frac{NIR-RED}{NIR+RED}}$
MCARI	Modified Chlorophyll Absorption in Reflectance Index	$\big((VNIR-RED)-0.2*(VNIR-GREEN)\big)*(VNIR/RED)$
DVI	Difference Vegetation Index	$\mathrm{NIR}-\mathrm{RED}$
TVI	Triangular Vegetation Index	$0.5*(120*(\mathrm{NIR}-\mathrm{GREEN})-200*(\mathrm{RED}-\mathrm{GREEN}))$

backscatter coefficient VH	VH
backscatter coefficient VV	VV
the polarisation ratio	VH/VV

The first approach : Regression model



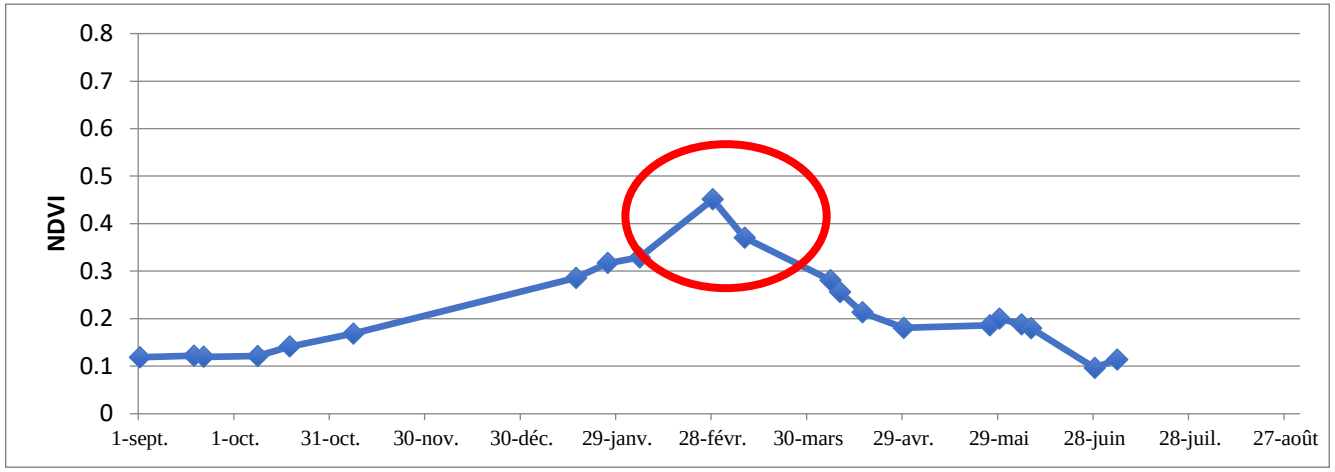
Evolution of vegetation indexes during the two agricultural years 2017-2018 and 2020-2021.

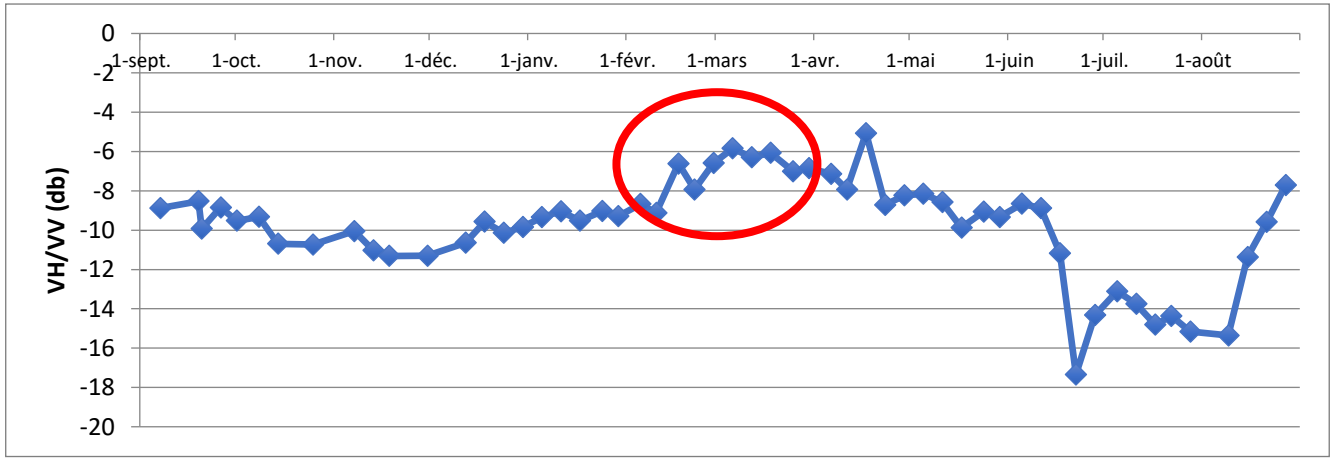


Correlation between different indexes and cereal yield (grain and straw) for the two agricultural years 2017-2018 and 2020-2021.

Early estimating seed and straw yields in March (3 month before harvest)

The first approach : Regression model



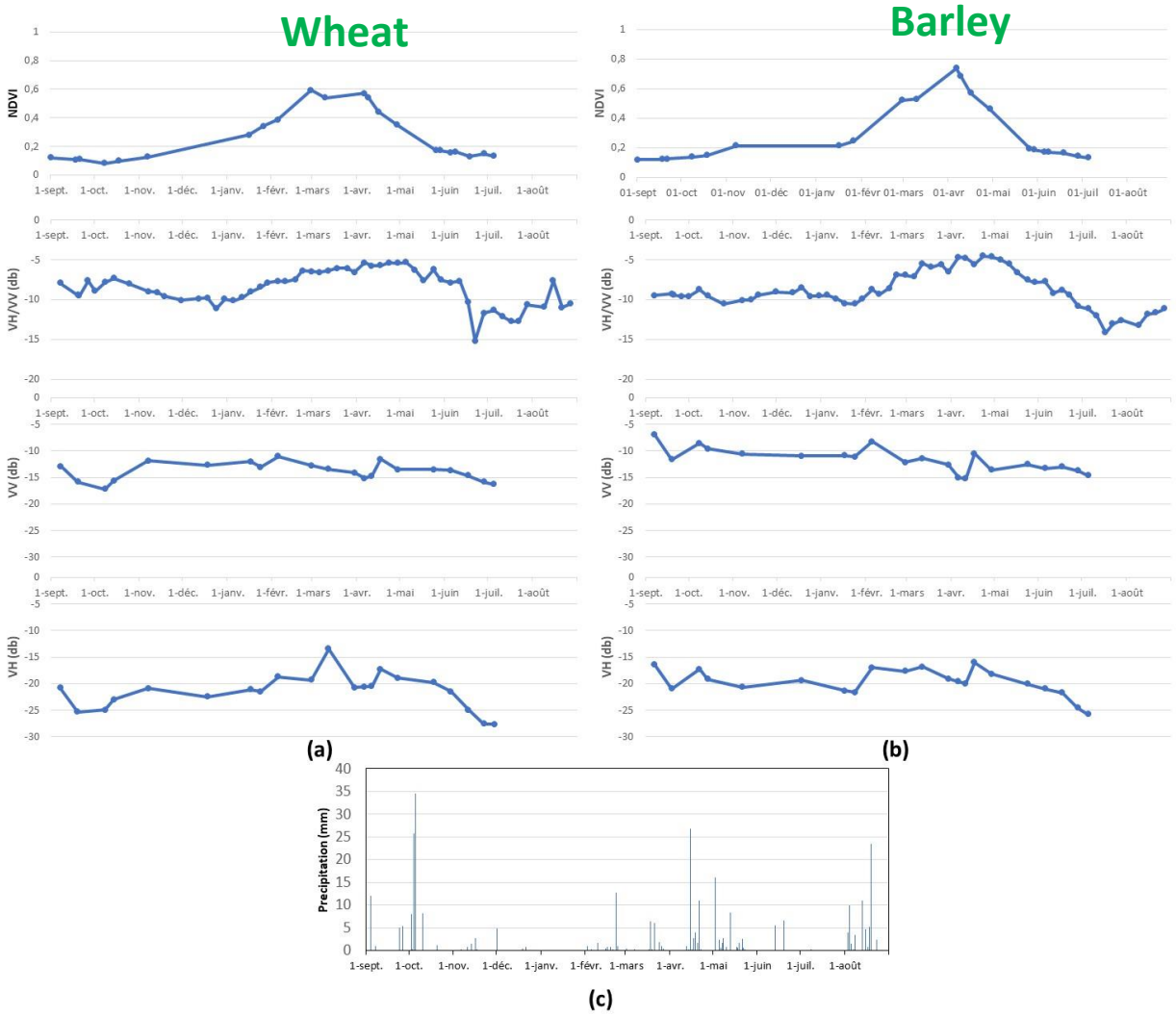


Evolution of the NDVI and the VH/VV ratio during the 2017-2018 agricultural year for a plot of barley

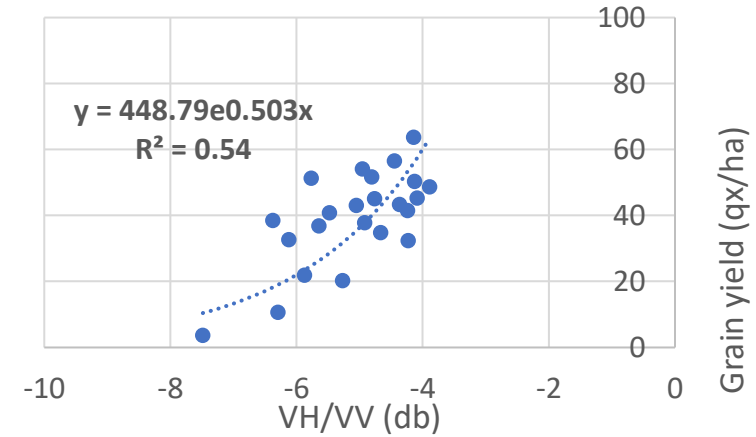
The VH/VV ratio is sensitive to the growth cycle of the culture and depends on the phenology stade of the plant

The possibility of early estimation of cereal yields using Radar images

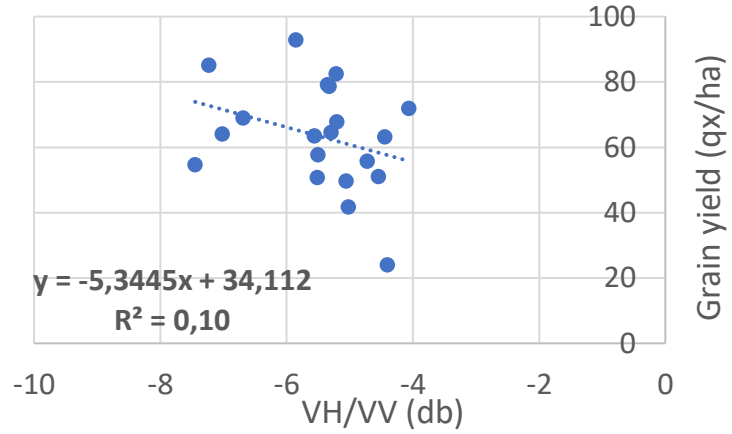
The first approach : Regression model



The behaviors of NDVI, VH/VV ratio, VH and VV on wheat field are like barley field from seeding to harvest.
→ Similar structure and functioning



Evolution of grain yield for 12 March 2018

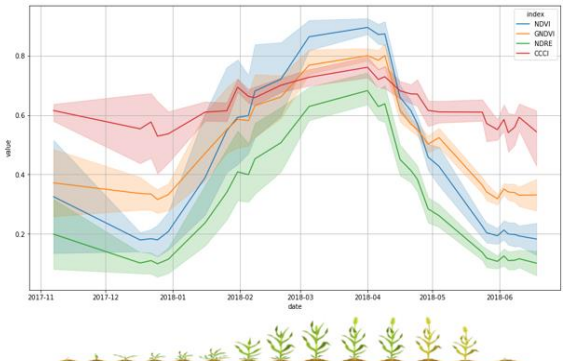


Evolution of grain yield for 21 March 2021

For the two agriculture years different cultural practices was applied : In 2021 intensive cultivation

The second approach : Machine Learning Algorithms

Approaches based on the most used machine learning algorithms : **SVM, RF, Neurons, and XGBoost.**



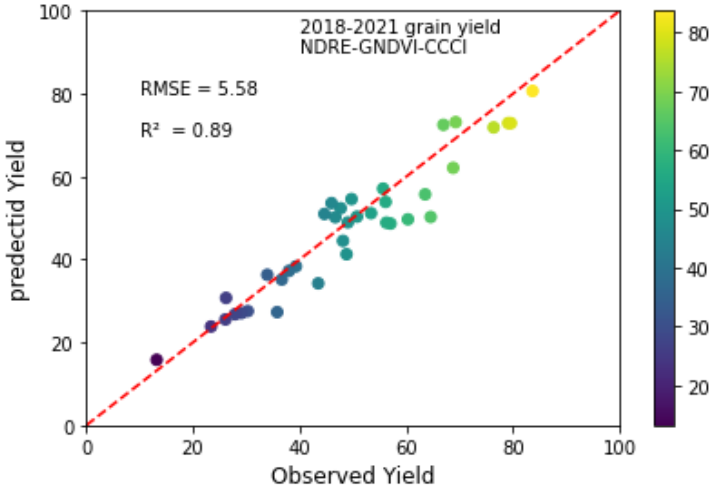
Red-Edge index : GNDVI; NDRE ; CCCI

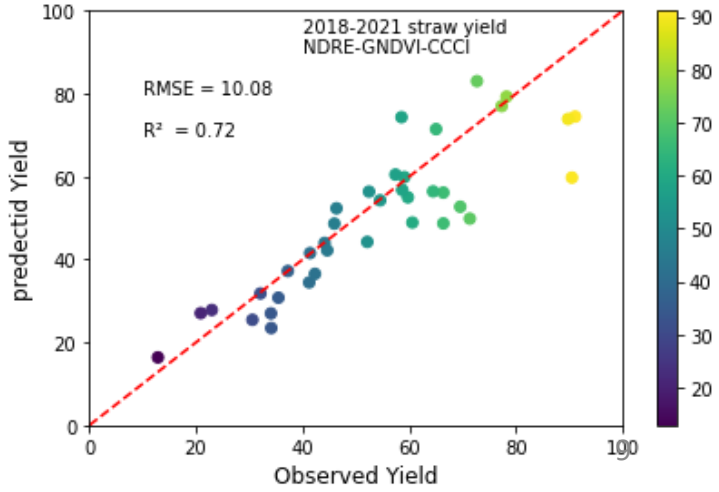
Statistical metrics for the forecasting models in March (3 month before harvest).

Machine Learning Algorithm	Grain yield		Straw yield	
	R^2	RMSE	R^2	RMSE
ANN	0.87	6.08	0.71	10.27
XGBoost	0.89	5.75	0.75	9.6
SVM	0.89	5.74	0.77	9.21
RF	0.89	5.58	0.72	10.08

→ The combination of **GNDVI; NDRE ; CCCI** performed better than models based on other combination.

→ Random Forest algorithm is the best tool for estimating seed and straw yields.

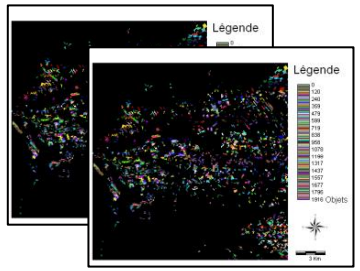


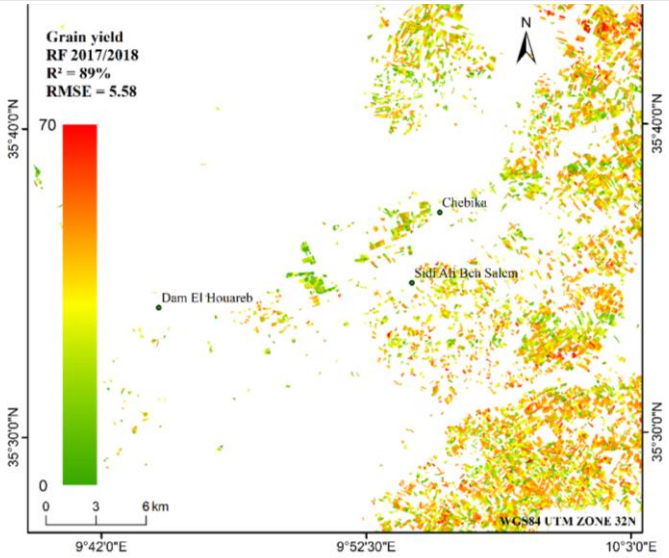


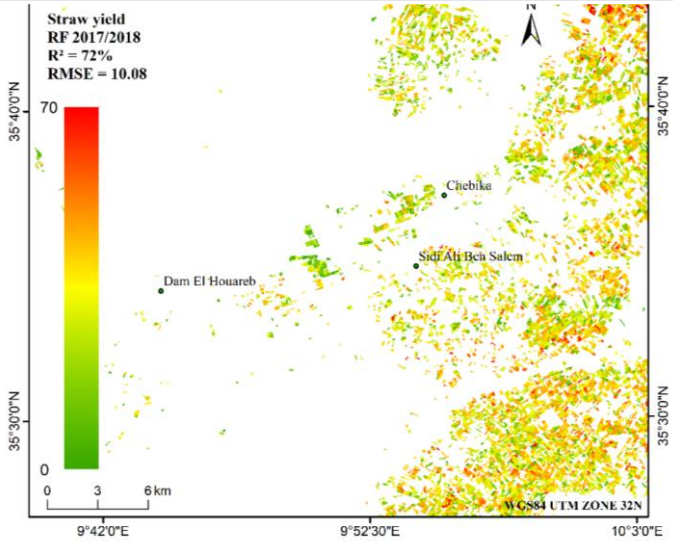
The second approach : Machine Learning Algorithms

Random Forest algorithm

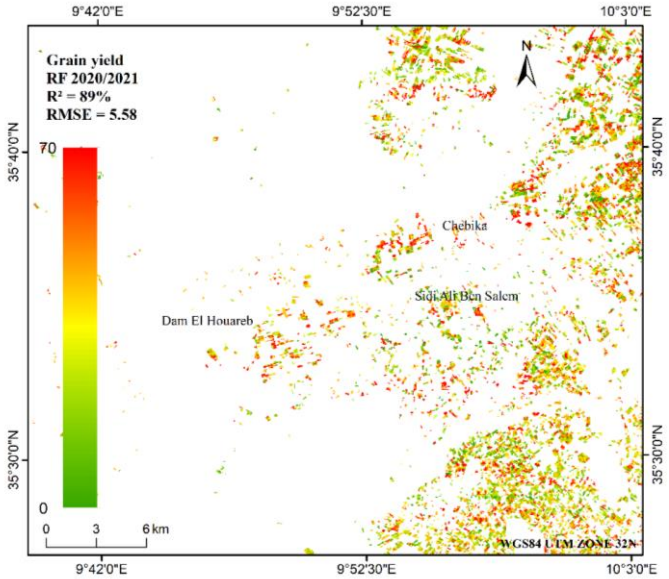
Spatialisation of the grain and straw yields for each cereal plots on the plain of Kairouan

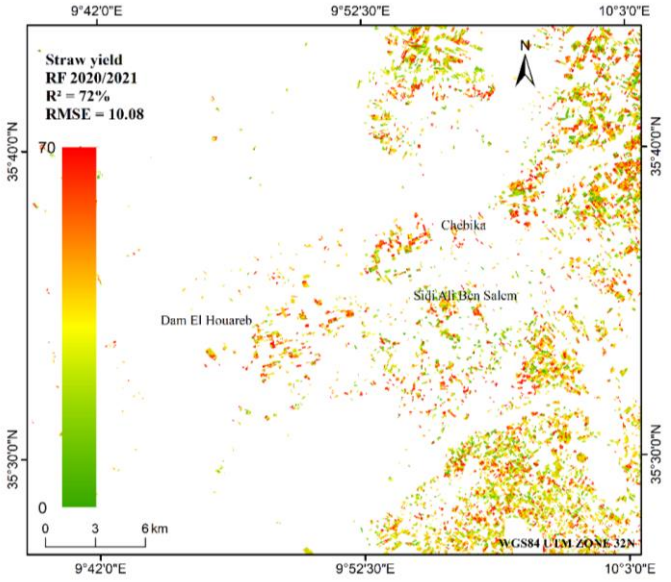






The agriculture year (2017-2018)





The agriculture year (2020-2021)

Conclusion

- **Regression Model :** Strong correlation between measured and estimated yield by Red-edge indices from mid-March (R^2_{grain} = 0,78 ; R^2_{straw} = 076).

- Radar time series allow to capture short phenological stages thanks to the high sensitivity of polarization ratio to plant phenology.

-The change in farming practices in the plain has influenced the capacity to predict yield using the polarization ratio

- **Machine Learning Algorithms :** Random Forest algorithm is the best tool for early estimating seed and straw yields in March (3 month before harvest).

- Red-Edge indices have demonstrated their performance for early estimation of cereal yields

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Thank you for your attention !