

# Proximal sensing of wheat to build the foundation for biotic stress monitoring from hyperspectral satellites

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## Context

Agriculture is both a key driver of the climate and biodiversity crises and one of their main victims. Yet it also has great potential to address them. Using adapted crop varieties and detecting biotic stresses—like fungal diseases in wheat—can help reduce chemical inputs, protect soils, optimize yields, and ensure food security. Today, digital agriculture mainly relies on multispectral imagery for crop monitoring and decision-making. This study explores the potential of near-infrared hyperspectral imaging for detecting biotic stress. As high-resolution hyperspectral satellite data with frequent revisit times remain limited, we simulate satellite pixels using proximal sensing of field plots. The findings will support future use as new hyperspectral satellite constellations become available.

## Biotic stress modelling

### Discrimination settings

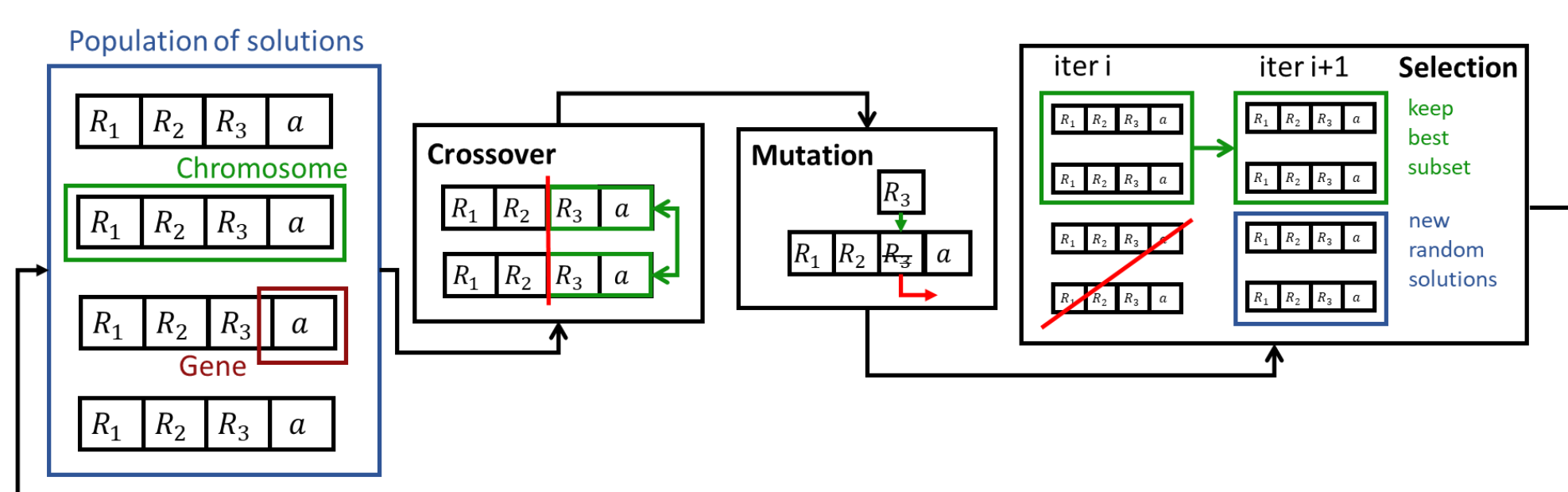
Observation are grouped in two classes in function of the level on biotic stress. To allow well balanced classes and better exploit the available information, the grouping is made according to the phenologic stage:

- Between elongation and heading: moderate to high stress (score 3-9) vs. low stress (score 1-2)
- Between heading and end of flowering: high stress (score 5-9) vs. low to moderate stress (score 1-4)

### Modelling methods

- Partial Least Squares Discriminant Analysis (PLS-DA)
- Support Vector Machine Discriminant Analysis (SVM-DA)
- Development of new spectral index using genetic algorithm (GA), an heuristic based on the mechanism of natural selection, to select optimal wavelengths:

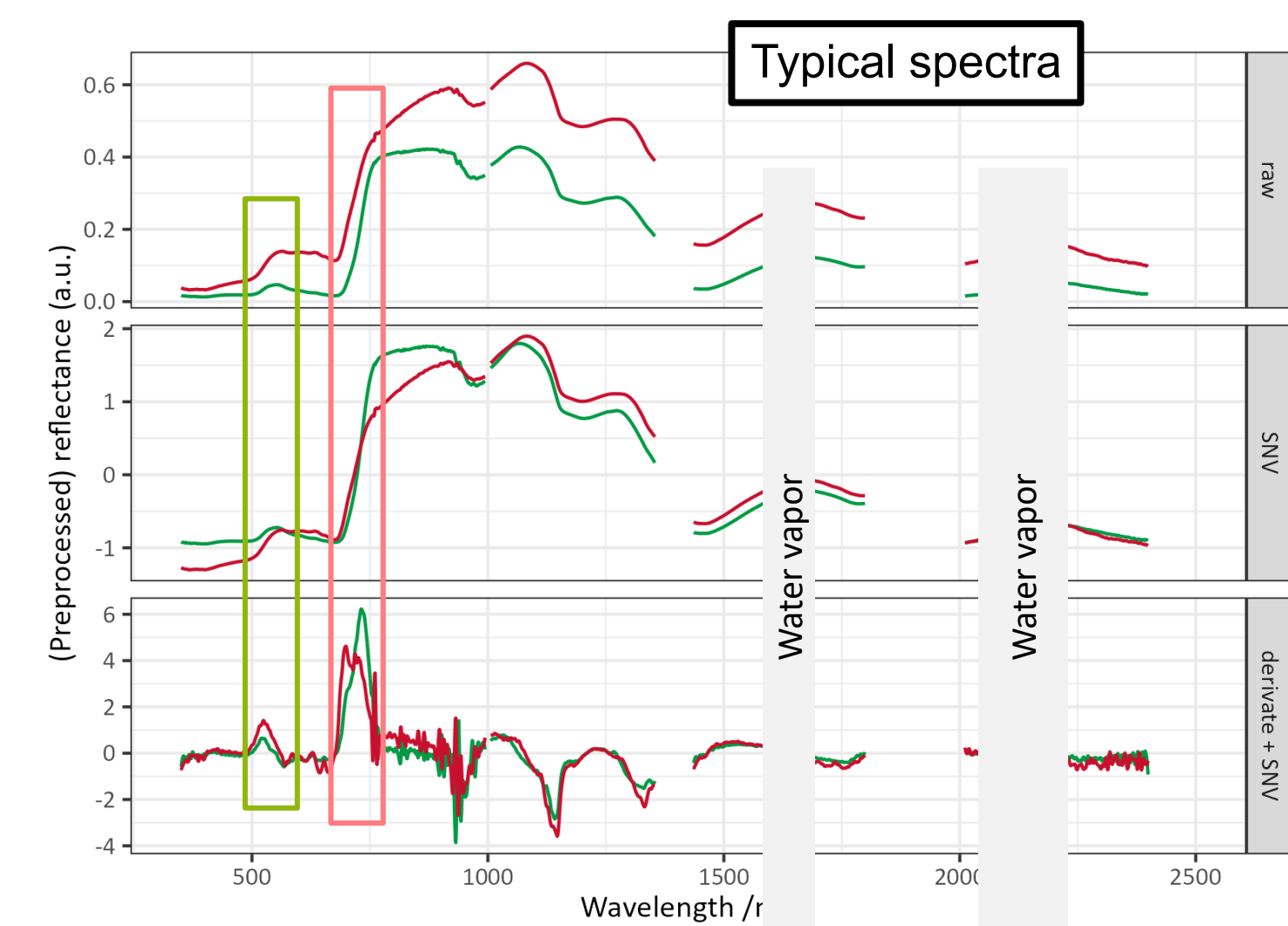
Optimal index:  $I(R_1, R_2, R_3, a) = \frac{R_1 - R_2}{R_1 + R_2} + a \cdot R_3$  with  $-1 < a < 1$ ,  $R_i$ : reflectance at wavelength  $i$



All methods were applied separately on the VNIR range (350-1350 nm), NIR range (1450-2400 nm) and the FULL range (VNIR + NIR). PLS-DA and SVM-DA were also applied on a set of popular spectral indices (IND).

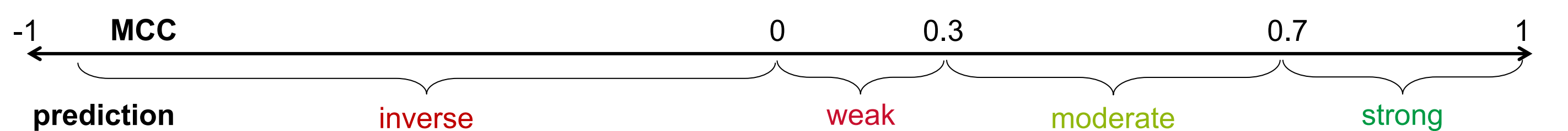
## Data acquisition

- Mainly two campaigns (2023-2024) in Wallonia, BE
- Field trials encompassing contrast in wheat variety, fungicide treatment and inoculation
- Also a few observations on farmers' field
- Proximal NIR sensing with the ASD FieldSpec4 spectrometer equipped with the pistol grip
- Yellow and brown rusts, take-all, septoria leaf blotch, fusarium head blight and common bunt
- Visual scoring of total biotic stress from 1 = no stress to 9 = maximum stress
- Recording of phenological stage (BBCH scale)



## Validation approach

The validation scheme prioritizes long-term robustness over short-term accuracy, with a focus on transparent performance evaluation. Calibration uses trials from 2023 (plus one in 2021 and 2022) while 2024 trials and farmers' fields serve as independent validation. Leave-one-trial-out cross-validation (CV) optimizes the model for future conditions. Model selection during CV relies on the area under the ROC curve (AUC), a threshold-independent metric. The classification threshold is set at the point closest to the top-left of the ROC curve—either globally (fixed from the full calibration set) or adjusted per trial. Final performance is assessed using the Matthews Correlation Coefficient (MCC), a balanced metric for binary classification:

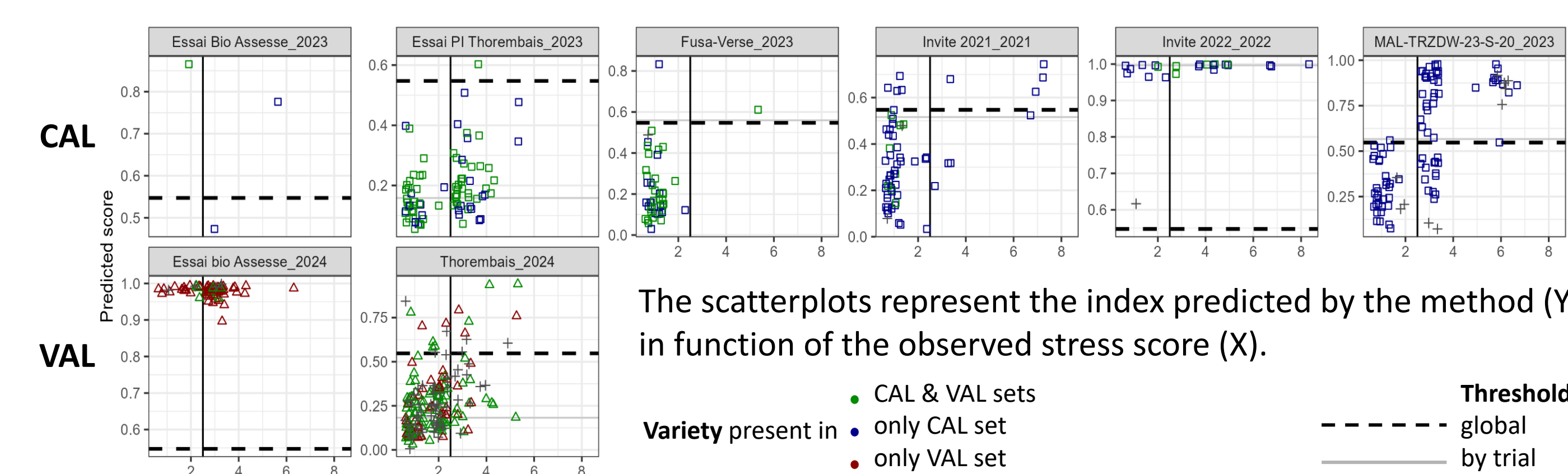


## Validation on proximal sensing data

### Between elongation and heading

Only SVM-DA (on indices) and GA models achieve moderate performance in validation (MCC: 0.22–0.59). Different trials show very contrasting results, with the organic trial Assesse 2024 showing notably bad validation performances, likely due to lower plant density and related soil interferences.

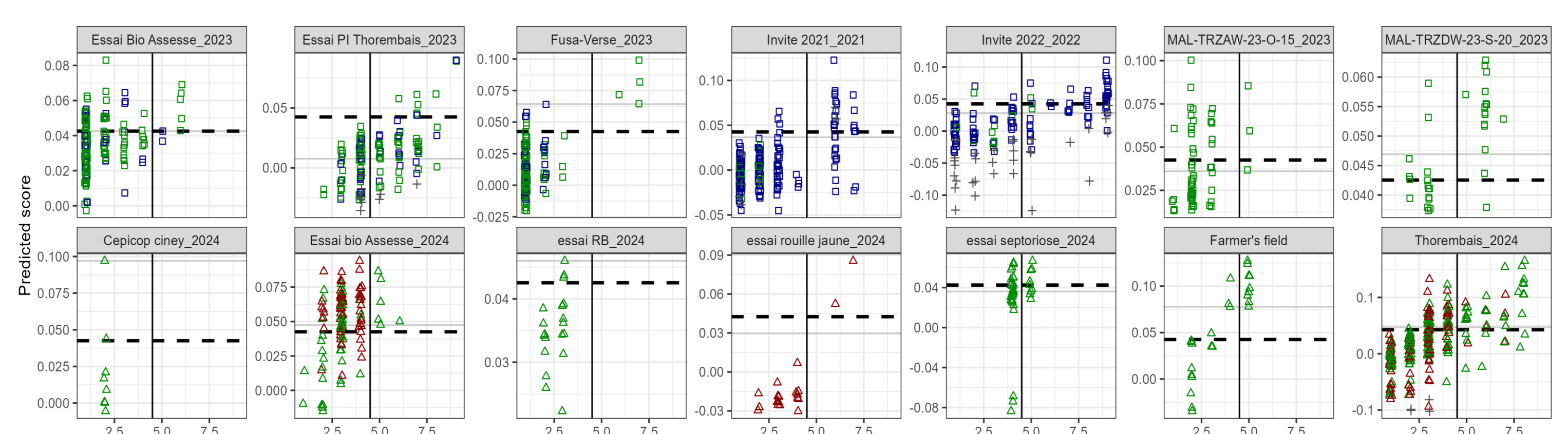
Set	Threshold	PLS-DA VNIR	PLS-DA NIR	PLS-DA FULL	PLS-DA IND	SVM-DA VNIR	SVM-DA NIR	SVM-DA FULL	SVM-DA IND	GA VNIR	GA NIR	GA FULL
Cal	Global	0.70	0.60	0.71	0.66	1.00	0.62	0.83	0.45	0.62	0.55	0.63
Cal	By trial	0.69	0.59	0.68	0.63	1.00	0.69	0.81	0.59	0.59	0.42	0.58
Val	Global	0.39	-0.30	0.39	-0.13	-0.34	-0.40	0.26	0.59	0.25	0.22	0.29
Val	By trial	0.09	-0.14	0.00	0.05	-0.15	0.01	0.06	0.40	0.39	0.39	0.29



### Between heading and end of flowering

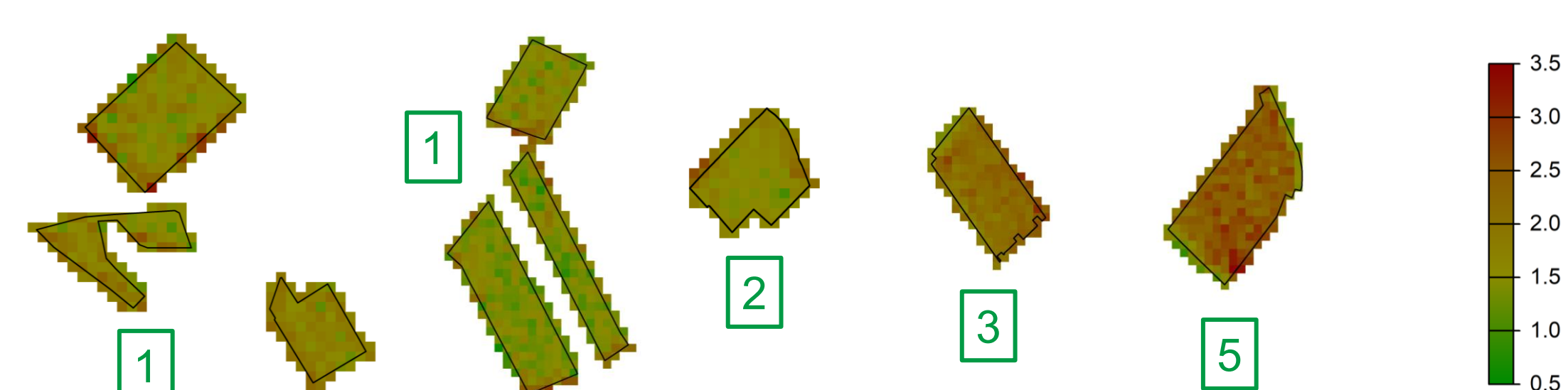
PLS-DA and GA models including the VNIR range or based on selected spectral indices (IND) provide moderate predictive performances. A positive trend between observed score and predicted index is visible for most trials in CAL and VAL sets, and notably also for farmer's fields.

Set	Threshold	PLS-DA VNIR	PLS-DA NIR	PLS-DA FULL	PLS-DA IND	SVM-DA VNIR	SVM-DA NIR	SVM-DA FULL	SVM-DA IND	GA VNIR	GA NIR	GA FULL
Cal	Global	0.64	0.27	0.67	0.41	0.52	0.62	0.29	0.78	0.40	0.34	0.37
Cal	By trial	0.64	0.22	0.62	0.45	0.56	0.73	0.06	0.73	0.57	0.33	0.51
Val	Global	0.32	0.02	0.23	0.31	0.22	0.15	-0.10	0.17	0.31	0.00	0.29
Val	By trial	0.32	0.21	0.29	0.38	0.38	0.19	0.15	0.26	0.38	0.19	0.39



## Validation on satellite image

Models were applied on a PRISMA satellite hyperspectral image. Here we see the prediction of the PLS-DA model using the VNIR range. The prediction of the model (colormap) is consistent with the stress scores previously observed is-situ (boxes).



## Conclusion

The different approaches tested showed the potential to detect biotic stress using near-infrared spectra, though with certain limitations. Between elongation and heading, stress was less frequent, and results should be interpreted with caution. Between heading and flowering, stress was more visible, and PLS-DA and GA models using VNIR wavelengths performed best, consistent with field observations and applicable to PRISMA imagery. Improving model performance and reliability requires expanding the dataset across more years and regions, as two seasons are not representative enough. This could be achieved using remote sensing spectral data combined with field-based stress observations.