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Agricultural Disease Management: Estimation of *Cercospora* Leaf Spot Severity in Table Beets using UAS

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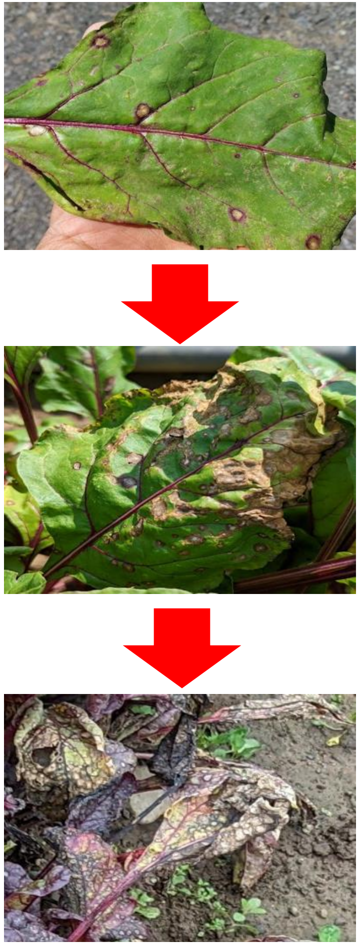
Background

- *Cercospora* leaf spot (CLS) is a foliar fugal disease common in beet plants.
- CLS causes reddish brown spots of size 2-5 mm on foliage.
- Spots spread and grow, eventually leading to defoliation.
- Early onset leading to significant yield losses.
- Associated defoliation poses a challenge for mechanical harvesters.



Disease Severity

- Disease severity (DS) is a metric that is used to quantify CLS in table beets, i.e., the percentage of leaf area covered by the lesions.

- Several leaves are sampled and visually scored to assess an entire plot.

- The same observer must score DS each season to ensure consistency.

Objective

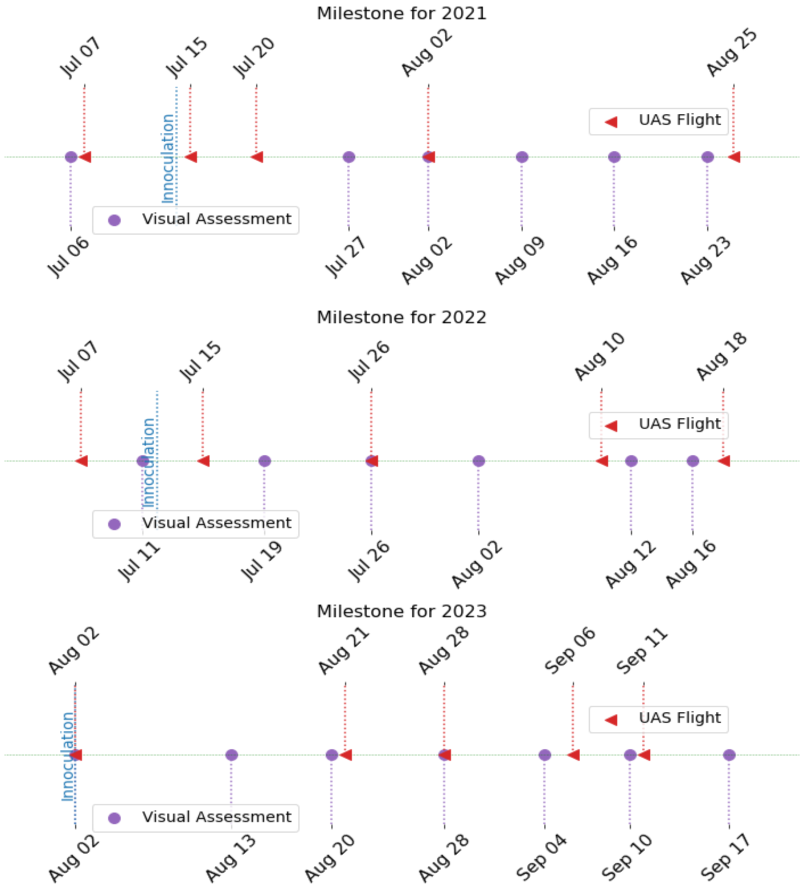
Assess *Cercospora* leaf spot (CLS) disease severity in table beets using unmanned aerial systems (UAS).

Data Collection

- **Study area:** Geneva, New York, USA, at Cornell AgriTech.
- **2021 & 2022 flights**: DJI Matrice-600 with a MicaSense RedEdge-M camera capturing five-band multispectral images (475, 560, 668, 717, & 840 nm).
- **2023 Flight**: DJI Mavic 3M was used to capture four-band multispectral images (560, 650, 730, & 860 nm)
- **Dimension of plot:** 10ft x 2, each plot demarcated by flags

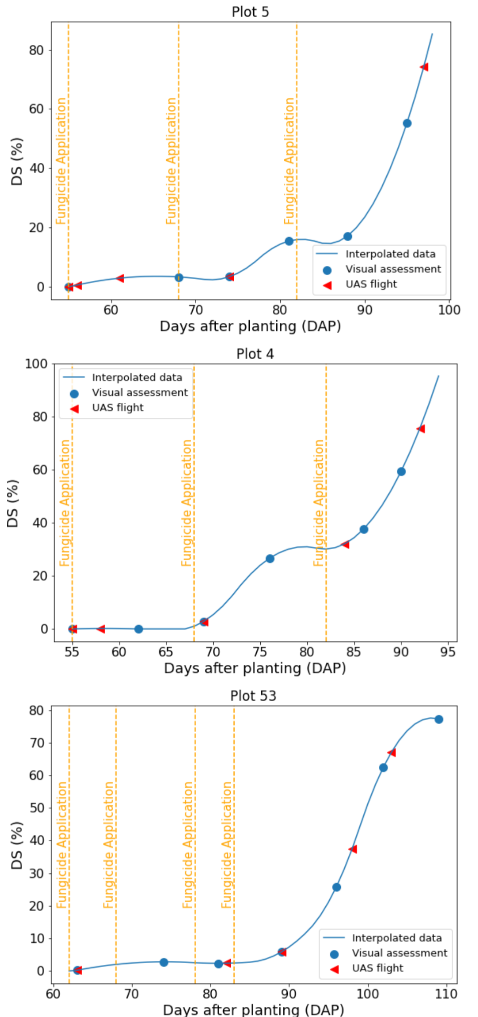
Timeline for Data Collection

- Five flight campaigns were performed each season, resulting a total of 15 flights across three seasons.
- For 2021 and 2022 there were 40 plots each year.
- For 2023 there were 56 plots.
- Total data points = 40x5 + 40x5 + 56x5 = 680



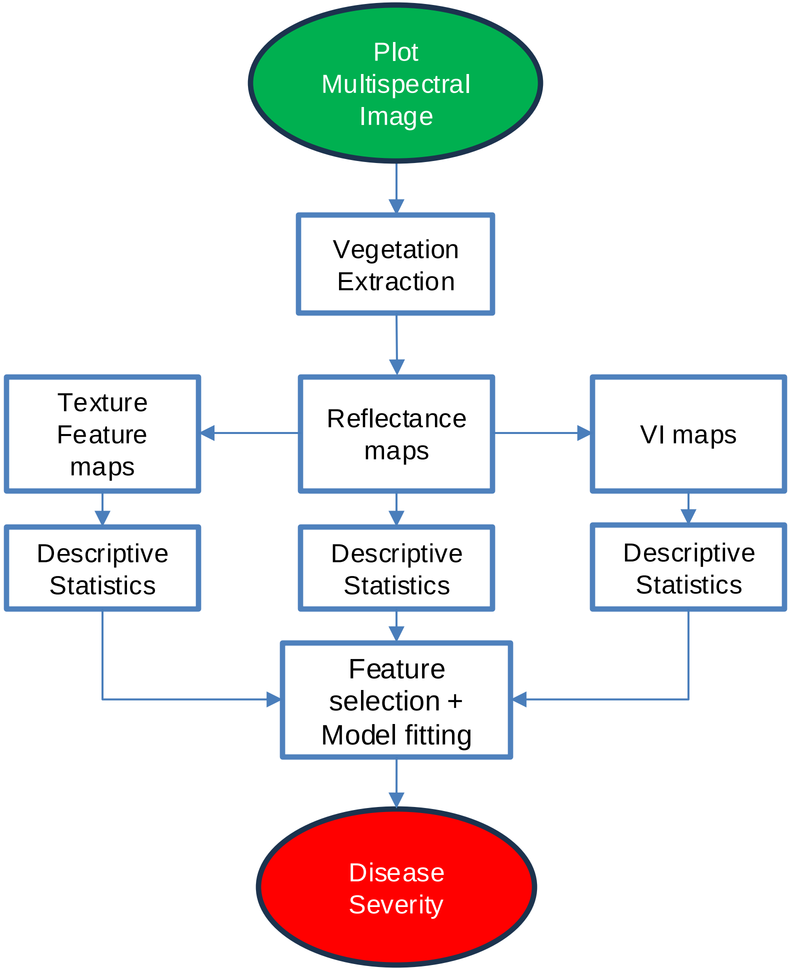
Note: Data Alignment

- Visual disease assessment did not always align with flight date.
- We thus used a 2nd order linear interpolation to approximate the disease severity on the day of the flight.



Processing Flow Chart

- MSAVI2 > 0.25 is used to extract beet vegetation canopy.
- Reflectance maps consists of 4 bands (green, red, red-edge, NIR).
- 6 descriptive statistics are extracted from each maps for each bands.



Vegetation Indices

- VI a placeholder for vegetation health
- VIs chosen based on past studies

Abbreviation	Name	Formula	Ref
RDVI	Renormalized Difference Vegetation Index	$\frac{R_{NIR} - R_{Red}}{\sqrt{R_{NIR} + R_{Red}}}$	Steddom et al., (2005)
NGRDVI	Normalized Green-Red difference vegetation index	$\frac{R_{Green} - R_{Red}}{R_{Green} + R_{Red}}$	Jay et al., (2020)
HI	Health Index	$\frac{R_{534} - R_{698}}{R_{534} + R_{698}} - 0.5R_{704}$	Mahlein et al. (2013)
CLSI	Cercospora Leaf Spot Index	$\frac{R_{698} - R_{570}}{R_{698} + R_{570}} - R_{734}$	
MCARI2	MCARI (variant with reduced soil contamination)	$\frac{1.5[2.5(R_{800} - R_{670}) - 1.3(R_{800} - R_{550})]}{\sqrt{(2R_{800} + 1)^2 - \left(6R_{800} - 5\sqrt{R_{670}}\right) - 0.5}}$	Barreto et al. (2023)
MSAVI2	Modified Soil-adjusted Vegetation Index (variant)	$\frac{2R_{NIR} + 1 - \sqrt{(2R_{NIR} + 1)^2 - 8(R_{NIR} - R_{Red})}}{2}$	
GVI	Green Vegetation Index	$-0.283R_{Green} - 0.660R_{Red} + 0.577R_{RedEdge} + 0.388R_{NIR}$	
MCARIOSAVI	Modified chlorophyll absorption ratio/ Optized soil adjusted vegetation indices	$\frac{[(R_{700} - R_{670}) - 0.2(R_{700} - R_{550})](R_{840} + R_{670} + 0.16)}{1.16(R_{840} - R_{670})(R_{700}/R_{670})},$	

Texture Features

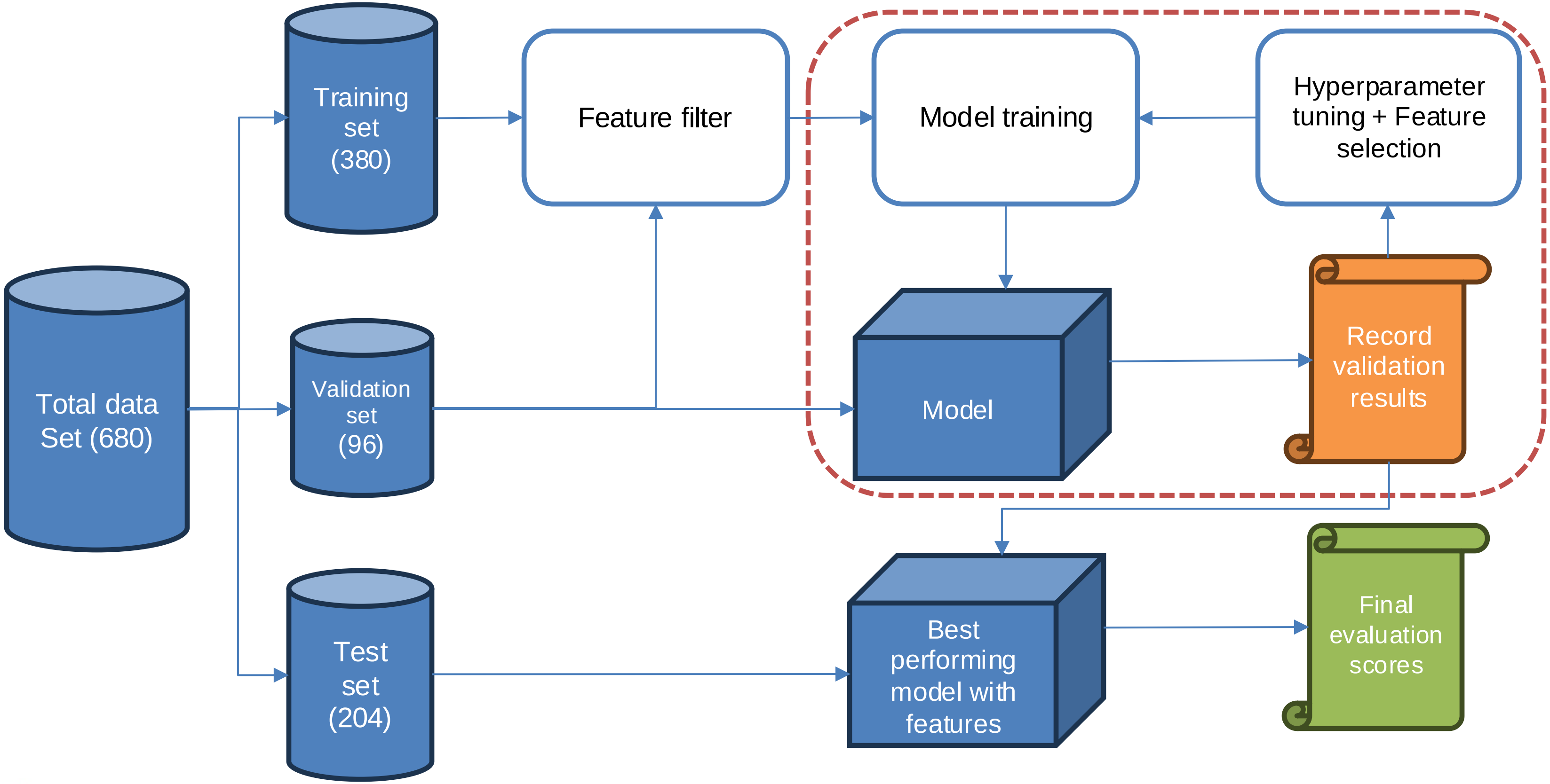
- Proxy for a pixel-spatial relationship.
- Spatial variation of pixels could provide information about the frequency of CLS presence in a plot.
- Find gray level co-occurrence Matrix (GLCM) (Haralick et al., 1973).
- Extract each texture feature using descriptive statistics of GLCM.
- A single four band image generates 4x8 = 32 feature maps

No.	Texture Features	Formula
1	Mean (mean)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} i * P(i,j)$
2	Variance (var)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g}(i-ME)^2 * P(i,j)$
3	Contrast (cont)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g}(i-j)^2 * P(i,j)$
4	Dissimilarity (dis)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g}\lvert i-j\rvert * P(i,j)$
5	Homogenity (homo)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} i * \frac{P(i,j)}{1+(i-j)^2}$
6	Entropy (ent)	$-\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P(i,j) * \ln P(i,j)$
7	Angular Second Moment (asm)	$\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} P(i,j)^2$
8	Correlation	$\frac{\sum_{i=1}^{N_g}\sum_{j=1}^{N_g} ijP(i,j) - \mu_x\mu_y}{\sigma_x\sigma_y}$ Where μ_x, μ_y, $\sigma_x$and $\sigma_y$are the means and standard deviations of p_x and p_y $p_x(i) = \sum_{j=1}^{N_g} P(i,j)$ and $p_y(j) = \sum_{i=1}^{N_g} P(i,j)$

Feature Extraction

- Calculate **mean**, **coefficient of variation**, **first quartile**, **third quartile**, **skewness** and **kurtosis** from each feature maps.
- Total number of features:
  - 8 VIs x 6 statistics + 4 bands x 6 statistics + 4 bands x 8 texture features x 6 statistics = **264**

Model Development

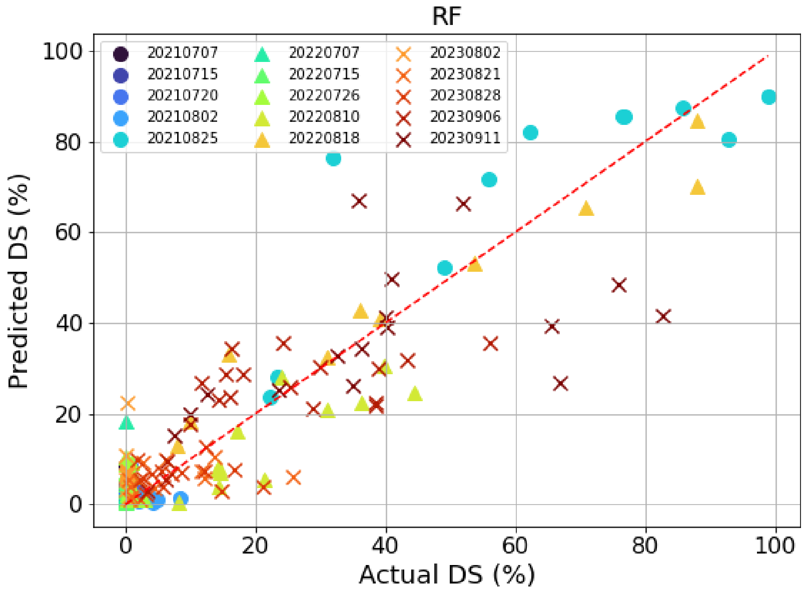


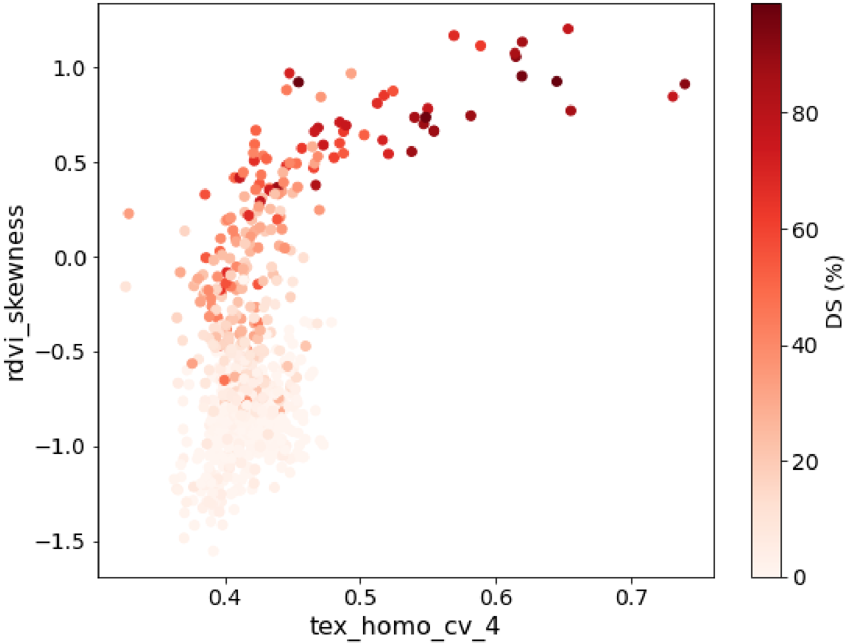
Best-performing Results

Random forest model exhibited the best result with the least number of features.

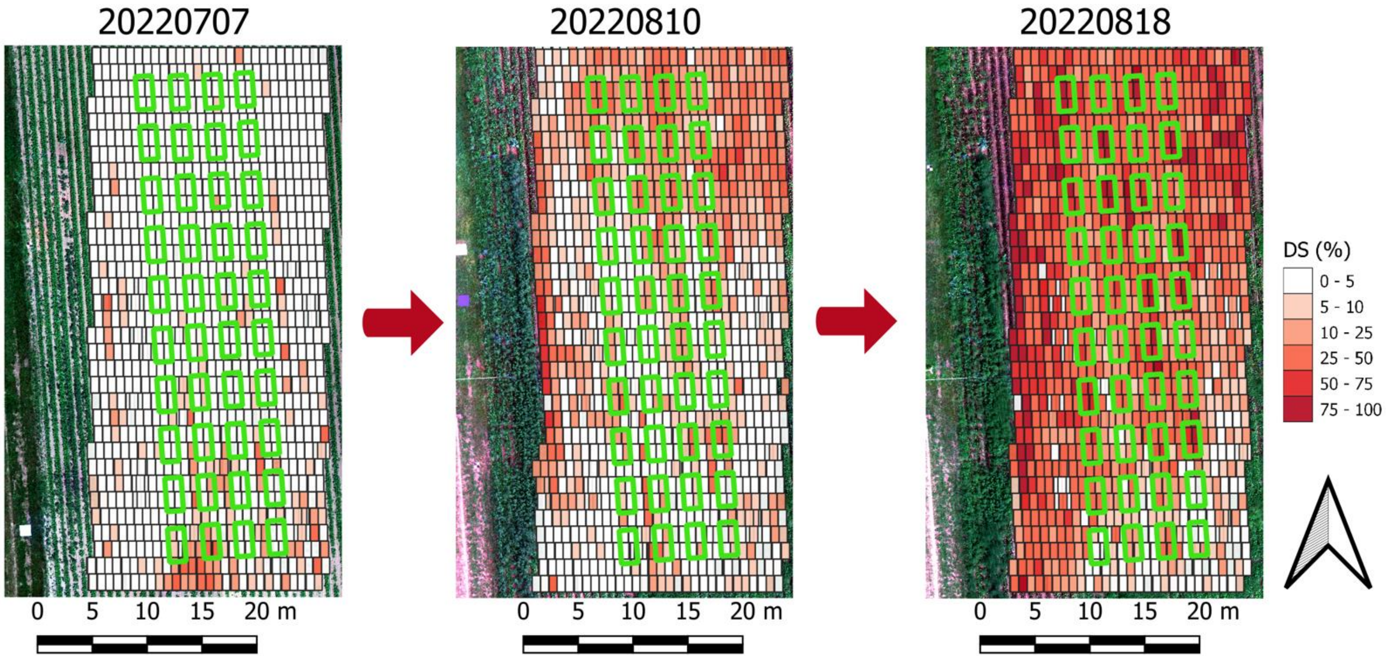
Models	Hyperparameters	No. of features	Features used	R^2_{train} / $RMSE_{train}$ (%)	R^2_{val} / $RMSE_{val}$ (%)	R^2_{test} / $RMSE_{test}$ (%)
RF	n_estimators: 100, max_depth: 8, min_samples_split: 3, min_samples_leaf: 2	2	rdvi_skewness, tex_homo_cv_4	0.89 / 6.92	0.87 / 8.09	**0.82 / 9.31**
XGB	n_estimators: 50, learning_rate: 0.1, max_depth: 3	7	rdvi_skewness, ref_q3_3, tex_cont_cv_2, tex_cont_q3_4, tex_homo_cv_4, tex_homo_kurtosis_4, tex_mean_q3_1	0.93 / 5.82	0.89 / 7.61	0.81 / 9.65
SVR	kernel: rbf, C: 1, epsilon: 0.001	8	gvi_kurtosis, ref_skewness_3, ref_skewness_4, tex_cont_q1_4, tex_homo_cv_3, tex_homo_skewness_4, tex_mean_cv_4, tex_var_kurtosis_4	0.88 / 7.50	0.81 / 9.90	0.78 / 10.27
PLSR	n_components: 5	5	gvi_kurtosis, ref_skewness_3, ref_skewness_4, tex_homo_cv_3, tex_mean_mean_4	0.76 / 10.33	0.83 / 9.36	0.79 / 10.17

Model Performance and Feature Analysis





CLS Maps: Examples of Field-level CLS



Conclusions

- Our work demonstrates the feasibility of utilizing multiple UAS systems for estimating CLS disease severity.

- We achieved comparable accuracy to contemporary literature at a relatively low resolution (~1 cm).

- RDVI skewness (red and NIR band) and texture homogeneity coefficient of variation of NIR band are important indices for determining CLS.

Questions?

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