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	Equation
VIs 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	NIR_V	$R_{800}(R_{800}-R_{670})/(R_{800}+R_{670})$	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)
VIs 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	SIPI	$(R_{800}-R_{445})/(R_{800}+R_{680})$	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	$R_{672}/(R_{550}\times 3R_{708})$	Datt (1998)
Datt NIR Cab Cx+c Index	DNCabxc	$R_{860}/(R_{550}\times R_{708})$	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	$PRI_{570}/[RDVI\times(R_{700}/R_{670})]$	Zarco-Tejada et al. (2013)
Carotenoid/Chlorophyll Ratio Index	PRI×CI	$(R_{570}-R_{530})/(R_{570}+R_{530})\times((R_{760}/R_{700})-1)$	Garrity et al. (2011)
Chlorophyll fluorescence			
Reflectance Curvature Index	CUR	$(R_{675}\times R_{690})/R_{683}^2$	Zarco-Tejada et al. (2000)
Stresses			
Health Index (534,698,704)	HI	$(R_{534}-R_{698})/(R_{534}+R_{698})-0.5\times R_{704}$	Mahlein et al. (2013)
Lichtenthaler	LIC_2	R_{440}/R_{690}	Lichtenthaler (1996)
Carter Indices	CTRI	R_{695}/R_{420}	Carter (1994)

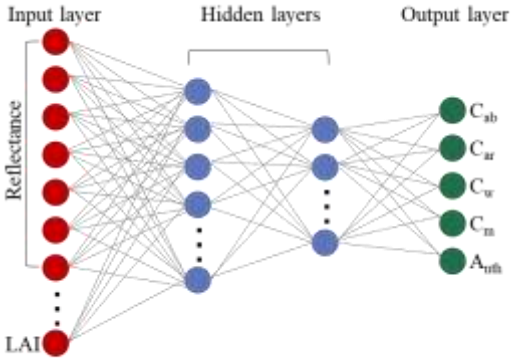

Fig. S6.1. *Architecture of the multilayer perceptron (MLP) regression model used to estimate key biophysical parameters, including chlorophyll content (C_{ab}), carotenoid content (C_{ar}), equivalent water thickness (C_w), dry matter content (C_m), and anthocyanin content (A_{nth}).*

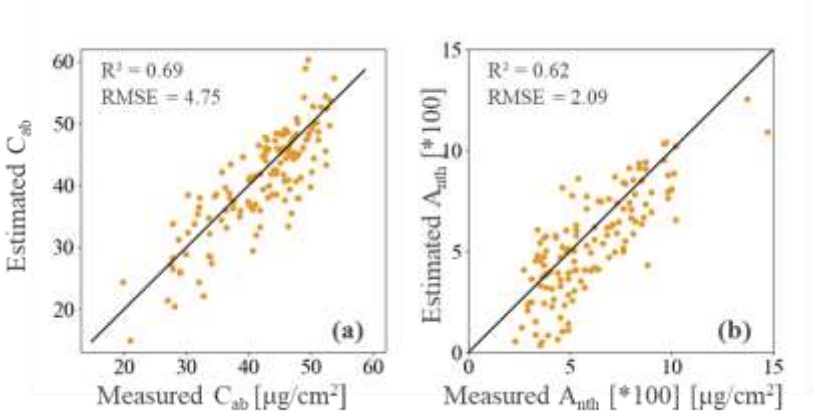

Fig. S6.2 *Correlation of measured vs. PROSAIL estimated C_{ab} and A_{nth}. A total of 132 samples from site A (12 plots × 11 times) were evaluated.*

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%**

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.

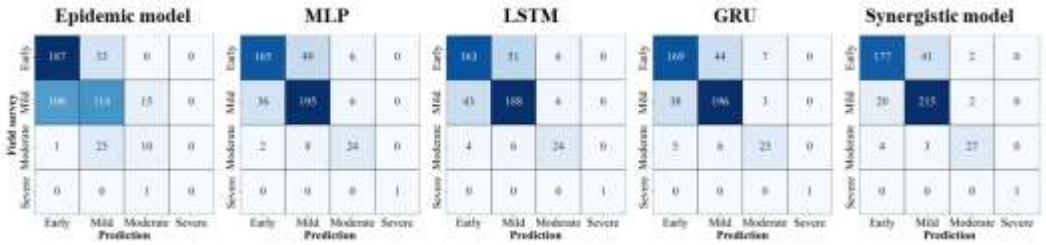

Fig.S6.3. *Confusion matrices for different models on 2021 test set*

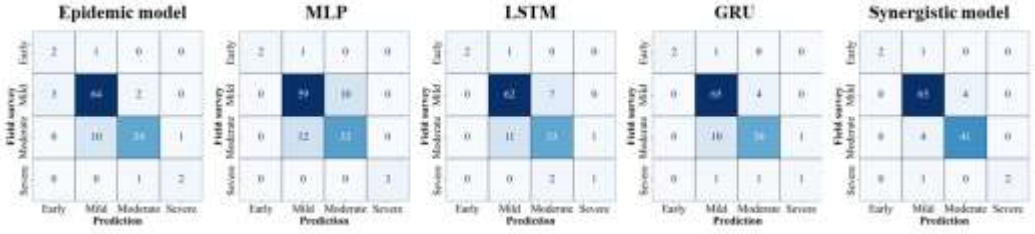

Fig.S6.4. *Confusion matrices for different models on 2023 test set*

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