Utilizing UAV-based RGB and Multispectral Imagery to Predict Yield-Contributing Physiological Parameters of Cotton

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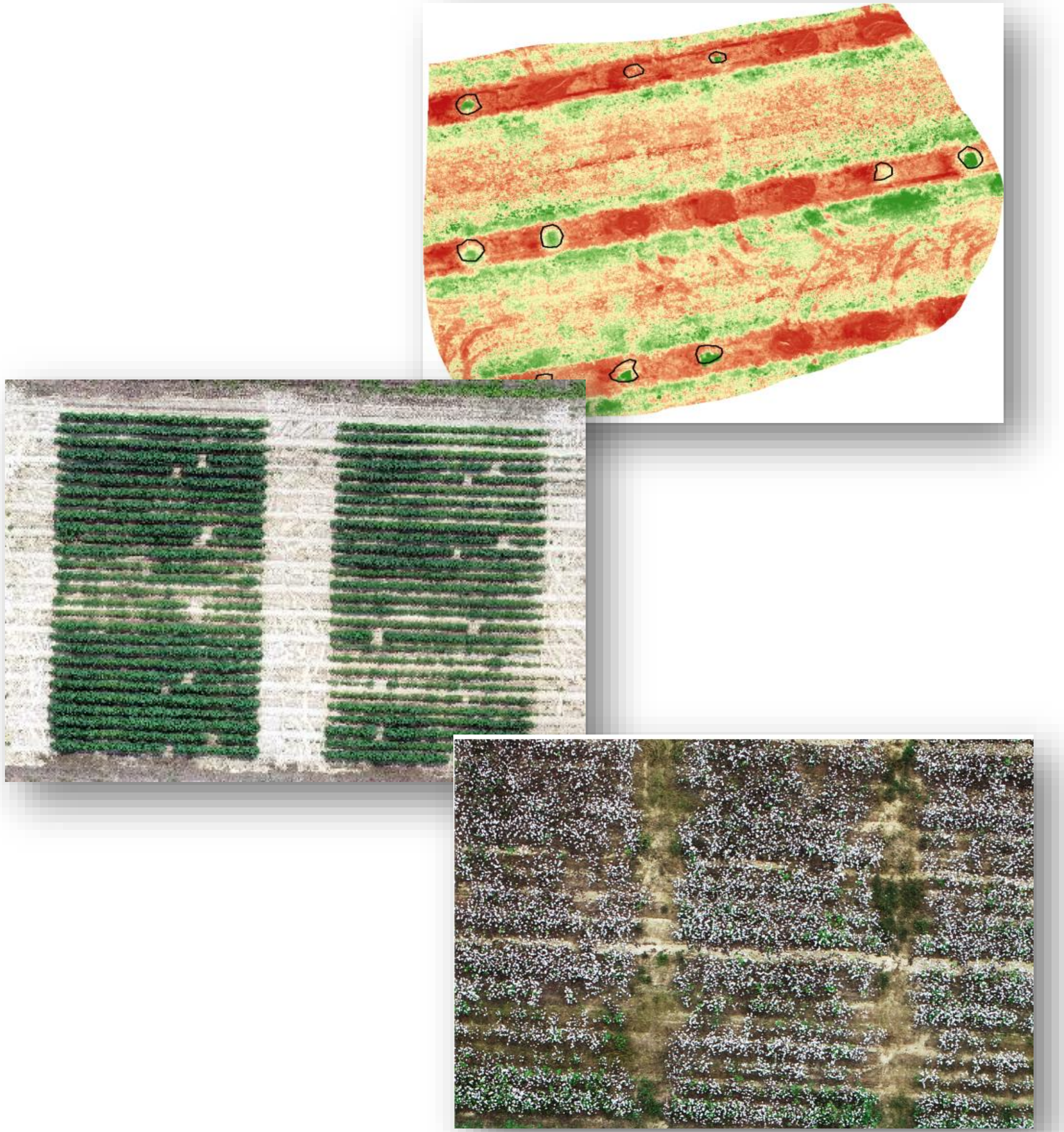
Open Science Inspires
2023 ASA - CSSA - SSSA INTERNATIONAL ANNUAL MEETING
October 29-November 1 | St. Louis, MO
Agronomy | Crop Science | Soil Science

Remote Sensing

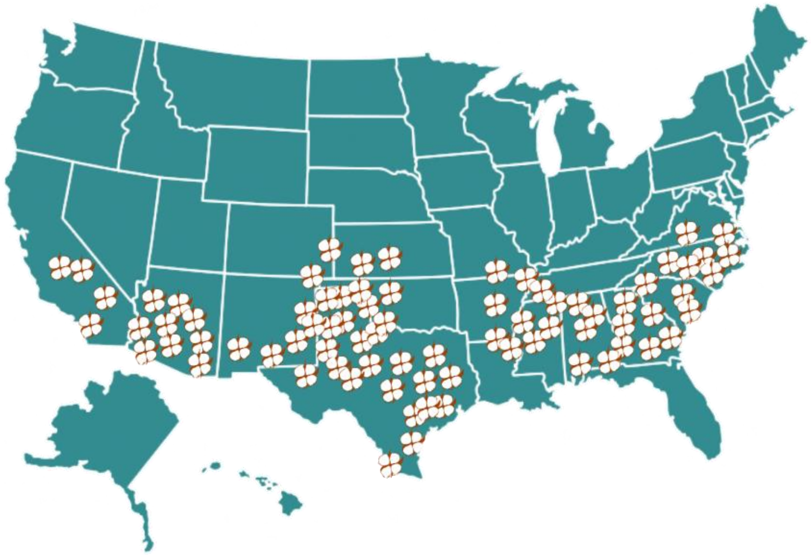
Unmanned Aerial Systems (UAS) application in agriculture:

- Mapping field variability
- Crop species classification
- Growth monitoring
- Stress detection
- Crop phenotyping
- Yield prediction



Importance of Cotton

- Cotton has global importance as a commercial crop and substantial contribution to clothing and textile industry.



❑ Among top 3 cotton-producing countries

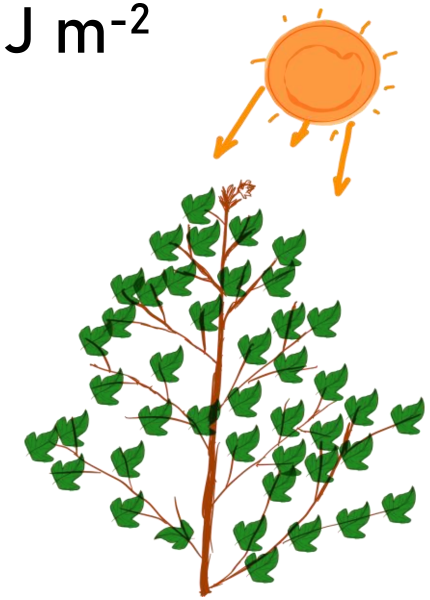
❑ Contribute 35% of global cotton export (USDA 2021)

Yield Function

Yield = IPAR x RUE x HI (Monteith, 1972)

IPAR

- Intercepted Photosynthetically Active Radiation
- MJ m^{-2}

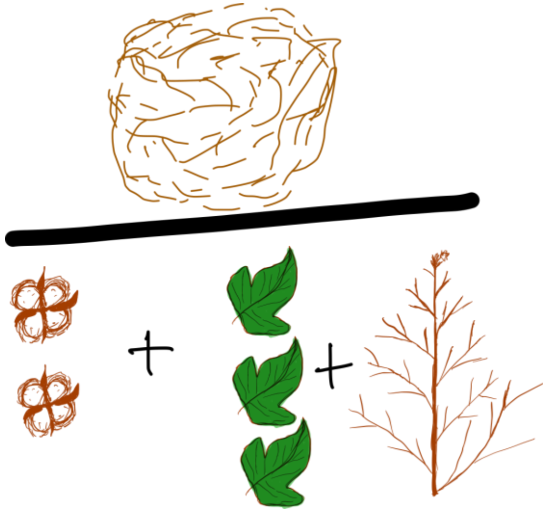


RUE

- Radiation Use Efficiency
- g MJ^{-1}

HI

- Harvest Index



Hypothesis

- UAV-based RGB and multispectral imagery can be utilized to predict in-season physiological parameters in cotton.

Objectives

- To develop and validate models to estimate $IPAR_f$, RUE, and HI throughout the season
- To estimate cotton lint yield using cotton fiber index (CFI)
- To investigate the potential of biomass and lint yield estimates to predict cotton harvest index (HI)

Experimental Layout

Study Year:

- 2021, 2022

Cultivar:

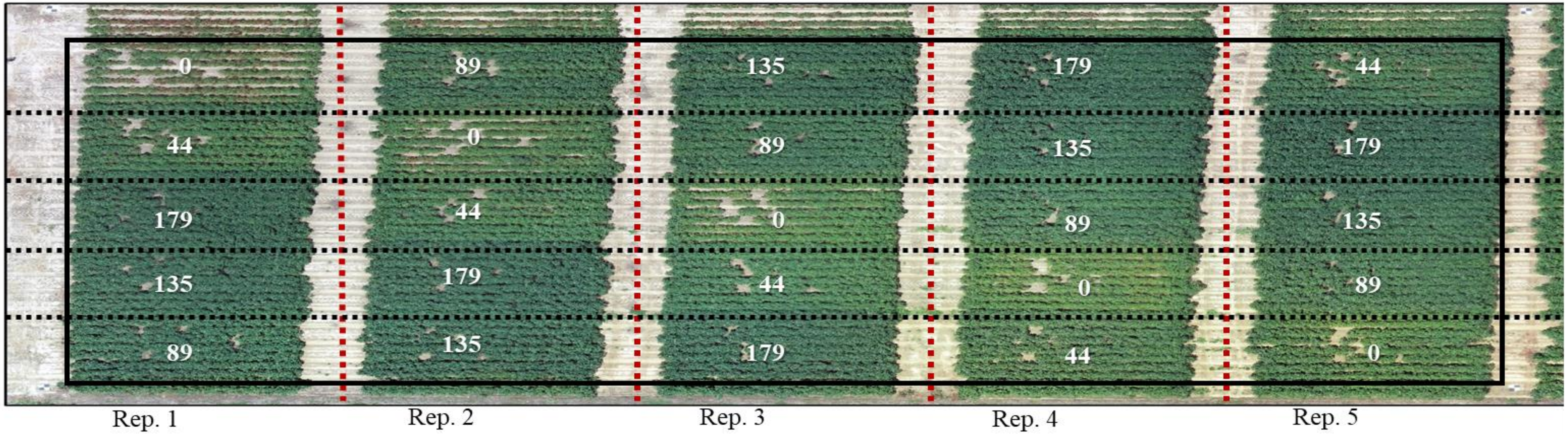
- DP 1646

Nitrogen Treatments:

- 0 kg N ha^{-1}
- 44 kg N ha^{-1}
- 89 kg N ha^{-1}
- 134 kg N ha^{-1}
- 179 kg N ha^{-1}

Design:

- RCBD
- 5 replications
- 6 and 8 row plots



Measurements

Planting Date
06/01/2021
04/26/2022

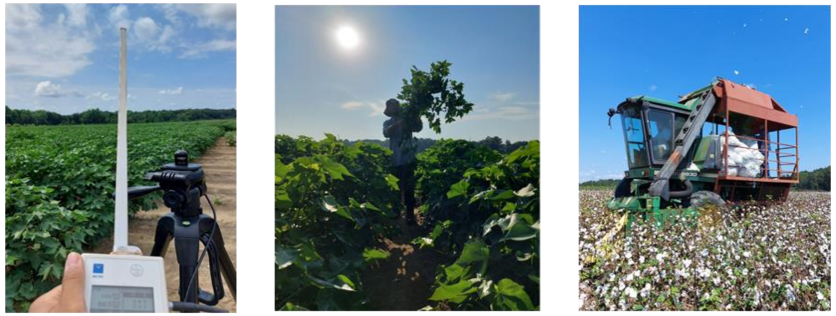
42-43 DAP | 56-58 DAP | 69-74 DAP | 93-97 DAP | 114-115 DAP

Harvest Date
10/22/2021
09/21/2022

1. UAV Imagery

- Multispectral imagery using MicaSense RedeEdge-MX^{TM} Camera on DJI Inspire 2
- RGB imagery using DJI Phantom 4 Pro V2.0

2. Physiological measurements

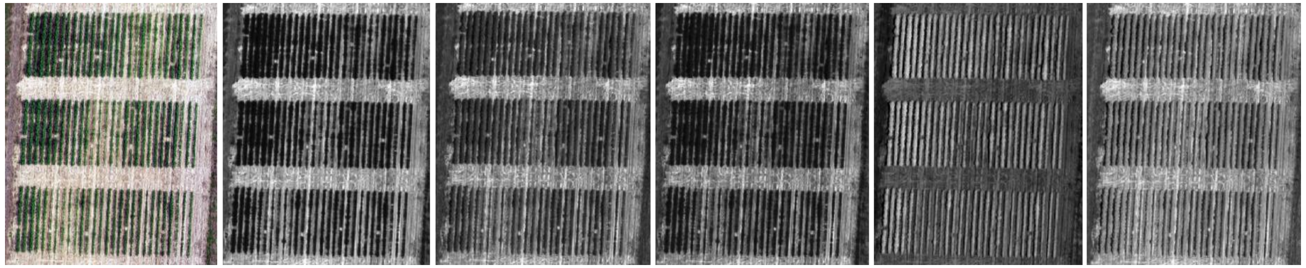


- Growing degree days and IPAR$_f$
- Above-ground biomass
- RUE
- Lint yield (Machine harvested) and HI

Image Processing and Analysis

- Image Processing: Pix4D® software was used to obtain mosaic images combining imagery for each sample date.

PIX4D

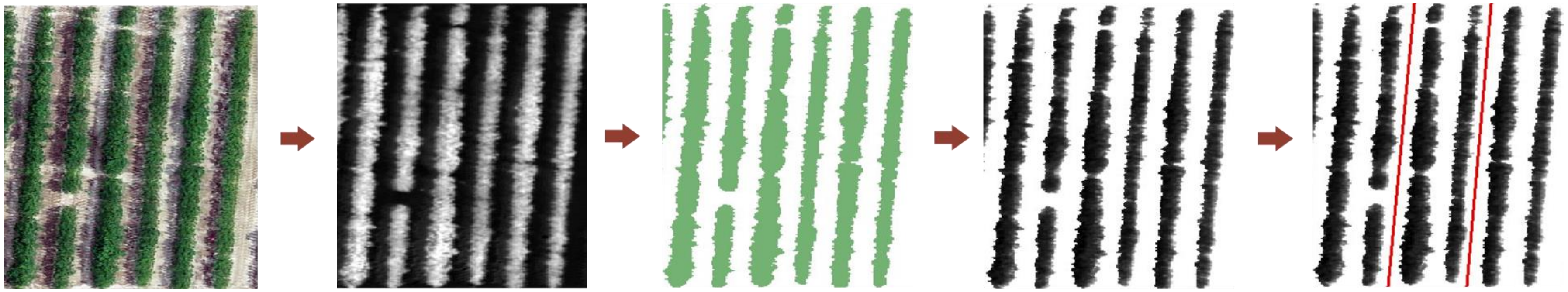


RGB Red Green Blue NIR Rededge

Sample aerial images at 56 DAP (2021) from 45 m height.

- Imagery Analysis: Arc Map 10.7.1® was used to extract reflectance index for vegetation indices (VI's) computation.

ArcGIS

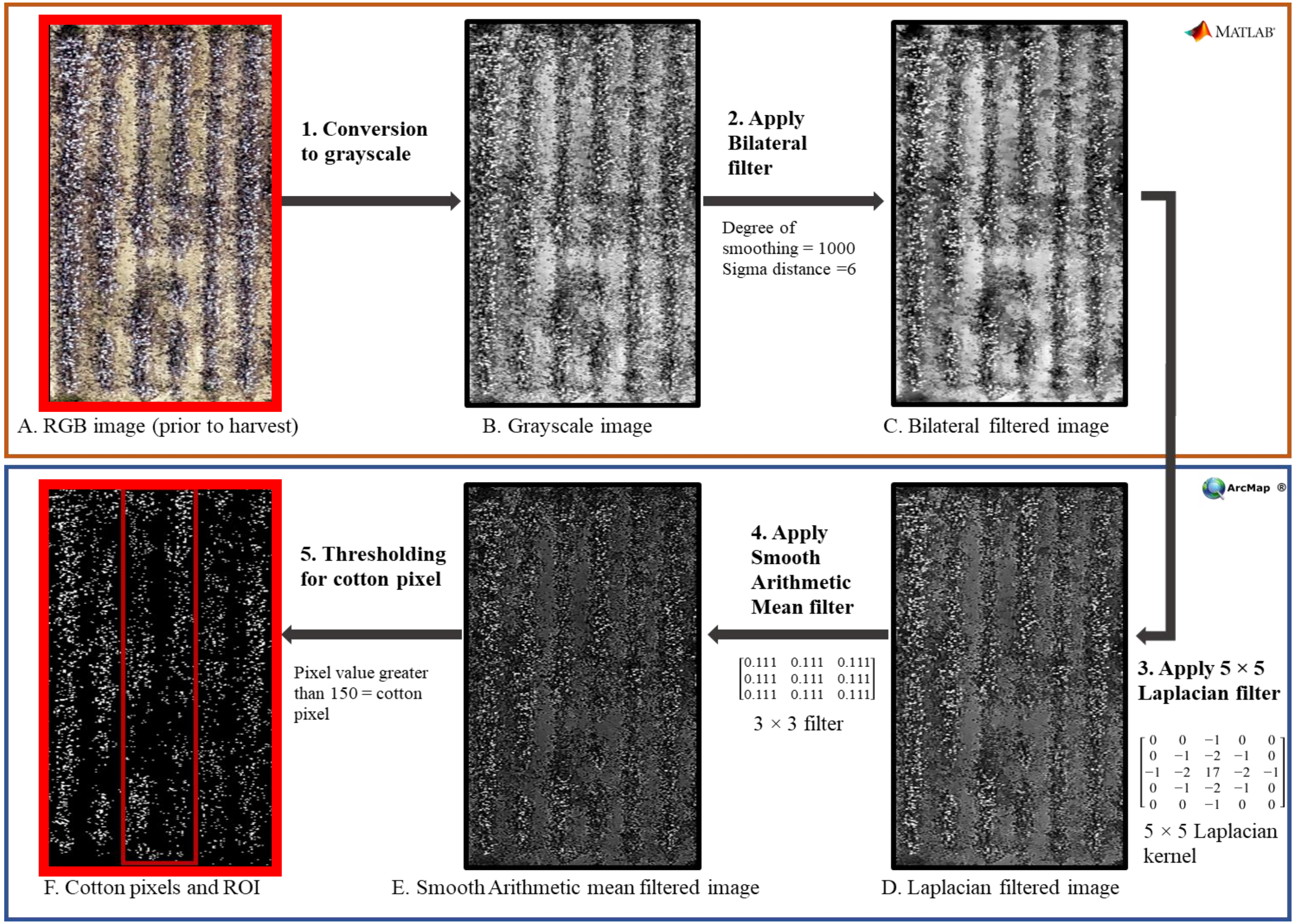


RGB Aerial Image → Classified Aerial Image → Binary Mask Layer → Red Band without soil → Region of Interest

Vegetation Indices (20 total)

Abbreviated VI's	Nomenclature	Formula
ExG	Excessive Greenness	$2 \times G - R - B$
NDVI	Normalized Difference Vegetation Index	$\frac{NIR - R}{NIR + R}$
ExG*NDVI	ExG multiplied by NDVI (Classification Index)	$(2 \times G - R - B)\left(\frac{NIR - R}{NIR + R}\right)$
GNDVI	Green Normalized Difference Vegetation Index	$\frac{NIR - G}{NIR + G}$
NDRE	Normalized Difference Red Edge Index	$\frac{NIR - RE}{NIR + RE}$
RVI	Ratio Vegetation Index	$\frac{NIR}{R}$
SCCCI	Simplified Canopy Chlorophyll Content Index	$\frac{NDRE}{NDVI}$
RE/R	Red edge and Red Ratio	$\frac{RE}{R}$
GRVI	Green Ratio Vegetation Index	$\frac{NIR}{G}$

Cotton Fiber Index (CFI)



Cotton Fiber Index (Huang et al., 2016)

$$= \frac{\text{Number of white pixels in ROI}}{\text{Total number of pixels in ROI}}$$

Physiological Measurements

- Growing Degree Days (GDDs) =

$$\sum_{i=1}^{n}\left[\frac{\text{Max. Temperature °C}_i + \text{Min. Temperature °C}_i}{2} - \text{Base Temperature °C}\right]$$

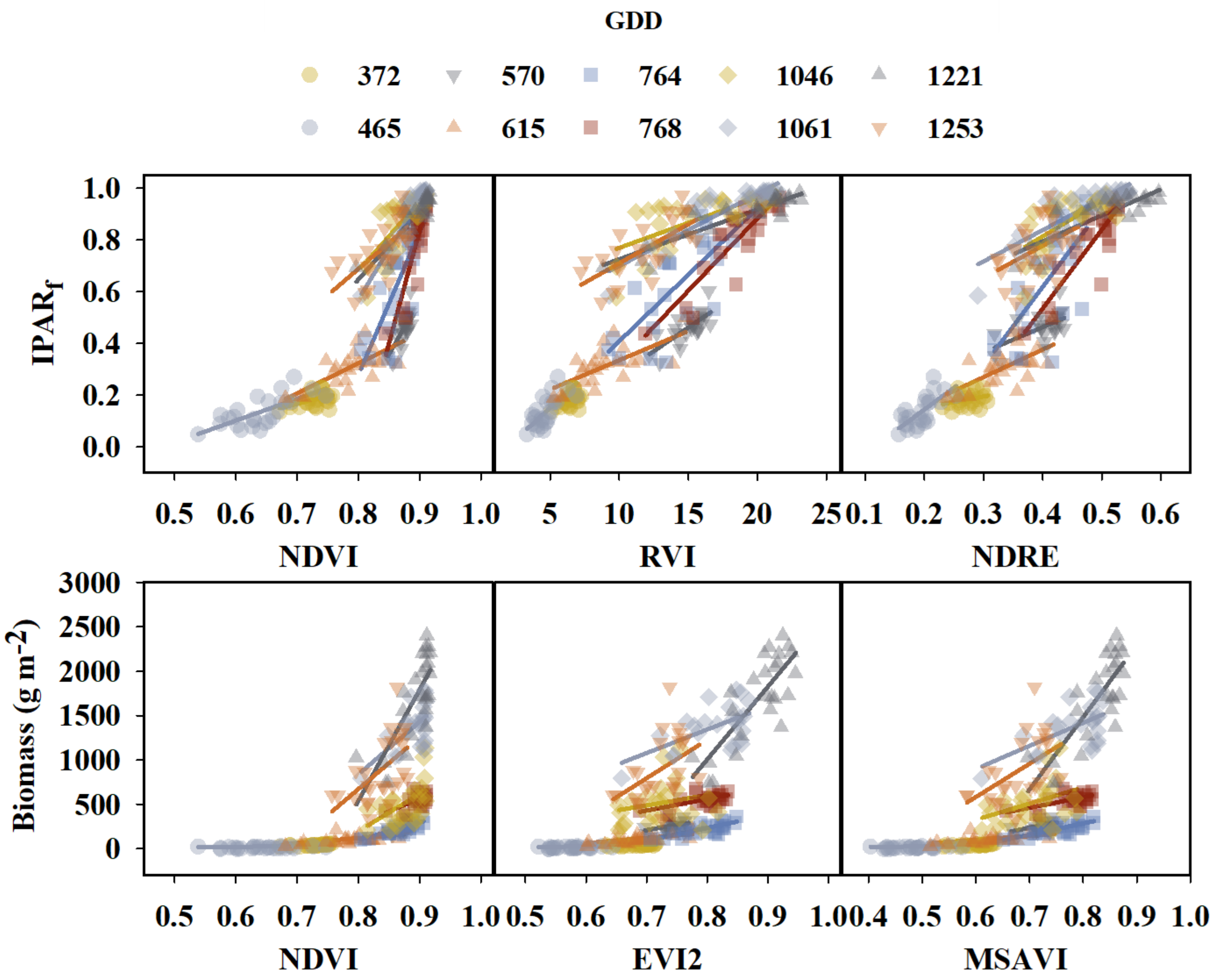
- $\text{IPAR}_f = \dfrac{\text{PAR above} - \text{PAR below}}{\text{PAR above}}$

- $\text{RUE (g MJ}^{-1}) = \dfrac{(\text{Dry biomass}_n - \text{Dry biomass}_1)}{(\text{Cumulative IPAR}_n - \text{Cumulative IPAR}_1)}$

- HI = Lint yield / Maximum biomass

Model Development

- $IPAR_f$ or Biomass = f (VI and GDD)
  - $IPAR_f$ always lies between 0 and 1
  - Biomass is strictly positive
- RUE = f (average VI)
- Lint yield = = f (CFI)
- HI = $\dfrac{\text{CFI−based lint yield}}{\text{VI−based maximum biomass}}$



Statistical Analysis

Data Analysis:

- Generalized Regression Models:
  - Beta regression for $IPAR_f$
  - Gamma regression for biomass
  - Standard linear regression for RUE
- 60:40 ratio for training and independent validation dataset
- Model Performance:

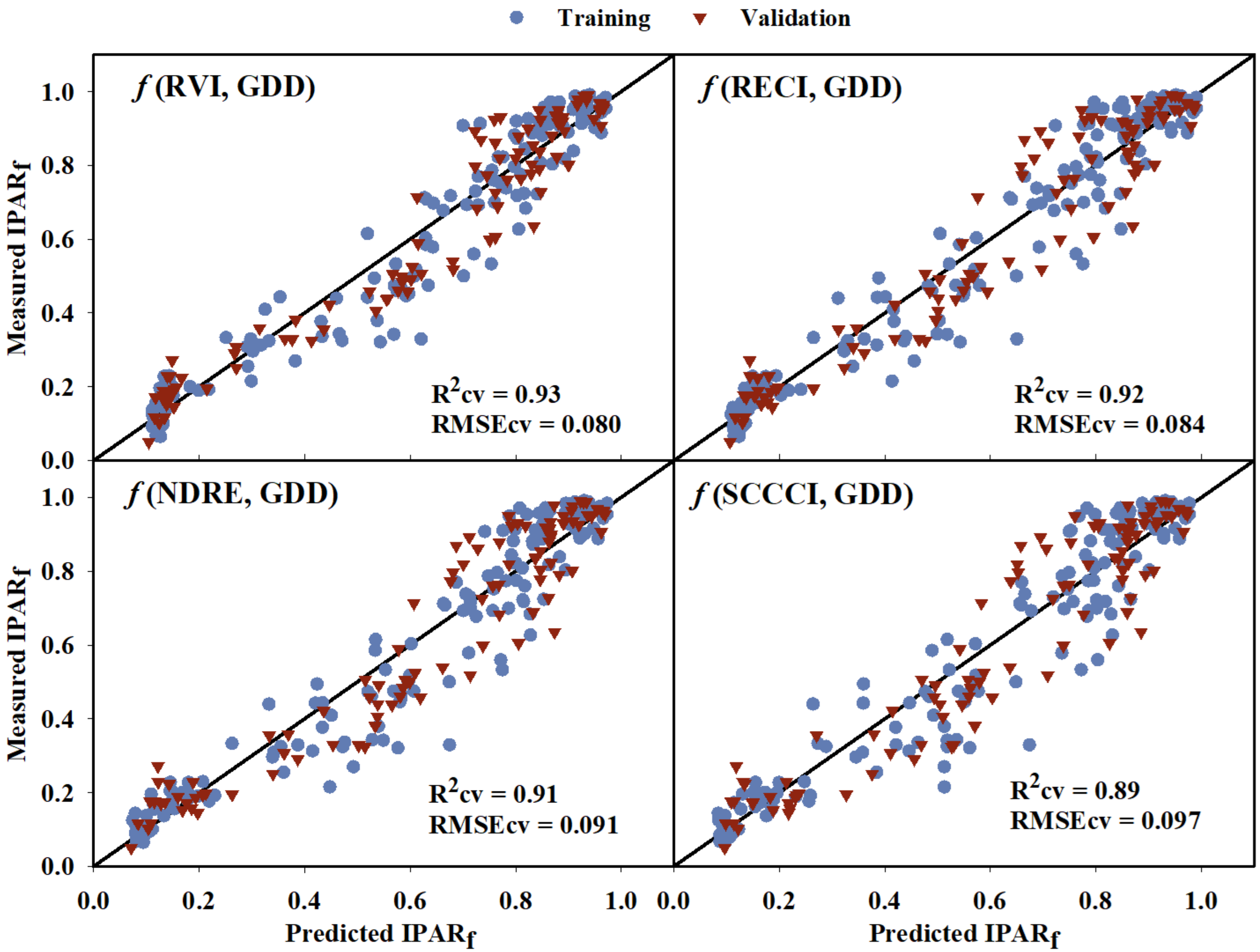
  Generalized R^2, AICc, and BIC for training data
- Cross-validation: R^2 and RMSE

Software:

- JMP® Pro 16.0.0 for training and cross-validation
- Sigmaplot 15.0 (Systat Software Inc., San Jose, CA) for graphs

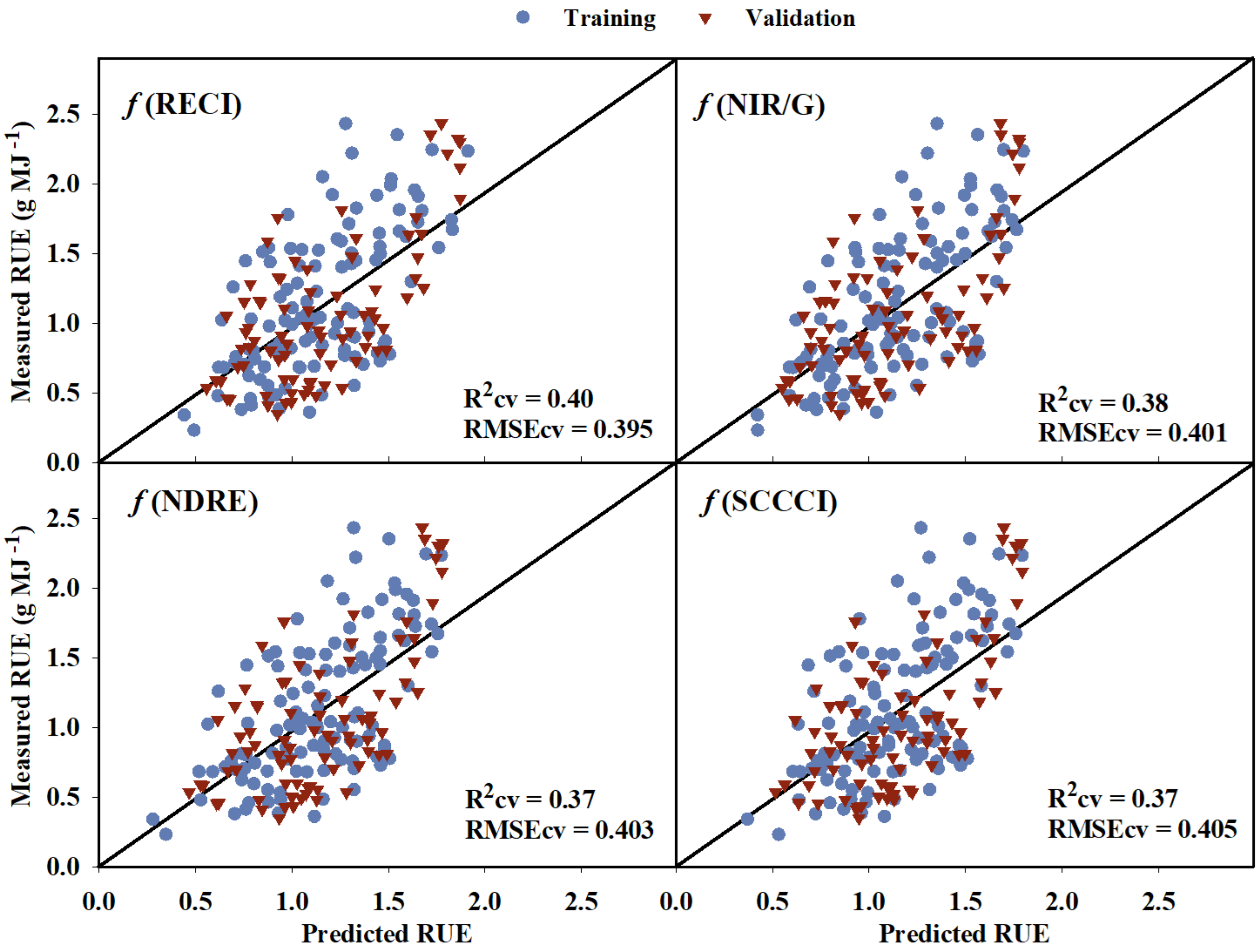
Results

Fraction of IPAR



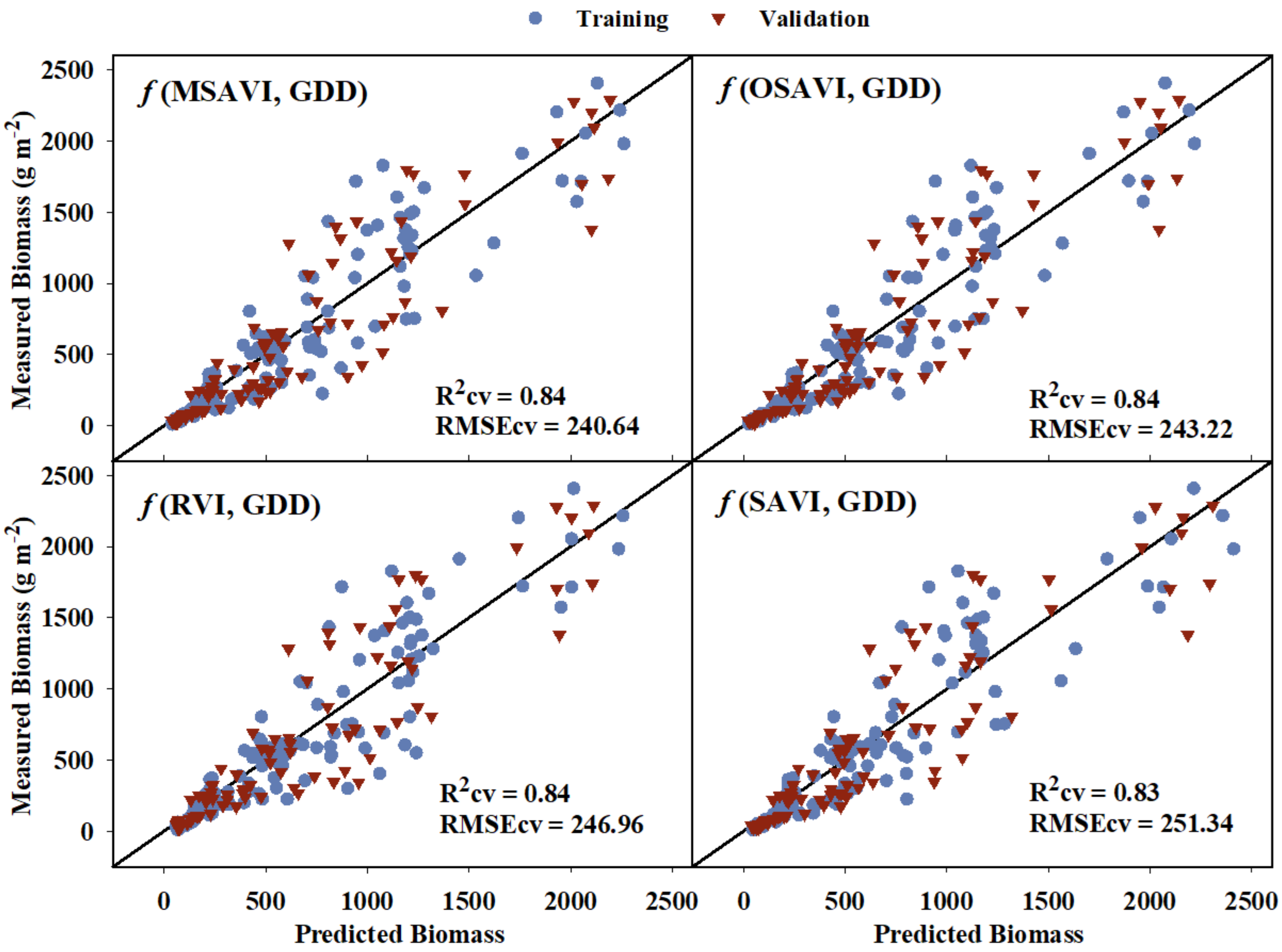
- Ratio Vegetation Index (RVI)
- Red-edge Chlorophyll Index (RECI)
- Normalized Differences Red-edge Index (NDRE)
- Simple Canopy Chlorophyll Content Index (SCCCI)

RUE



- Red-edge Chlorophyll Index (RECI)
- NIR to Green Ratio (NIR/G)
- Normalized Differences Red-edge Index (NDRE)
- Simple Canopy Chlorophyll Content Index (SCCCI)

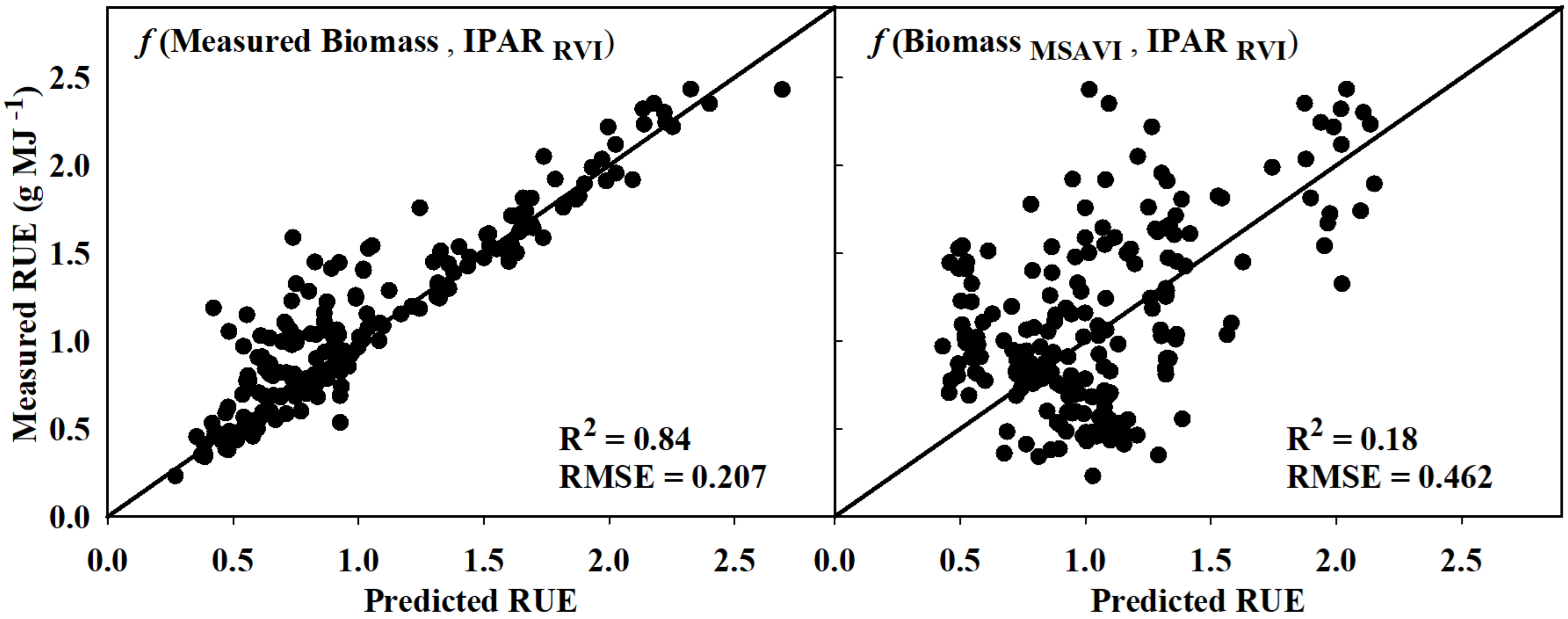
Biomass



- Modified Soil Adjusted Vegetation Index (MSAVI)
- Optimized Soil Adjusted Vegetation Index (OSAVI)
- Ratio Vegetation Index (RVI)
- Soil Adjusted Vegetation Index (SAVI)

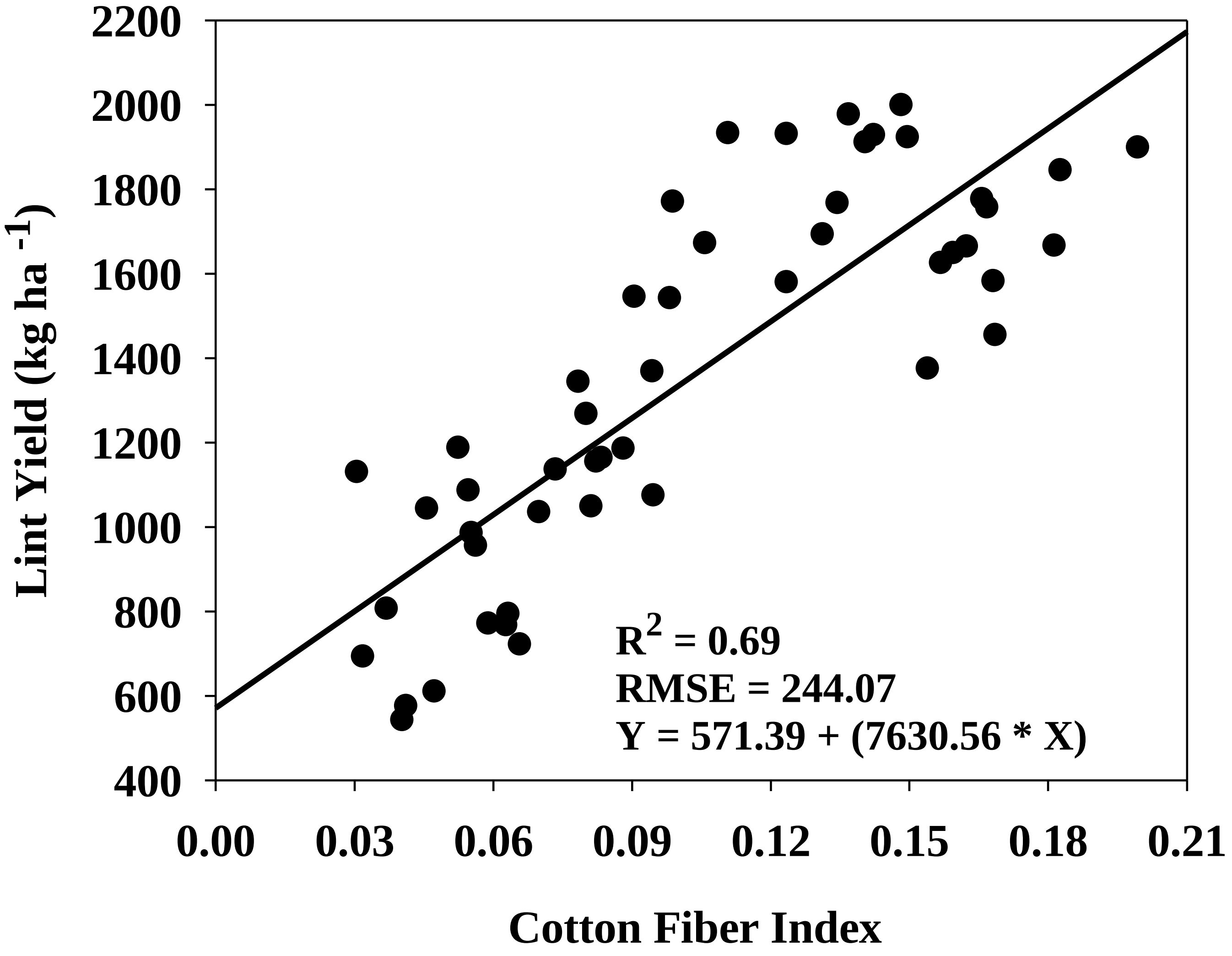
RUE

Biomass = IPAR × RUE



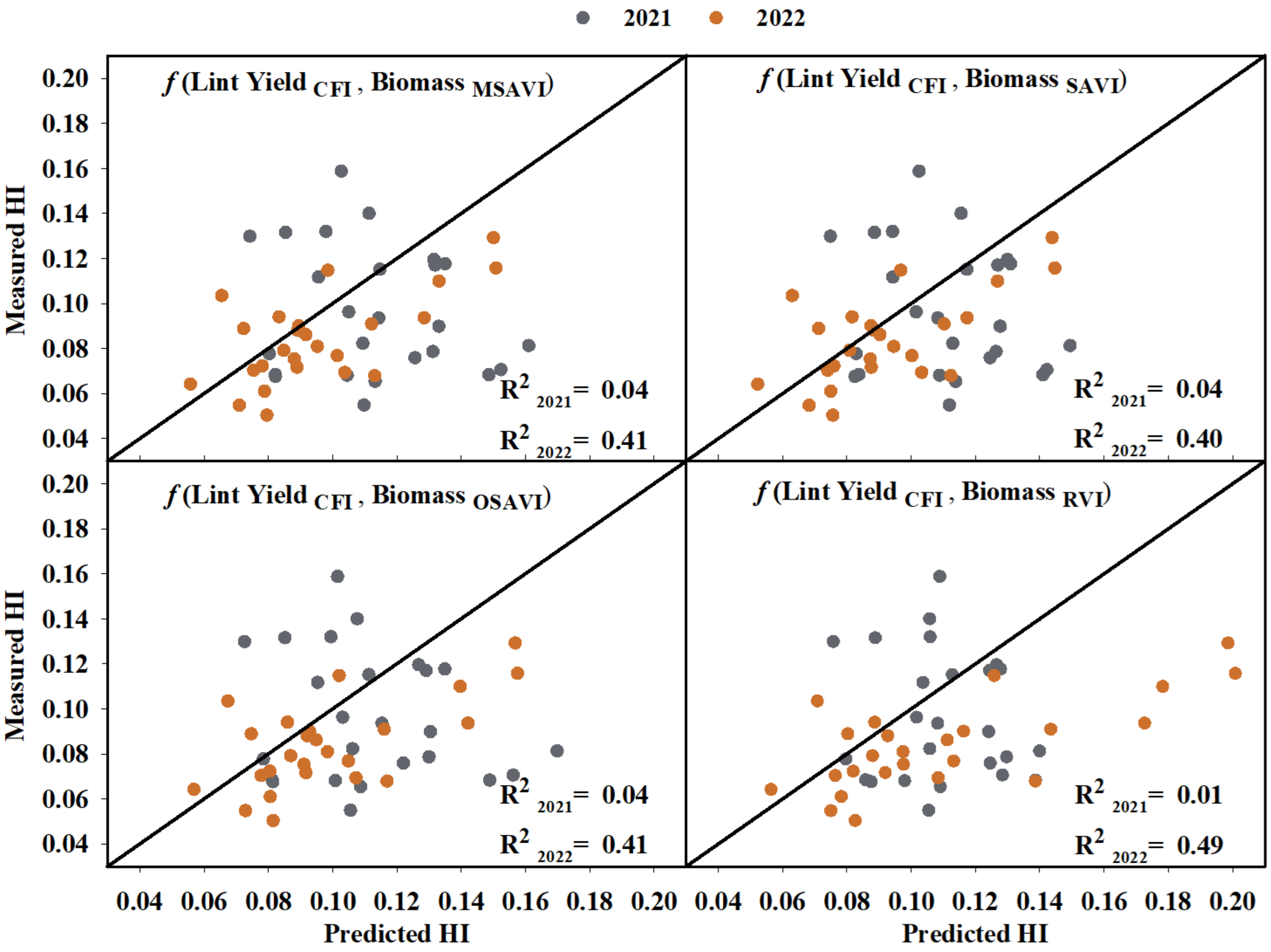
- $\frac{\text{Actual biomass}}{\text{RVI–based IPAR}}$
- $\frac{\text{MSAVI–based biomass}}{\text{RVI–based IPAR}}$

Lint Yield



2200
2000
1800
1600
1400
1200
1000
800
600
400
Lint Yield (kg ha -1)
0.00
0.03
0.06
0.09
0.12
0.15
0.18
0.21
Cotton Fiber Index
R2 = 0.69
RMSE = 244.07
Y = 571.39 + (7630.56 * X)

Harvest Index



- HI estimates = $\frac{\text{CFI-based Lint yield}}{\text{VI-based max. biomass}}$
- Not a significant relationship for both years combined
- Significant for 2022 growing season.

Conclusions

- $IPAR_f$ -
  - RVI, RECI, NDRE, and SCCCI in integration with GDD were able to predict 94% of variation in $IPAR_f$.
- RUE -
  - Average RECI, NIR/G, NDRE, and SCCCI were moderately (R^2 = 0.40) related with RUE.
  - Mechanistic model to predict RUE with actual biomass and RVI-based IPAR estimates had higher R^2 value (0.84).
- Lint yield- Cotton Fiber Index (CFI) explained 69% of variation in lint yield.
- HI –
  - Prediction of HI is possible with more accurate estimation of lint yield and above-ground biomass.

Applications, Limitations, and Future research

- Applications -
  - Agronomic decision making to prevent significant yield loss during limited nitrogen and excessive irrigation circumstances.
  - High-throughput phenotyping of cotton genotypes for yield determining physiological parameters.
- Limitations -
  - Single cotton cultivar and data within GDD range of 372 to 1253 GDD.
  - Flight height from 45m may not fully capture cotton bolls present in middle section of canopy.
- Future research –
  - Inclusion of training data from different cotton cultivars across multiple production environment.
  - Investigate the influence of flight height and sensor resolution for accurate estimation in cotton lint yield.

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UNIVERSITY OF GEORGIA

COTTON PHYSIOLOGY LAB

UGA Digital Ag

Cotton Incorporated

GEORGIA COTTON COMMISSION

THANK YOU!!

frontiers | Frontiers in Plant Science

TYPE Original Research
PUBLISHED 19 September 2023
DOI 10.3389/fpls.2023.1248152

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Estimating yield-contributing physiological parameters of cotton using UAV-based imagery

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