

Supplementary information

A synergistic UAV-driven deep learning and epidemic modeling framework for dynamic spatiotemporal prediction of maize leaf spot

Table S6.1 Vegetation indices derived from hyperspectral images

Name	Abbreviation	Equation	Reference
VIIs for plant biophysical properties: structure, crop cover			
Structural			
Normalized Difference Vegetation Index	NDVI	$(R_{800} - R_{670}) / (R_{800} + R_{670})$	Rouse et al. (1974)
Near-Infrared Reflectance of Vegetation	NIRv	$R_{800}(R_{800} - R_{670}) / (R_{800} + R_{670})$	Badgley et al. (2017)
Renormalized Difference Vegetation Index	RDVI	$(R_{800} - R_{670}) / (R_{800} + R_{670})^{1/2}$	Roujean and Breon (1995)
Simple Ratio	SR	R_{800}/R_{670}	Carter (1994)
Modified Red-edge Ratio	mSR	$(R_{750} - R_{445}) / (R_{705} - R_{445})$	Sims and Gamon (2002)
Optimized Soil-Adjusted Vegetation Index	OSAVI	$(1+0.6)(R_{800} - R_{670}) / (R_{800} + R_{670} + 0.16)$	Rondeaux et al. (1996)
Modified Triangular Vegetation Index 1	MTVI1	$1.2(1.2(R_{800} - R_{550}) - 2.5(R_{670} - R_{550}))$	Haboudane et al. (2004)
Modified Triangular Vegetation Index 2	MTVI2	$1.5 \frac{2.5(R_{800} - R_{550}) - 1.3(R_{670} - R_{550})}{\sqrt{(2R_{800} + 1)^2 - (6R_{800} - 5\sqrt{R_{670}}) - 0.5}}$	Haboudane et al. (2004)
Enhanced Vegetation Index	EVI	$2.5(R_{800} - R_{670}) / (R_{800} + 6R_{670} - 7.5R_{400} + 1)$	Huete et al. (2002)
Lichtenthaler Index	LIC ₁	$(R_{800} - R_{680}) / (R_{800} + R_{680})$	Lichtenthaler et al. (1996)
VIIs for plant biochemical properties: pigments, water and nitrogen Chlorophyll			
Vogelmann Indices	VOG1	R_{740}/R_{720}	Vogelmann et al. (1993)
	VOG2	$(R_{734} - R_{747}) / (R_{715} - R_{726})$	Vogelmann et al. (1993)
	VOG3	$(R_{734} - R_{747}) / (R_{715} + R_{720})$	Vogelmann et al. (1993)
Gitelson and Merzlyak Indices	GM1	R_{750}/R_{550}	Gitelson and Merzlyak (1996)
	GM2	R_{750}/R_{700}	Gitelson and Merzlyak

			(1996)
Transformed Chlorophyll Absorption in Reflectance Index	TCARI	$3 \times [(R_{700} - R_{670}) - 0.2 \times (R_{700} - R_{550}) \times (R_{700}/R_{670})]$	Haboudane et al. (2002)
TCARI/OSAVI	TCARI/OSAVI	TCARI/OSAVI	Haboudane et al. (2002)
Chlorophyll Index	CI	R_{750}/R_{710}	Zarco-Tejada et al. (2001)
Simple Ratio Pigment Index	SRPI	R_{430}/R_{680}	Penuelas et al. (1995)
Normalized Phaeophytinization Index	NPQI	$(R_{415} - R_{435})/(R_{415} + R_{435})$	Barnes et al. (1992)
Pigment Specific Simple Ratio for Chl a	PSSRa	R_{800}/R_{680}	Blackburn (1998)
Pigment Specific Simple Ratio for Chl b	PSSRb	R_{800}/R_{635}	Blackburn (1998)
Pigment Specific Normalized Difference	PSND	$(R_{800} - R_{675})/(R_{800} + R_{675})$	Blackburn (1998)
Carotenoid			
Carotenoid Reflectance Index	CRI ₅₅₀	$(1/R_{510}) - (1/R_{550})$	Gitelson et al. (2002)
Carotenoid Reflectance Index	CRI ₇₀₀	$(1/R_{510}) - (1/R_{700})$	Gitelson et al. (2003)
Modified Carotenoid Reflectance Index 550	CRI _{550m}	$(1/R_{515}) - (1/R_{550})$	Gitelson et al. (2003)
Modified Carotenoid Reflectance Index 700	CRI _{700m}	$(1/R_{515}) - (1/R_{700})$	Gitelson et al. (2003)
Near-Infrared Carotenoid Reflectance Index 550	RCRI ₅₅₀	$(1/R_{510}) - (1/R_{550})R_{770}$	Gitelson et al. (2006)
Near-Infrared Carotenoid Reflectance Index 700	RCRI ₇₀₀	$(1/R_{510}) - (1/R_{700})R_{770}$	Gitelson et al. (2006)
Simple Ratio Carotenoids	CAR	R_{695}/R_{760}	Hernández-Clemente et al. (2012)
Lichtenthaler Index	LIC ₃	R_{440}/R_{740}	Lichtenthaler et al. (1996)
Anthocyanins			
Visible Atmospherically Resistant Index	VARI	$(R_{555} - R_{650})/(R_{555} + R_{650} - R_{475})$	Gitelson et al. (2001)
Visible Atmospherically Resistant Index 2	VARI2	$(R_{560} - R_{668})/(R_{560} + R_{668} - R_{475})$	Gitelson et al. (2001)
Anthocyanin Reflectance Index	ARI	$1/R_{550} - 1/R_{700}$	Gitelson et al. (2001)
Modified Anthocyanin Reflectance Index	ARIm	$R_{800}(1/R_{550} - 1/R_{700})$	Gitelson et al. (2006)
Pigments: Carotenoid and chlorophyll			
Normalized Pigments Index	NPCI	$(R_{680} - R_{430})/(R_{680} + R_{430})$	Penuelas et al. (1995)
Structure-Intensive Pigment Index	SICI	$(R_{800} - R_{445})/(R_{800} + R_{680})$	Penuelas et al. (1995)
Plant Senescence Reflectance Index	PSRI	$(R_{680} - R_{500})/R_{750}$	Merzlyak et al. (1999)
Blue Index	B	R_{450}/R_{490}	Calderón et

			al. (2013)
Greenness Index	G	R ₅₇₀ /R ₆₇₀	Calderón et al. (2013)
Redness Index	R	R ₇₀₀ /R ₆₇₀	Gitelson et al. (2000)
Blue/green Indices	BGI1	R ₄₀₀ /R ₅₅₀	Zarco-Tejada et al. (2005)
	BGI2	R ₄₅₀ /R ₅₅₀	Zarco-Tejada et al. (2005)
Blue Fraction	BF1	R ₄₀₀ /R ₄₁₀	Zarco-Tejada et al. (2018)
	BF2	R ₄₀₀ /R ₄₂₀	Zarco-Tejada et al. (2018)
	BF3	R ₄₀₀ /R ₄₃₀	Zarco-Tejada et al. (2018)
	BF4	R ₄₀₀ /R ₄₄₀	Zarco-Tejada et al. (2018)
	BF5	R ₄₀₀ /R ₄₅₀	Zarco-Tejada et al. (2018)
Blue/Red Indices	BRI1	R ₄₉₀ /R ₆₉₀	Zarco-Tejada et al. (2012)
	BRI2	R ₄₅₀ /R ₆₉₀	Zarco-Tejada et al. (2012)
Relative Greenness Index	RGI	R ₆₉₀ /R ₅₅₀	Zarco-Tejada et al. (2005)
Ratio Analysis of Reflectance Spectra	RARS	R ₇₄₆ /R ₅₁₃	Chappelle et al. (1992)
Pigment Specific Simple Ratio for Cars	PSSRc	R ₈₀₀ /R ₄₇₀	Blackburn (1998)
Datt Cab Cx+c Index	DCabxc	R ₆₇₂ /(R ₅₅₀ ×3R ₇₀₈)	Datt (1998)
Datt NIR Cab Cx+c Index	DNCabxc	R ₈₆₀ /(R ₅₅₀ ×R ₇₀₈)	Datt (1998)
Nitrogen			
Double-peak Canopy Nitrogen Index	DCNI	(R ₇₂₀ −R ₇₀₀)/(R ₇₀₀ −R ₆₇₀)/(R ₇₂₀ −R ₆₇₀ +0.03)	Chen et al. (2010)
Structure and chlorophyll			
Triangular Vegetation Index	TVI	0.5(120(R ₇₅₀ −R ₅₅₀)−200(R ₆₇₀ −R ₅₅₀))	Broge and Leblanc (2001)
VIs for plant physiological properties			
Xanthophyll and photosynthetic efficiency			
Photochemical Reflectance Indices	PRI	(R ₅₇₀ −R ₅₃₁)/(R ₅₇₀ +R ₅₃₁)	Gamon et al. (1992)
Photochemical Reflectance Index (515)	PRI ₅₁₅	(R ₅₁₅ −R ₅₃₁)/(R ₅₁₅ +R ₅₃₁)	Hernandez-Clemente et al. (2011)
Photochemical Reflectance Index (512)	PRI _{m1}	(R ₅₁₂ −R ₅₃₁)/(R ₅₁₂ +R ₅₃₁)	Hernandez-Clemente et al. (2011)
Photochemical Reflectance Index (600)	PRI _{m2}	(R ₆₀₀ −R ₅₃₁)/(R ₆₀₀ +R ₅₃₁)	Gamon et al. (1992)
Photochemical Reflectance Index (670)	PRI _{m3}	(R ₆₇₀ −R ₅₃₁)/(R ₆₇₀ +R ₅₃₁)	Gamon et al. (1992)
Photochemical Reflectance Index (670 and 570)	PRI _{m4}	(R ₅₇₀ −R ₅₃₁ −R ₆₇₀)/(R ₅₇₀ +R ₅₃₁ +R ₆₇₀)	Hernandez-Clemente et al. (2011)

Normalized Photosynthetic Reflectance Index	PRI _n	$\text{PRI}_{570}/[\text{RDVI} \times (\text{R}_{700}/\text{R}_{670})]$	Zarco-Tejada et al. (2013)
Carotenoid/Chlorophyll Ratio Index	PRI \times CI	$(\text{R}_{570}-\text{R}_{530})/(\text{R}_{570}+\text{R}_{530}) \times ((\text{R}_{760}/\text{R}_{700})-1)$	Garrity et al. (2011)
Chlorophyll fluorescence			
Reflectance Curvature Index	CUR	$(\text{R}_{675} \times \text{R}_{690})/\text{R}_{683}^2$	Zarco-Tejada et al. (2000)
Stresses			
Health Index (534,698,704)	HI	$(\text{R}_{534}-\text{R}_{698})/(\text{R}_{534}+\text{R}_{698})-0.5 \times \text{R}_{704}$	Mahlein et al. (2013)
Lichtenthaler	LIC ₂	$\text{R}_{440}/\text{R}_{690}$	Lichtenthaler (1996)
Carter Indices	CTRI	$\text{R}_{695}/\text{R}_{420}$	Carter (1994)

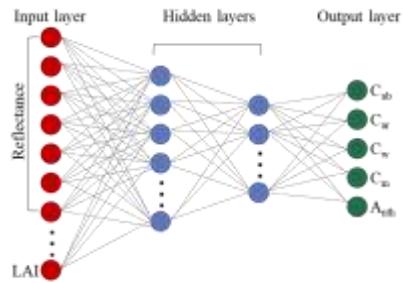


Fig. S6.1. Architecture of the multilayer perceptron (MLP) regression model used to estimate key biophysical parameters, including chlorophyll content (C_{ab}), carotenoid content (C_{ar}), equivalent water thickness (C_w), dry matter content (C_m), and anthocyanin content (A_{nth}).

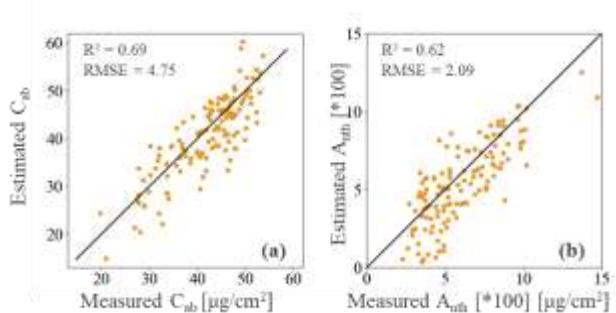


Fig. S6.2 Correlation of measured vs. PROSAIL estimated C_{ab} and A_{nth} . A total of 132 samples from site A (12 plots \times 11 times) were evaluated.

Table S6.2 Prediction report of different models on 2021 test set

Metric	Class	Epidemic model	RS-DL			RS-DeepSpread model
			MLP	LSTM	GRU	
Precision	Early	63.18%	81.28%	77.62%	79.72%	88.06%
	Mild	67.06%	77.38%	76.73%	79.67%	83.01%
	Moderate	38.46%	66.67%	66.67%	69.70%	87.10%
	Severe	0.00%	100.00%	100.00%	100.00%	100.00%
	weighted avg	63.21%	78.43%	76.48%	79.05%	85.59%
Recall	Early	85.00%	75.00%	74.09%	76.82%	80.45%
	Mild	48.10%	82.28%	79.32%	82.70%	90.72%
	Moderate	29.41%	70.59%	70.59%	67.65%	79.41%
	Severe	0.00%	100.00%	100.00%	100.00%	100.00%
	weighted avg	63.21%	78.25%	76.42%	79.07%	85.37%
F1-score	Early	72.48%	78.01%	75.81%	78.24%	84.09%
	Mild	56.02%	79.75%	78.01%	81.16%	86.69%
	Moderate	33.33%	68.57%	68.57%	68.66%	83.08%
	Severe	0.00%	100.00%	100.00%	100.00%	100.00%
	weighted avg	61.70%	78.24%	76.42%	79.03%	85.30%
Overall accuracy		63.21%	78.25%	76.42%	79.07%	85.37%

批注 [CC1]: This correct for all severe classes??

Table S6.3 Prediction report of different models on 2023 test set

Metric	Class	Epidemic model	RS-DL			RS-DeepSpread model
			MLP	LSTM	GRU	
Precision	Early	40.00%	100.00%	100.00%	100.00%	100.00%
	Mild	85.33%	81.94%	83.78%	84.42%	91.55%
	Moderate	91.89%	76.74%	78.57%	87.18%	91.11%
	Severe	66.67%	100.00%	50.00%	50.00%	100.00%
	weighted avg	86.19%	80.90%	81.39%	84.98%	91.81%
Recall	Early	66.67%	66.67%	66.67%	66.67%	66.67%
	Mild	92.75%	85.51%	89.86%	94.20%	94.20%
	Moderate	75.56%	73.33%	73.33%	75.56%	91.11%
	Severe	66.67%	100.00%	33.33%	33.33%	66.67%
	weighted avg	85.00%	80.83%	81.67%	85.00%	91.67%
F1-score	Early	50.00%	80.00%	80.00%	80.00%	80.00%
	Mild	88.89%	83.69%	86.71%	89.04%	92.86%
	Moderate	82.93%	75.00%	75.86%	80.95%	91.11%
	Severe	66.67%	100.00%	40.00%	40.00%	80.00%
	weighted avg	85.13%	80.75%	81.31%	84.56%	91.56%
Overall accuracy		85.00%	80.83%	81.67%	85.00%	91.67%

Note: weighted avg refers to the support-weighted average across all labels. Bold values indicate the best performance, while underlined values represent the second-best.

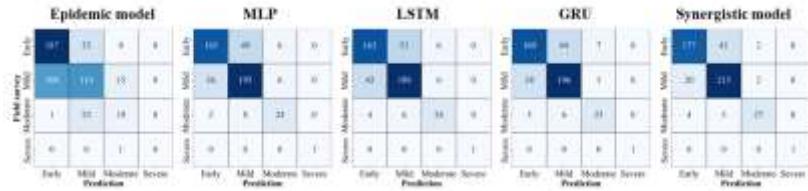


Fig.S6.3. Confusion matrices for different models on 2021 test set

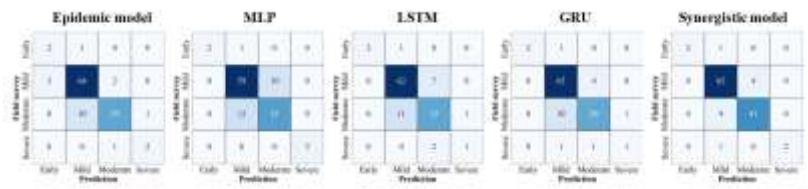


Fig.S6.4. Confusion matrices for different models on 2023 test set

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