Imaging Alfalfa to Predict Yield & Quality & Impacts of Water Deficits Using Innovative Overhead Irrigation Systems

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Alfalfa
NAFA
U.S. Alfalfa Farmer Research Initiative

2022 NAAIC Meetings, Lansing, MI

THE UNIVERSITY OF CALIFORNIA DAVIS
UCDAVIS



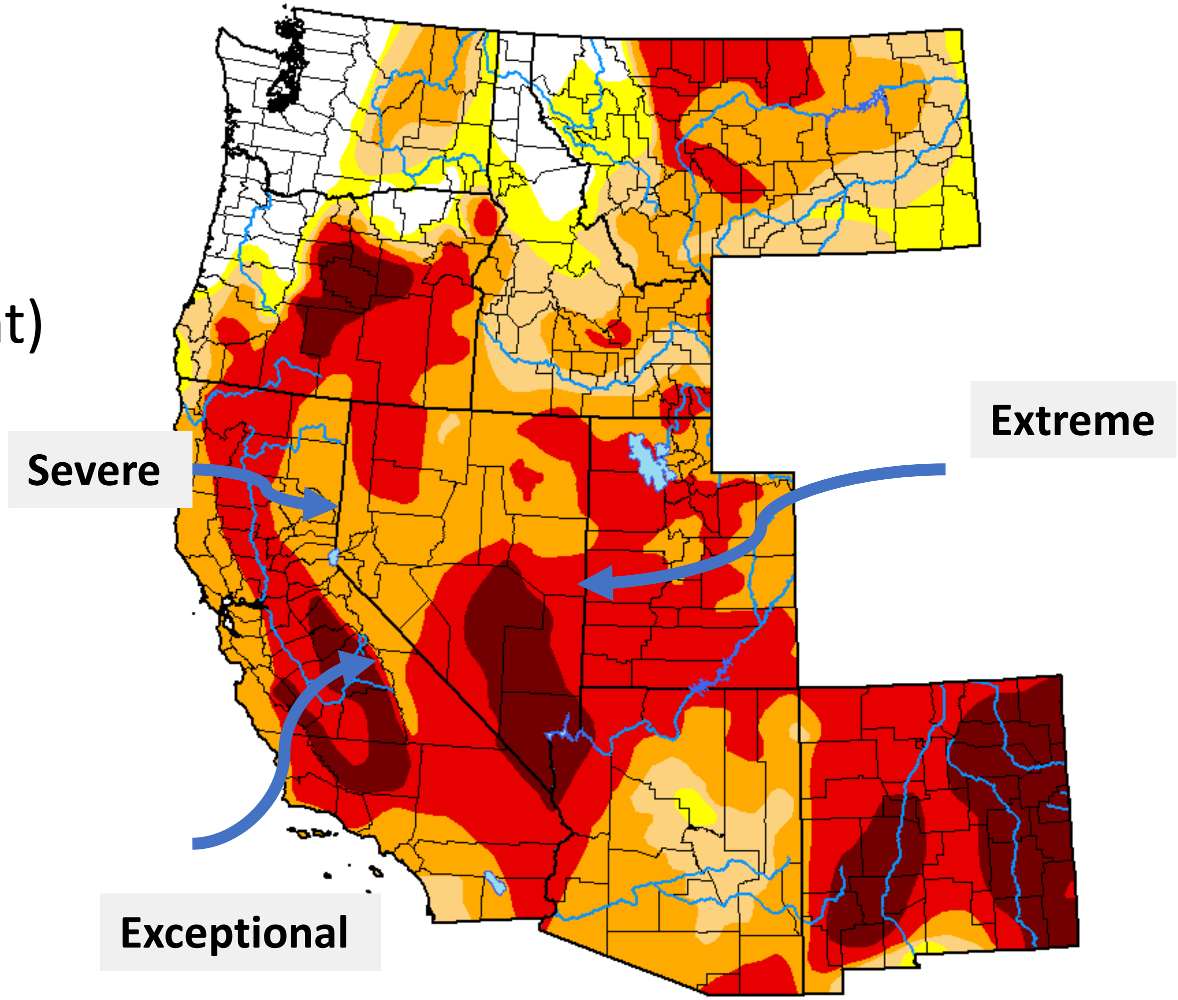


VALLEY

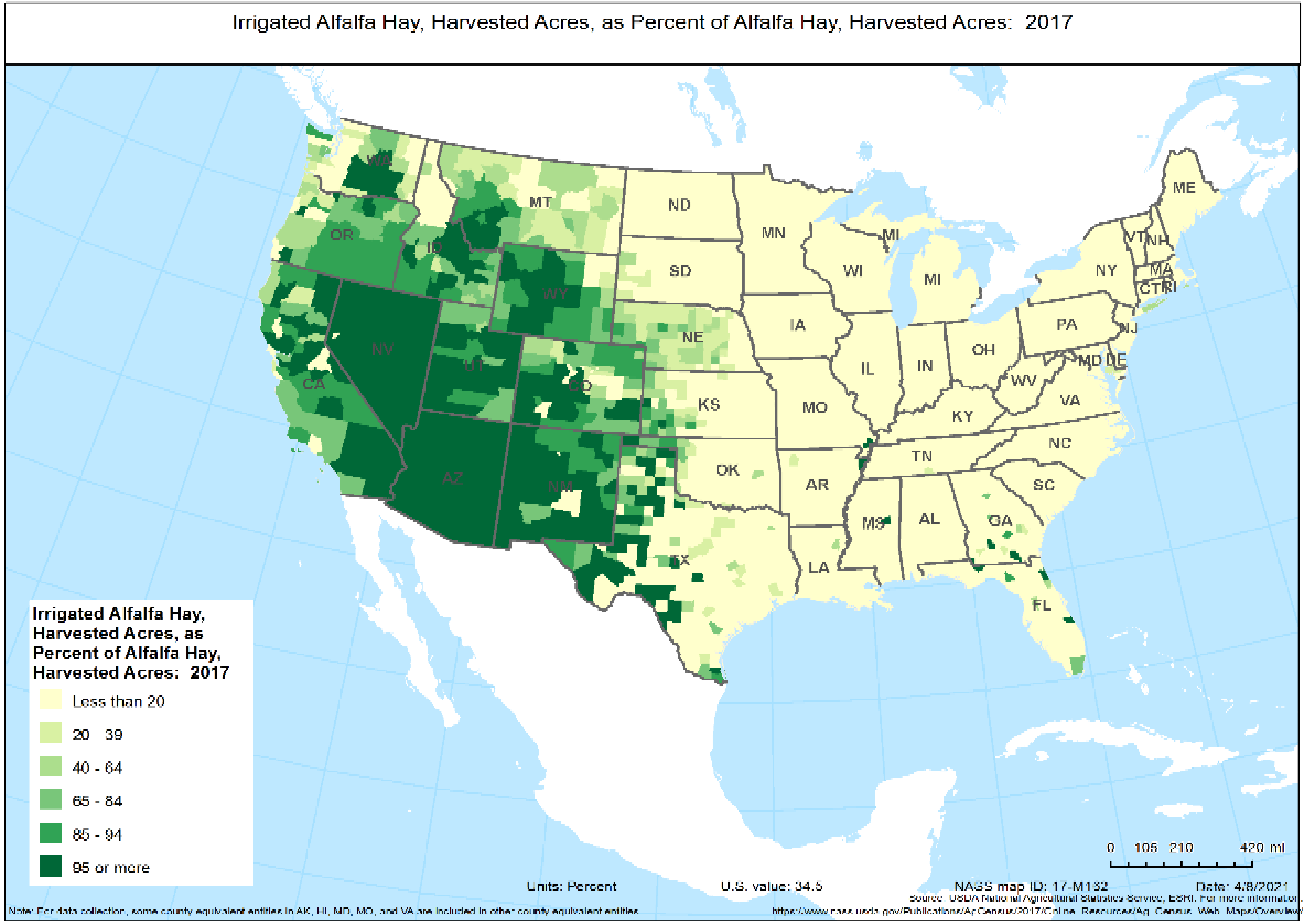
Context:

- Severe challenges:
  - ‘Exceptional’ Drought –water supply limits
  - Competition for Water (crops, environment)
  - Water Transfers to other users
  - Long term coping with deficits
- Strategies to Cope:
  - ‘Triage’ (leaving old fields behind)
  - Abandoned fields
  - Deficit Irrigation
  - Technology Improvements

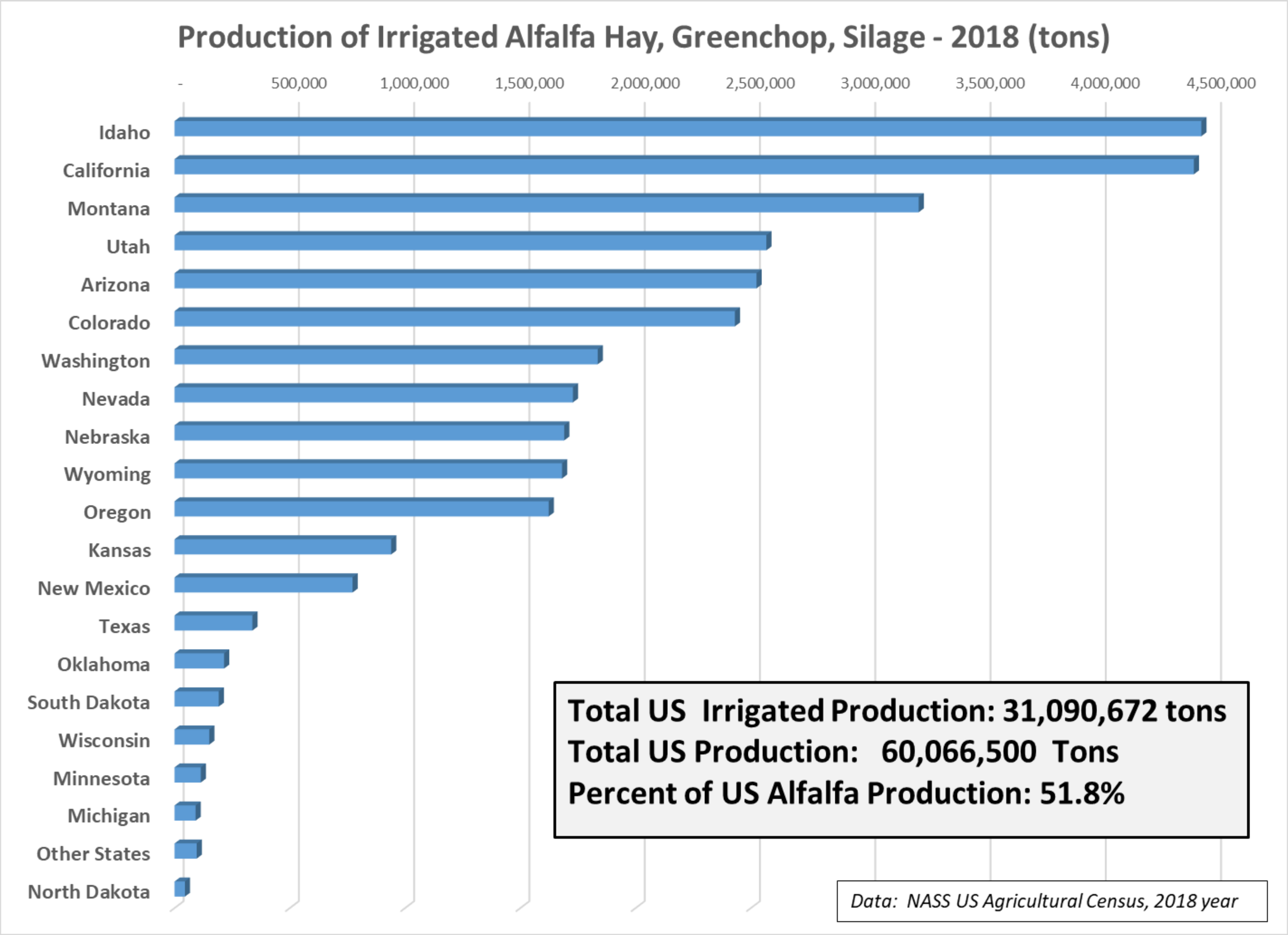
Current Situation (June 2, 2022)



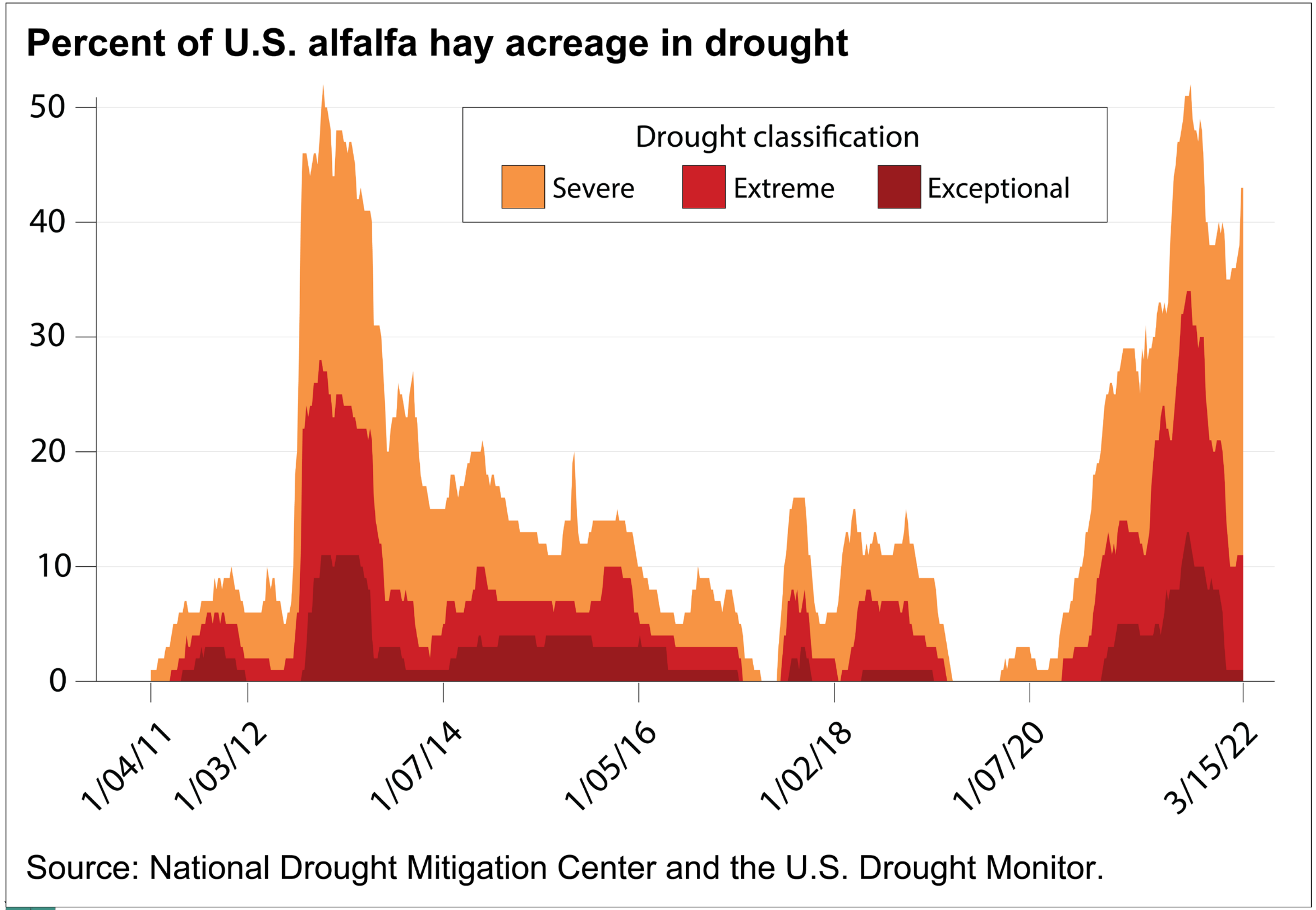
Irrigated Alfalfa



2022 NAAIC Meetings, Lansing, MI


Production of Irrigated Alfalfa Hay, Greenchop, Silage - 2018 (tons)
-
500,000
1,000,000
1,500,000
2,000,000
2,500,000
3,000,000
3,500,000
4,000,000
4,500,000
Idaho
California
Montana
Utah
Arizona
Colorado
Washington
Nevada
Nebraska
Wyoming
Oregon
Kansas
New Mexico
Texas
Oklahoma
South Dakota
Wisconsin
Minnesota
Michigan
Other States
North Dakota
Total US Irrigated Production: 31,090,672 tons
Total US Production: 60,066,500 Tons
Percent of US Alfalfa Production: 51.8%
Data: NASS US Agricultural Census, 2018 year

Percent US Alfalfa impacted by drought



>50% of Hay acres (US), spring/summer of 2022 (NDMC, and ERS). (April, 2022)

Response to Water Limits in Irrigated Alfalfa:

- Need for Innovative techniques to improve water-application efficiency (Overhead Systems, Pivots, Linears, Subsurface Drip, Automated Surface Systems)
- LESA/LEPA (Low Elevation, Low Pressure, Low losses)- nozzling systems & close spacings.
- Deficit Irrigation (How to do partial season applications when not enough water).
- Imaging/Monitoring. Effects of drought and deficits on yields. Estimating ET and yield impacts remotely.
- Water transfers to other users (credits to farmers)

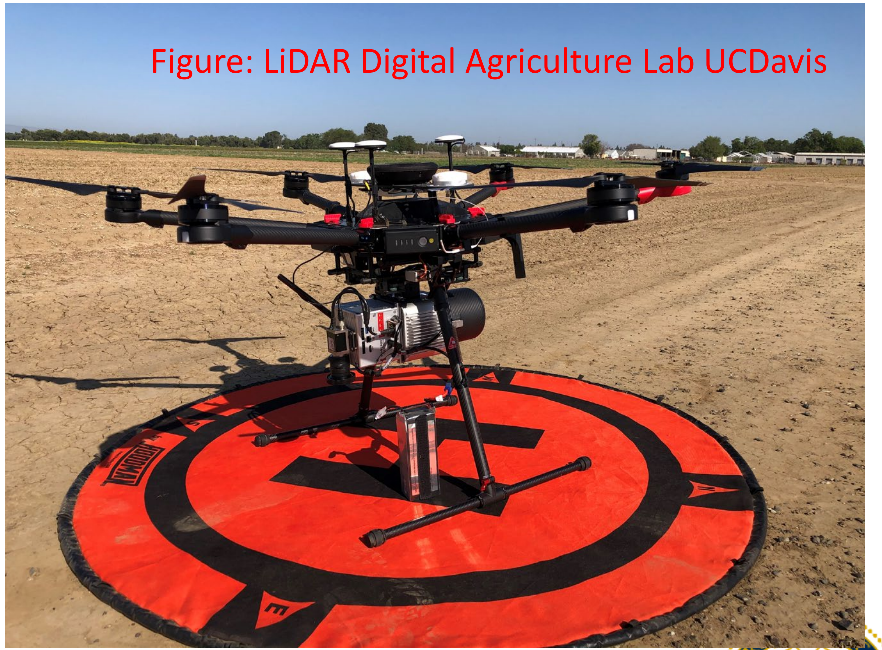
Linear Overhead Irrigation

Objectives:

- Yield response to deficits
- Develop an image to yield relationship using multispectral and LiDAR imagery for alfalfa
- Create a yield and quality map for understanding spatial temporal variability
- Identify the best models to estimate alfalfa yield and quality

Crop Imaging:

- Analysis of Yield Limitations in fields (field diagnostic tool) to understand the variability in yield due to abiotic stresses.
- Less labor involved as compared with traditional sampling methods.
- The results may be provided in short time for field management



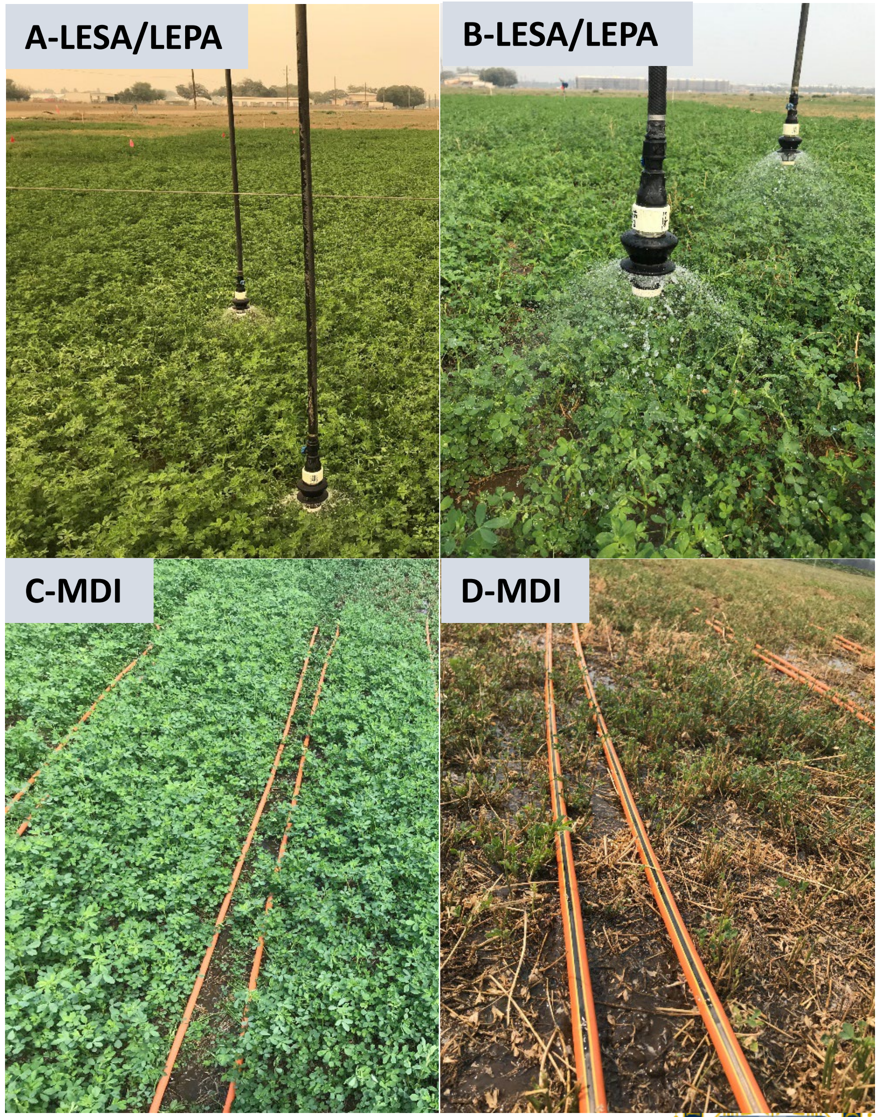
Source: Chandel et al., 2021, Dvorak et al., 2021, Tang et al., 2021

Material and Methods: (Year 2019 and 2020)

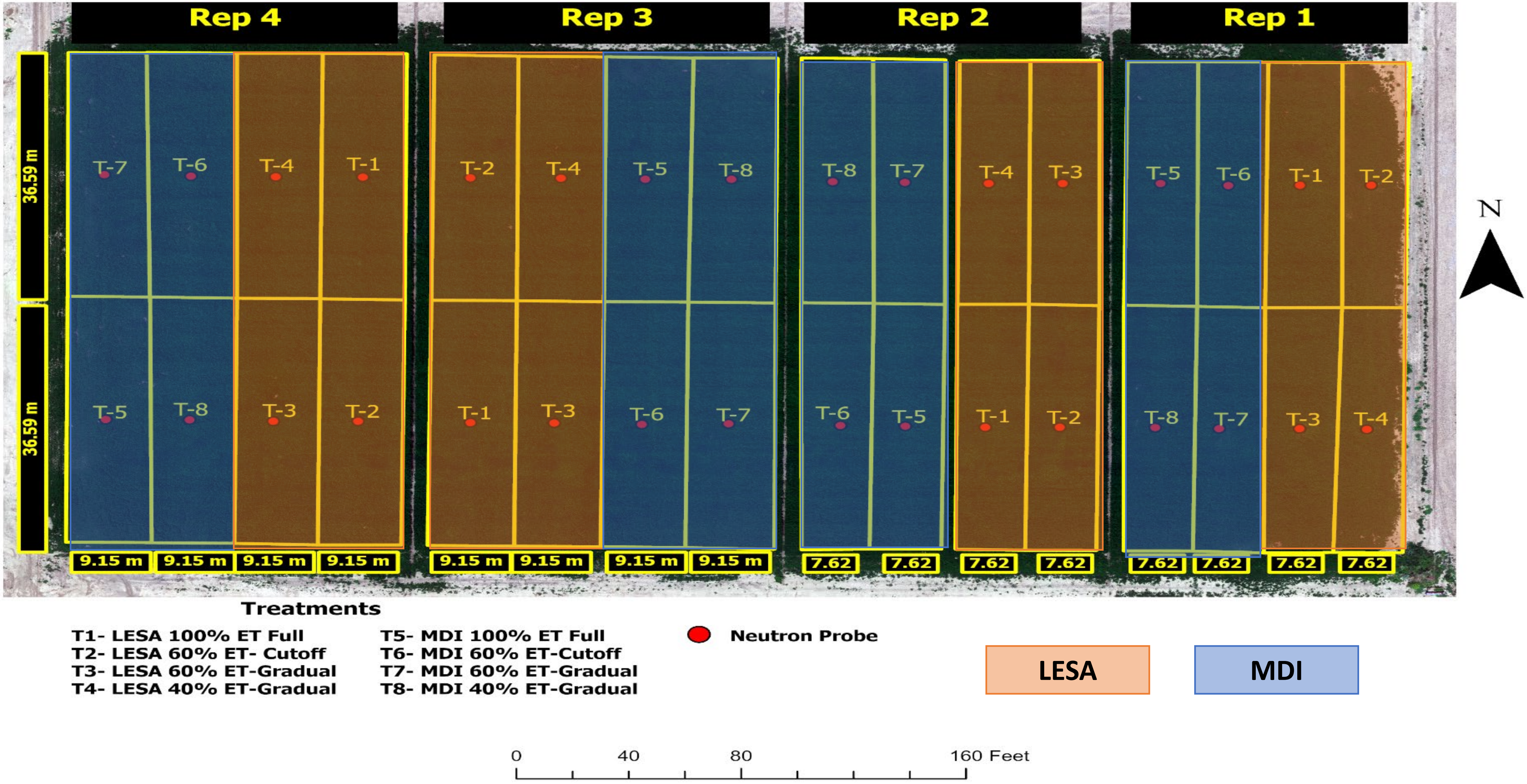
Source: Gull et. al., 2021

LESA/LEPA
- 100% ET Full
- 60% ET-Cutoff
- 60% ET-Gradual
- 40% ET-Gradual

MDI
- 100% ET Full
- 60% ET-Cutoff
- 60% ET-Gradual
- 40% ET-Gradual



Davis Alfalfa Overhead Irrigation Experiment 2019-2020 Plot Layout



Advantages and Disadvantages

LESA/LEPA

Low Elevation Spray Application
Low Energy Precision Application

- Close to the ground
- Efficiency ~ 88% and 97%
- Wind Losses minimum
- 18% reduced pumping cost

MDI

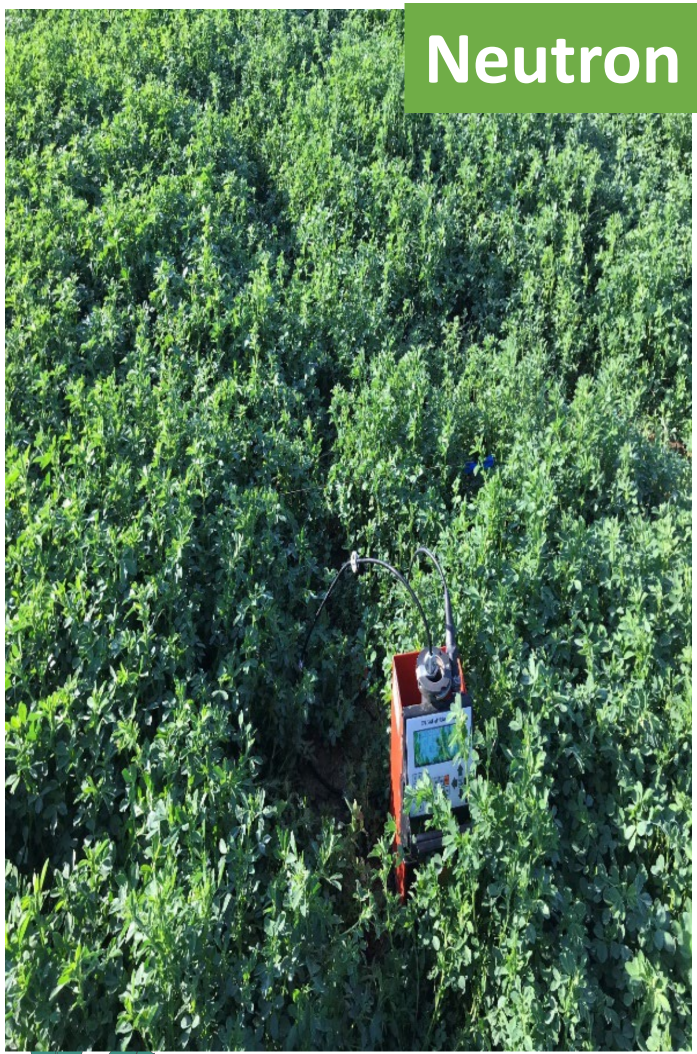
Mobile Drip Irrigation

- Travelling trickle irrigation
- Reduced wind losses
- Less soil evaporation (35%)
- Minimum repair costs

Source: Peters et al., 2016; Kisekka et al., 2017; O'Shaughnessy and Colaizzi, 2017; Oker et al., 2018; Aguilar et al., 2019; Reynolds et al., 2020

Monitoring Soil Water Status

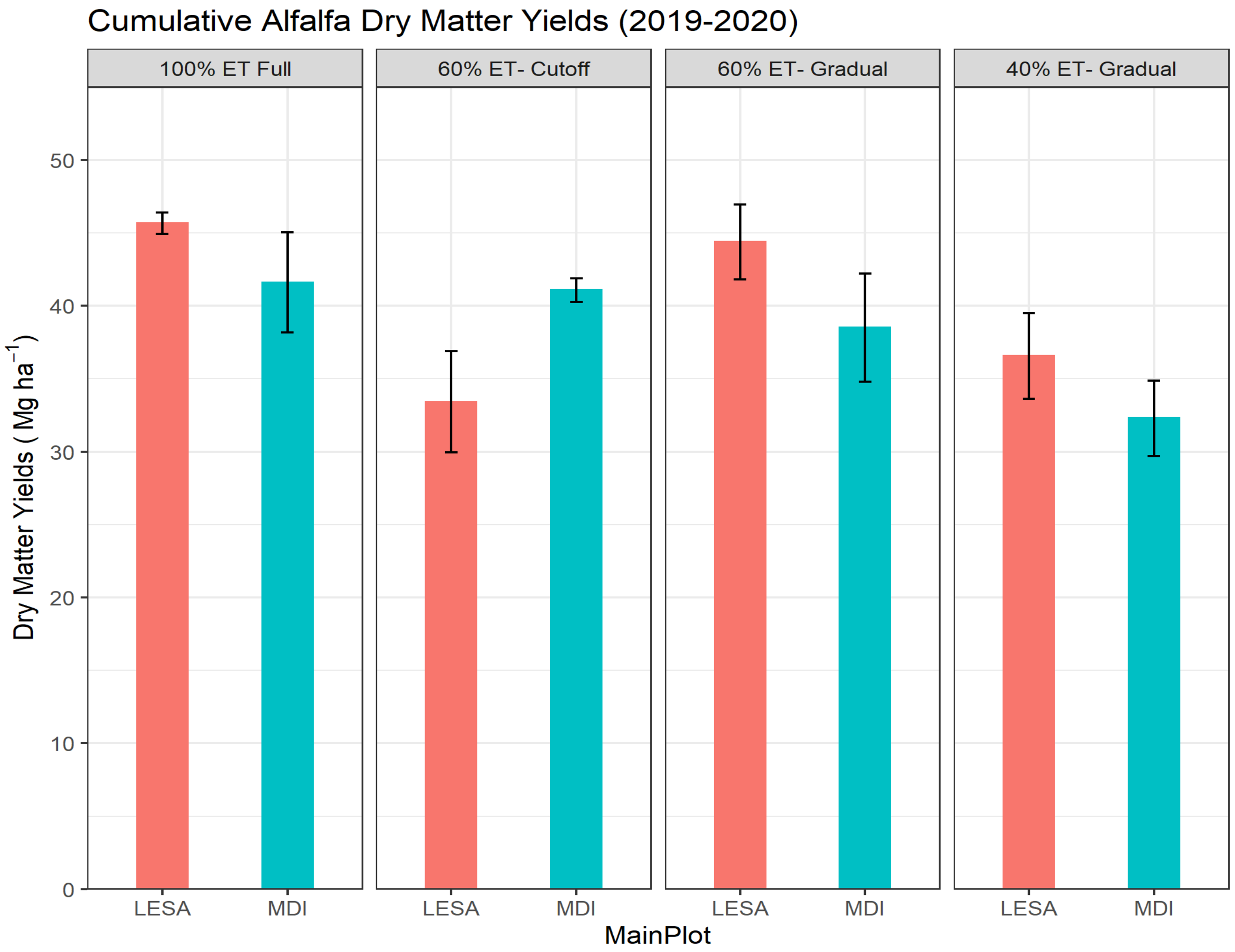
Neutron Probe



EM38 Calibration

Source: Gull et. al., 2021

Yield Response to Deficits:



Imaging Material and Methods:

Table 1. Image acquisition details using Micasense Rededge and LiDAR in alfalfa during 2020

Harvest Date	Flight Date	Sensor Used
23-Apr-20	------------------	------------------
28-May-20	26-May-20	Micasense Rededge
	27-May-20	LiDAR
25-Jun-20	24-Jun-20	Micasense Rededge
23-Jul-20	22-Jul-20	Micasense Rededge
	21-Jul-20	LiDAR
20-Aug-20	19-Aug-20	Micasense Rededge
17-Sep-20	16-Sep-20	Micasense Rededge
	16-Sep-20	LiDAR
22-Oct-20	20-Oct-20	Micasense Rededge
	20-Oct-20	LiDAR

Source: Gull et. al., 2021

Source: MicaSense

Multispectral Processing Steps:

Image Data collection → Preprocessing in Pix4DMapper → Orthomosaic Generation

↓

Reflectance Maps → Index Calculation → Soil Pixels Masking

Soil Pixels Masking ↓ CHM= DSM- DTM

Index Calculation ↓ Model Development

Selecting Parameters by Step Wise Regression → Predicted Yield

Observed Yield

Source: Gull et. al., 2021

LiDAR Processing Steps:

Image Data collection → Preprocessing by Digital Ag. Lab UCDavis

↓

Raster with Absolute Height

←

Soil Pixels Masking

←

Observed Plant height

LiDAR Plant height

↓

Predicted Yield from LiDAR Height

Source: Gull et. al., 2021

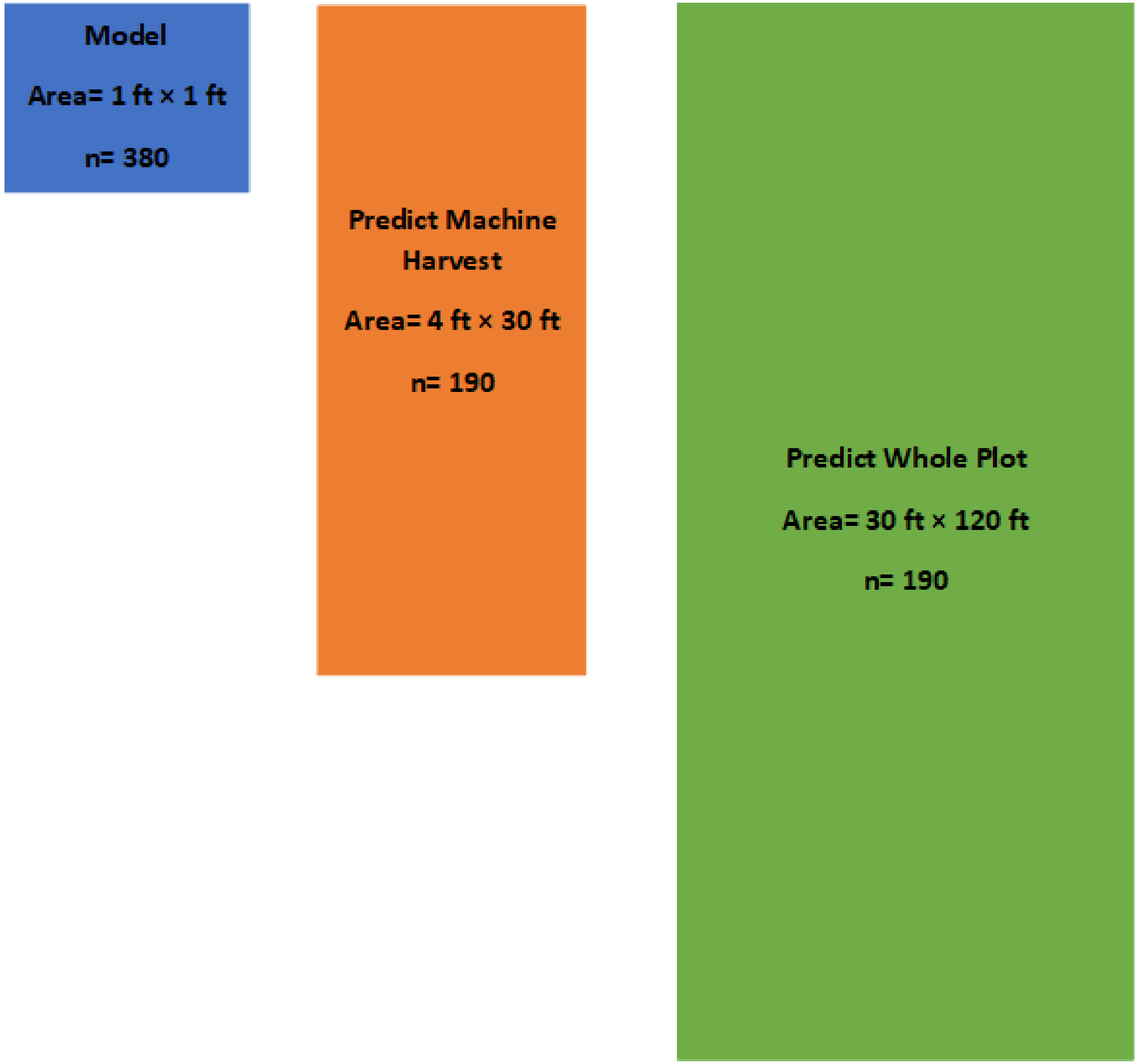


Figure 1. An illustration of observed data collected from 0.09 m² (blue square), 11.15 m² (orange rectangle) and estimated whole plot 334.45 m² (green rectangle).

Source: Gull et. al., 2021

Table 2. Vegetation indices used in the present study were adopted from Tang et al., 2021 for developing the model.

Source: Gull et. al., 2021

Indices	Abbreviation	Formula
Chlorophyll Index of Green	ClGreen	(NIR-Green)/(Green)
Chlorophyll Index of Red Edge	ClRe	NIR-RedEdge/RedEdge
Chlorophyll Vegetation Index	CVI	(NIR*Red)/(Green*Green)
Enhanced Vegetation Index	EVI2	2.5*(NIR-Red)/(NIR+(6*Red)-(7.5*Blue)+1)
Excess Green	ExG	2*Green-Red-Blue
Green Leaf Index	GLI	(2*Green-Red-Blue)/(2*Green+Red+Blue)
Green Normalized Difference Vegetation Index	GNDVI	(NIR-Green)/(NIR+Green)
Green Red Blue Vegetation Index	GRBVI	((Green^2)-(Blue*Red))/((Green^2)+(Blue*Red))
Green Ratio Vegetation Index	GRVI	NIR/Green
Leaf Chlorophyll Index	LCI	(NIR-RedEdge)/(NIR-Red)
Modified Chlorophyll Absorption in Reflectance Index	MCARI	((RedEdge-Red)-0.2*(RedEdge-Green))*(RedEdge/Red)
Normalized Difference Red Edge Index	NDRE	(NIR-RedEdge)/NIR+RedEdge)
Normalized Difference of Vegetation Index	NDVI	(NIR-Red)/(NIR+Red)
Normalized Green-Red Difference Index	NGRDI	((Green-Red))/((Green+Red))
Ratio Vegetation Index	RVI	(Red/NIR)
Simple Ratio	SR	(NIR/Red)
Triangular Vegetation Index	TVI	60*(NIR-Red)-100*(Red-Green)
Visible Atmospherically Resistant Index	VARI	(Green-Red)/(Green+Red-Blue)
Wide Dynamic Range Vegetation Index	WDRVI	(0.1*NIR-Red)/(0.1*NIR+Red)
Predicted Plant Height	PH	Relationship between Observed and UAV

Statistical Analysis:

- Mostly conducted in R with following packages
- Caret (Kuhn, 2021), raster (Hijmans, 2020),
- sf (Pebesma, 2018), rgdal (Bivand et al., 2021), Hmisc (Harrell Jr et al., 2021).
- HydroGOF (Bigiarini, 2020),
- Corrplot (Wei and Simko, 2017).
- Ggplot (Wickham, 2016).

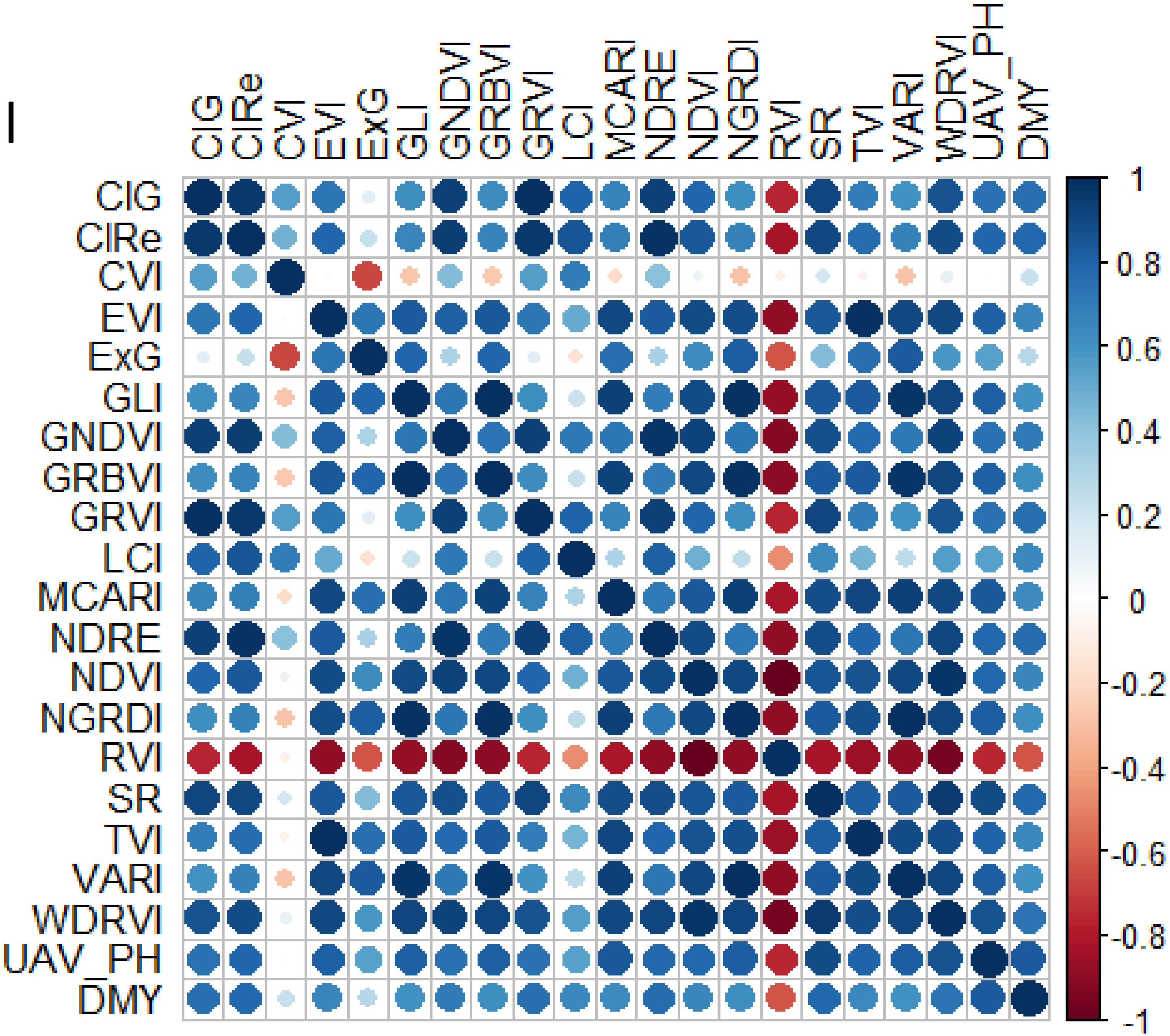
$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Predicted - Observed)^2}{n}}$$

$$MAE = \frac{\sum_{i=1}^{n}|Predicted - Observed|}{n}$$

$$nRMSE = \frac{RMSE}{sd(observed)}$$

Source: Gull et. al., 2021

- Multispectral



Model

Area= 1 ft × 1 ft

n= 380

Source: Gull et. al., 2021

Plant Height

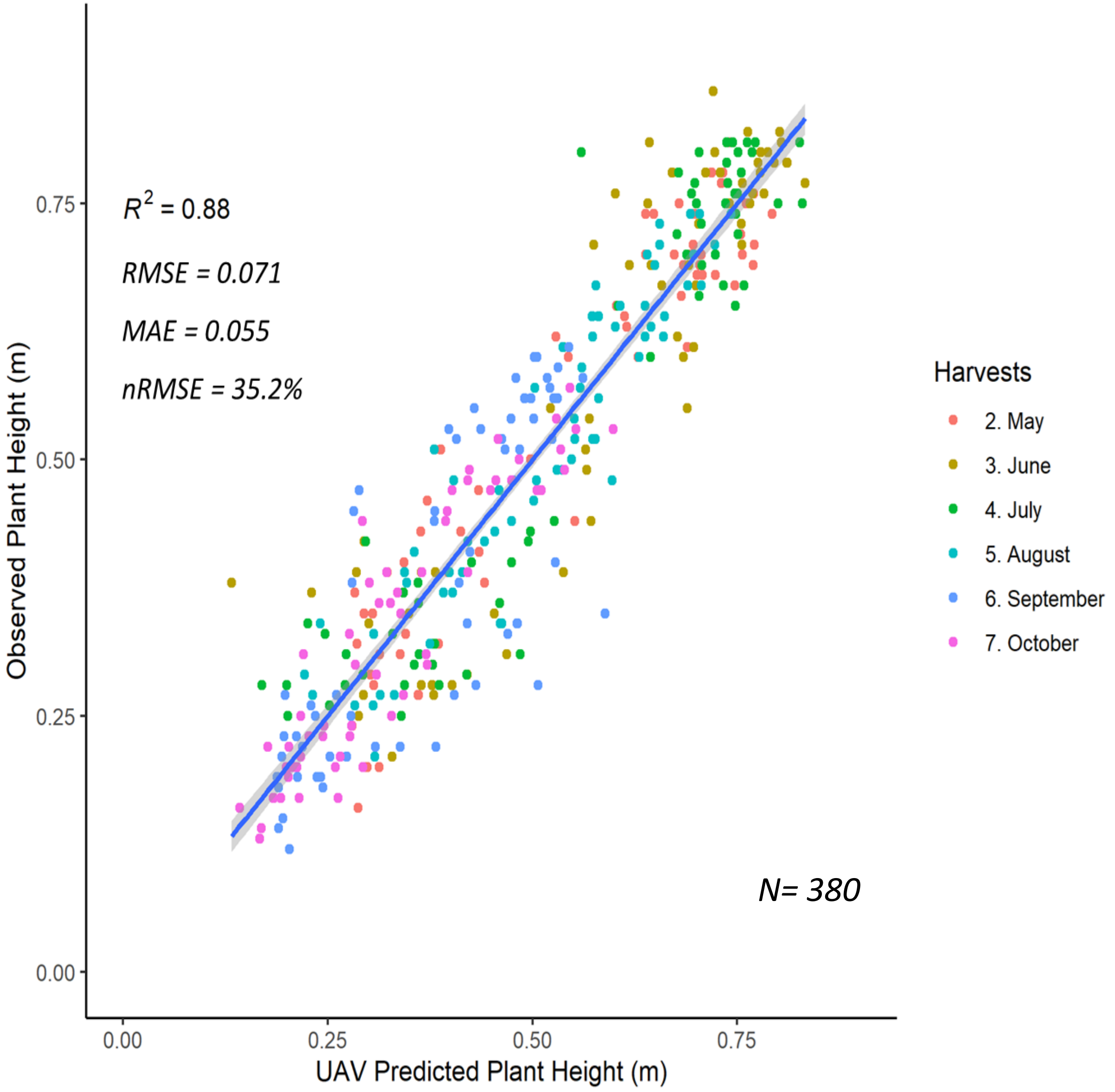
- Multispectral

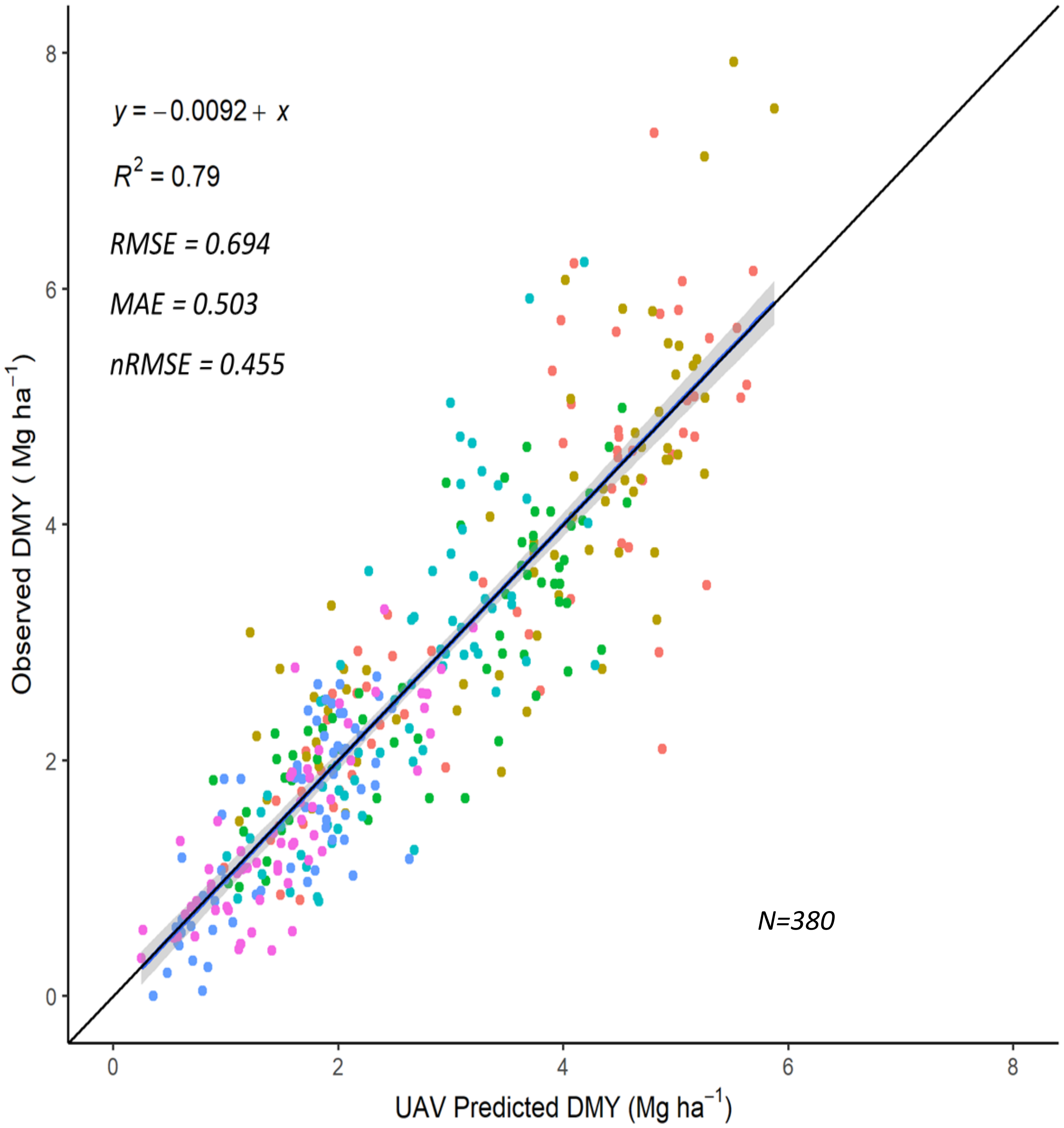
Model

Area= 1 ft × 1 ft

n= 380

Source: Gull et. al., 2021





Model

Area= 1 ft × 1 ft

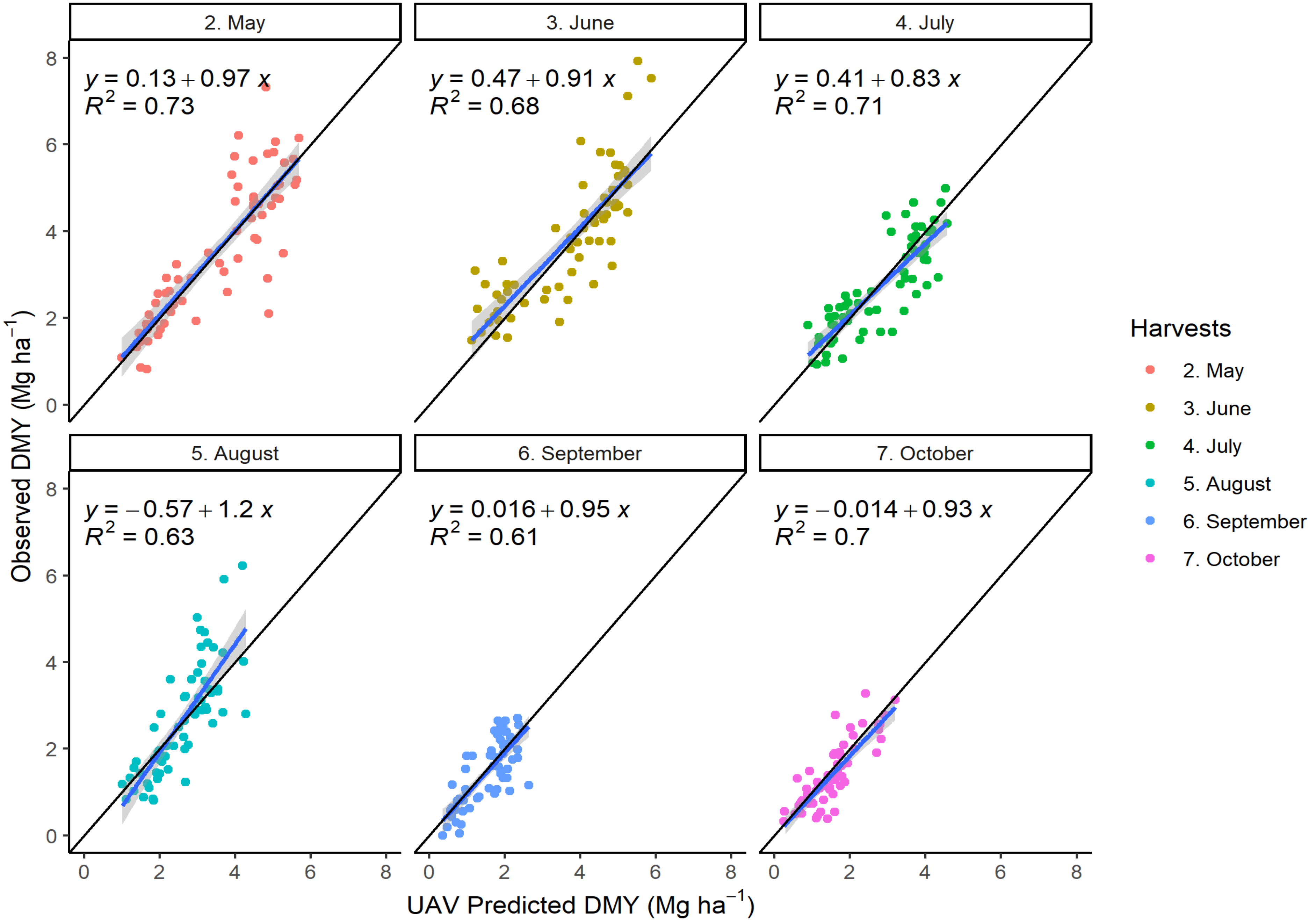
n= 380

- Multispectral

Yield (Mg/ha) = -35.772 – 0.660 * ClGreen + 8.188 * ClRe + 19.242 * GLI – 18.275 * GNDVI + 58.159 * LCI – 4.921 * MCARI – 115.297 * NDRE + 58.406 * NDVI – 29.124 * NGRDI +0.334 * SR +0.118 * TVI + 5.942 * PH

MAY DELETE IT

Source: Gull et. al., 2021



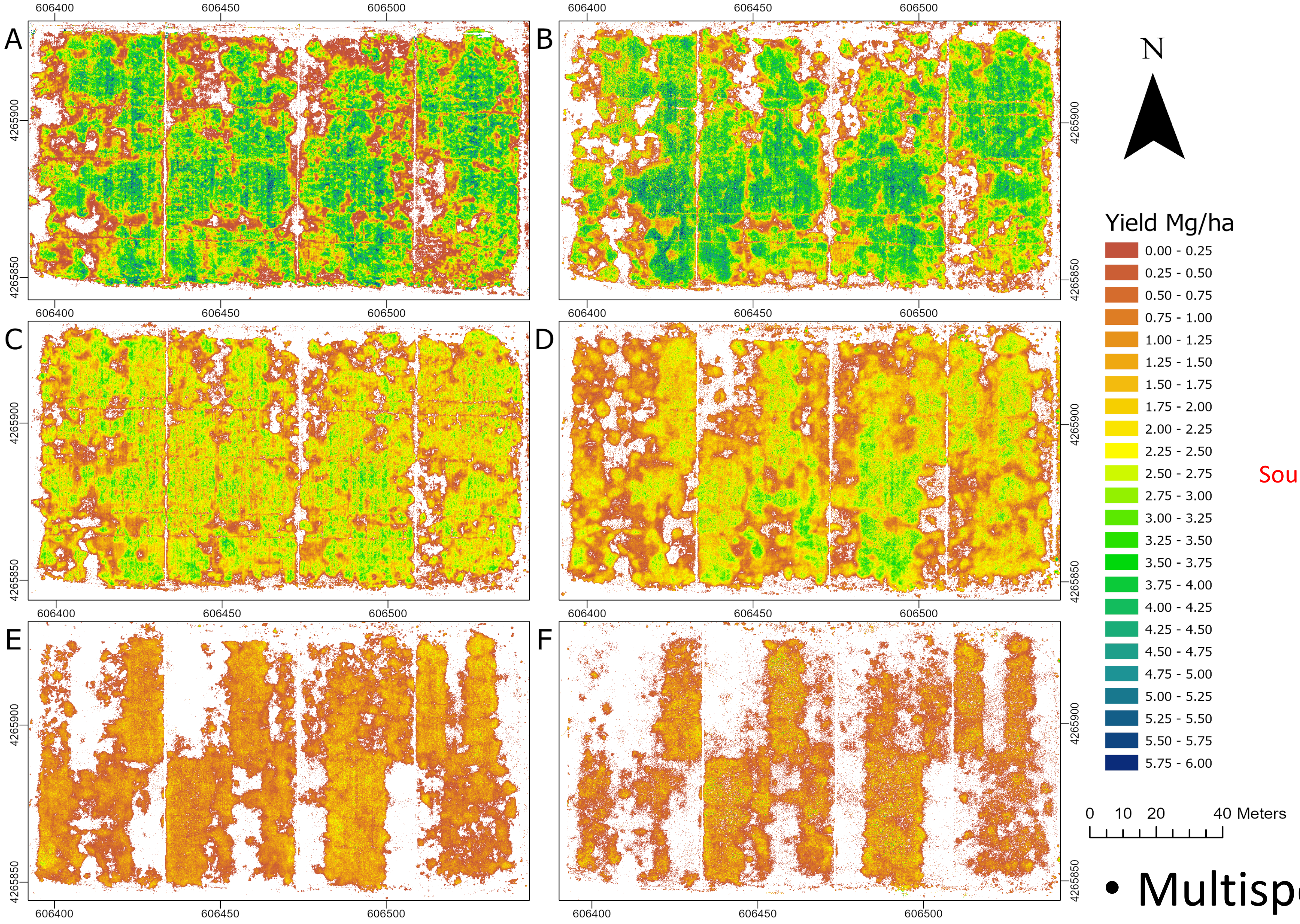
- Multispectral

Model

Area= 1 ft × 1 ft

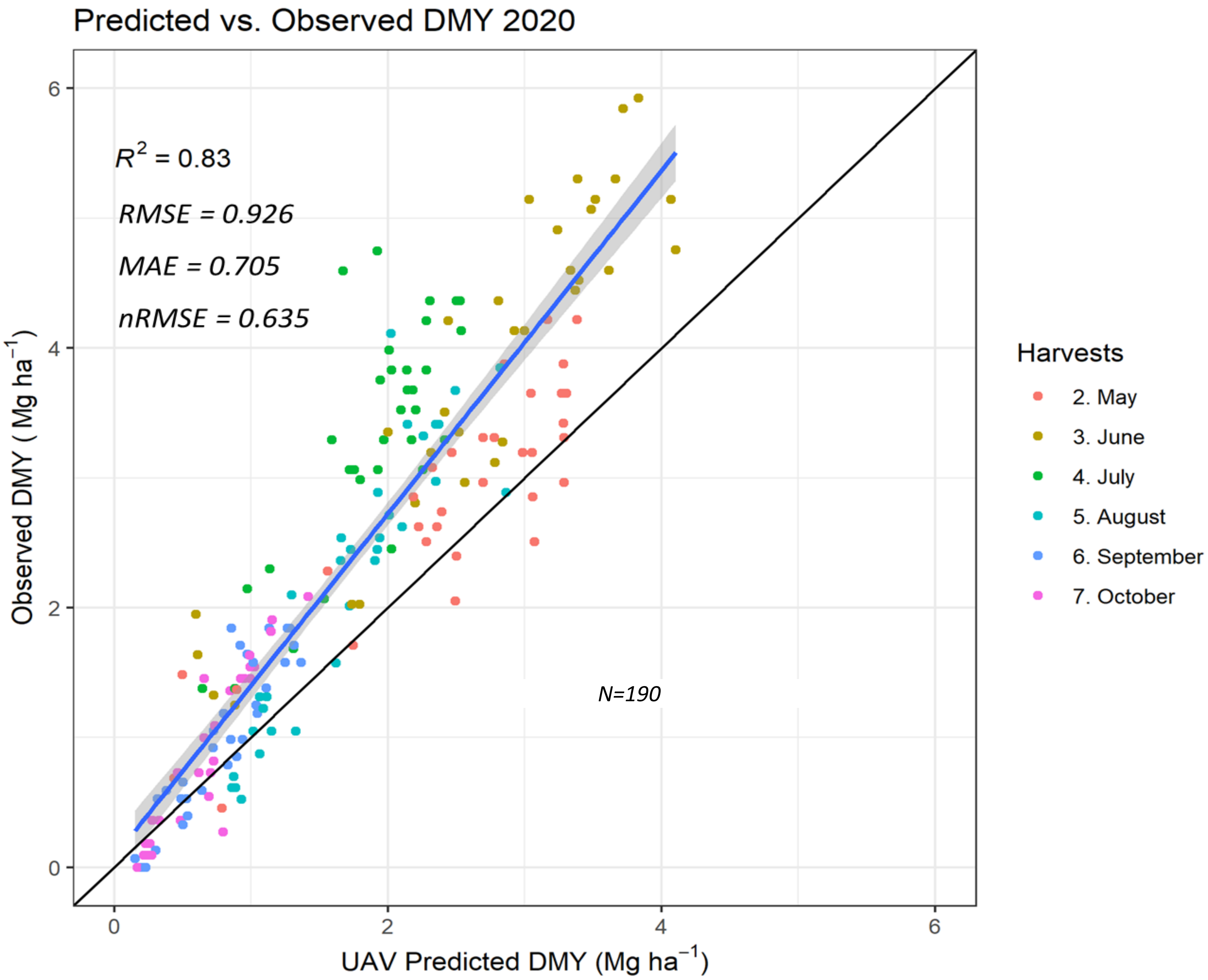
n= 380

Source: Gull et. al., 2021



Source: Gull et. al., 2021

- Multispectral



- Multispectral

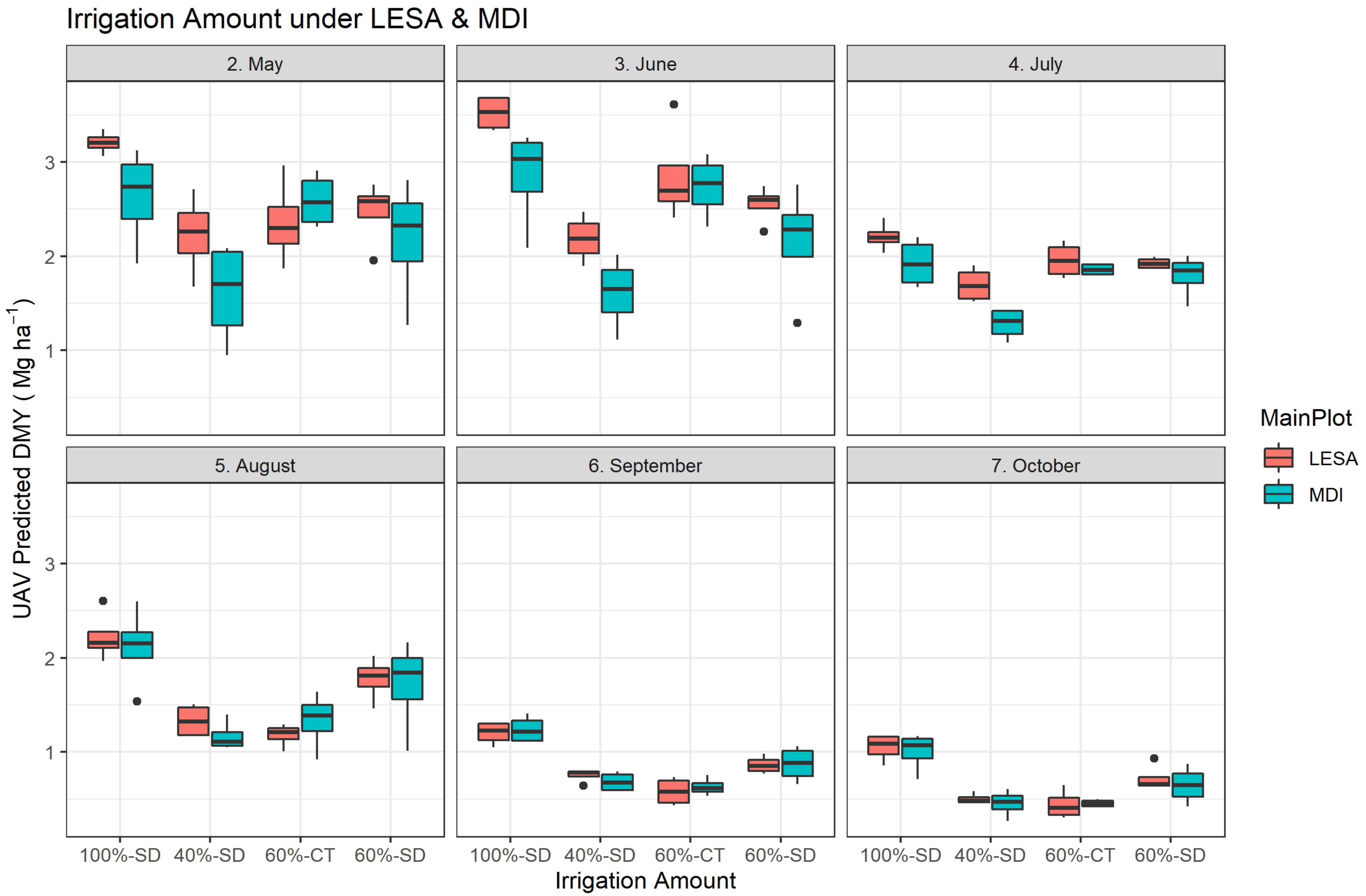
Predict Machine Harvest

Area= 4 ft × 30 ft

n= 190

Source: Gull et. al., 2021

• Multispectral



Source: Gull et. al., 2021

Predict Whole Plot

Area= 30 ft × 120 ft

n= 190

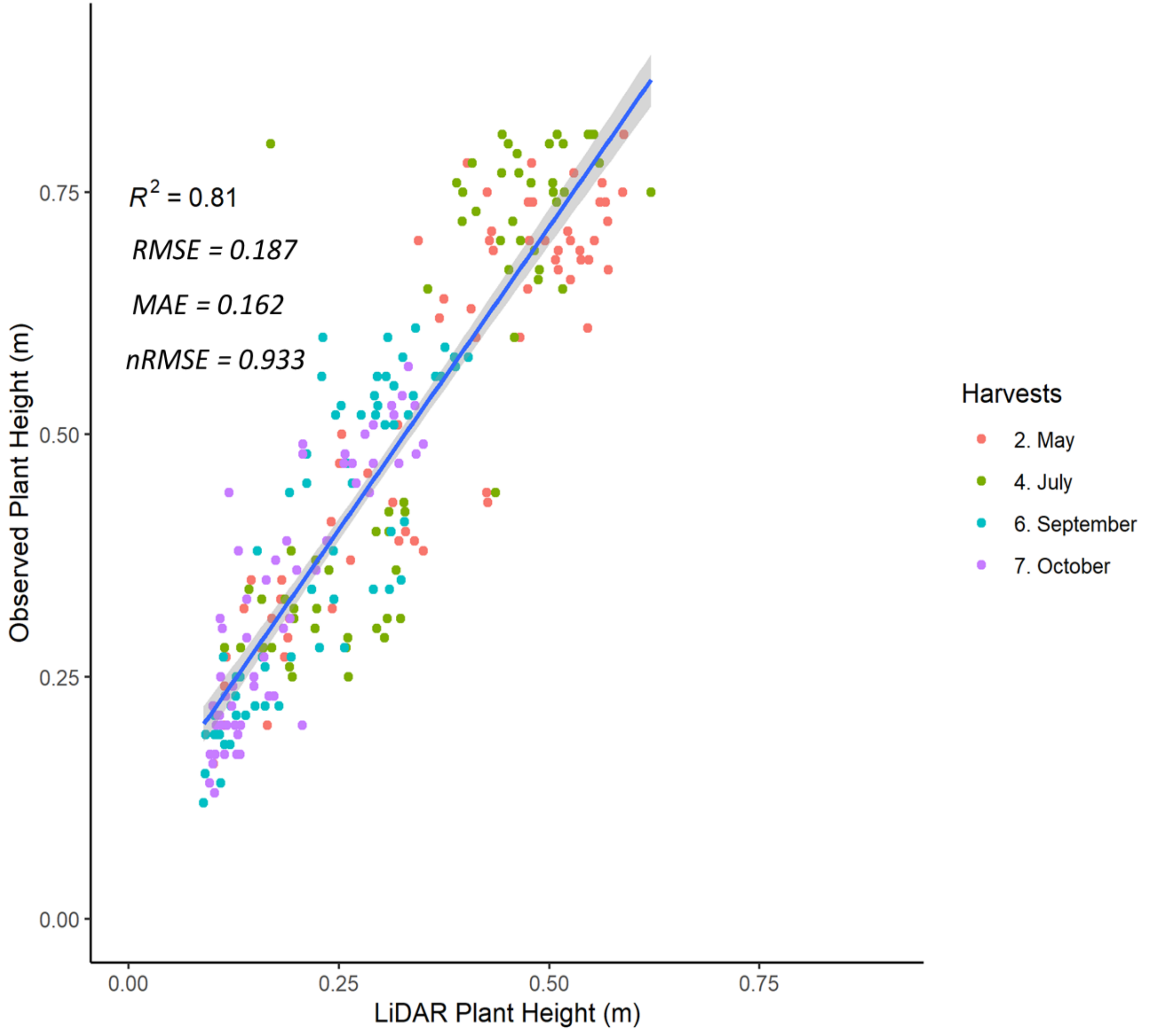
Results and Discussion:

- LiDAR

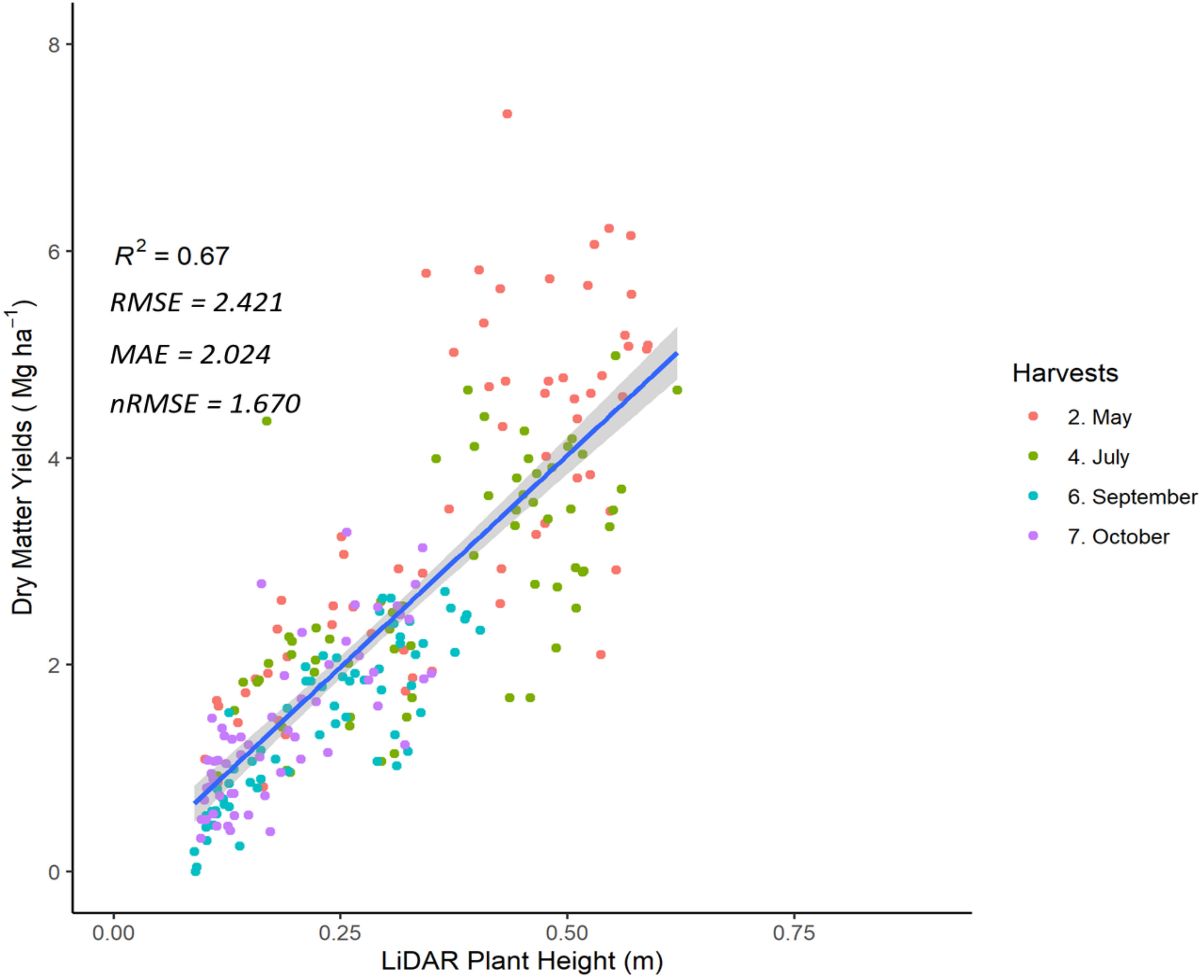
Model

Area= 1 ft × 1 ft

n= 252



Source: Gull et. al., 2021



- LiDAR

Source: Gull et. al., 2021

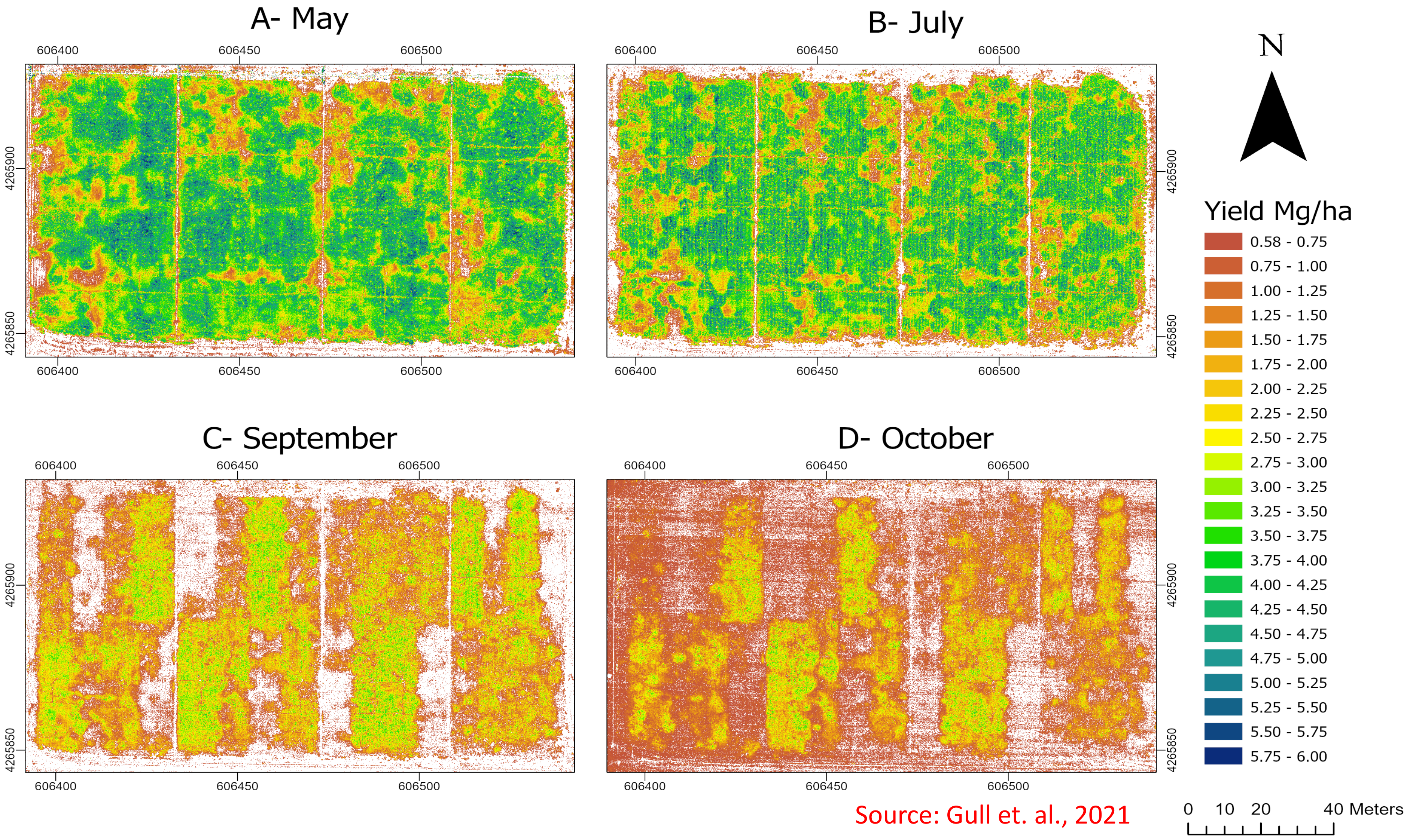
Model

Area= 1 ft × 1 ft

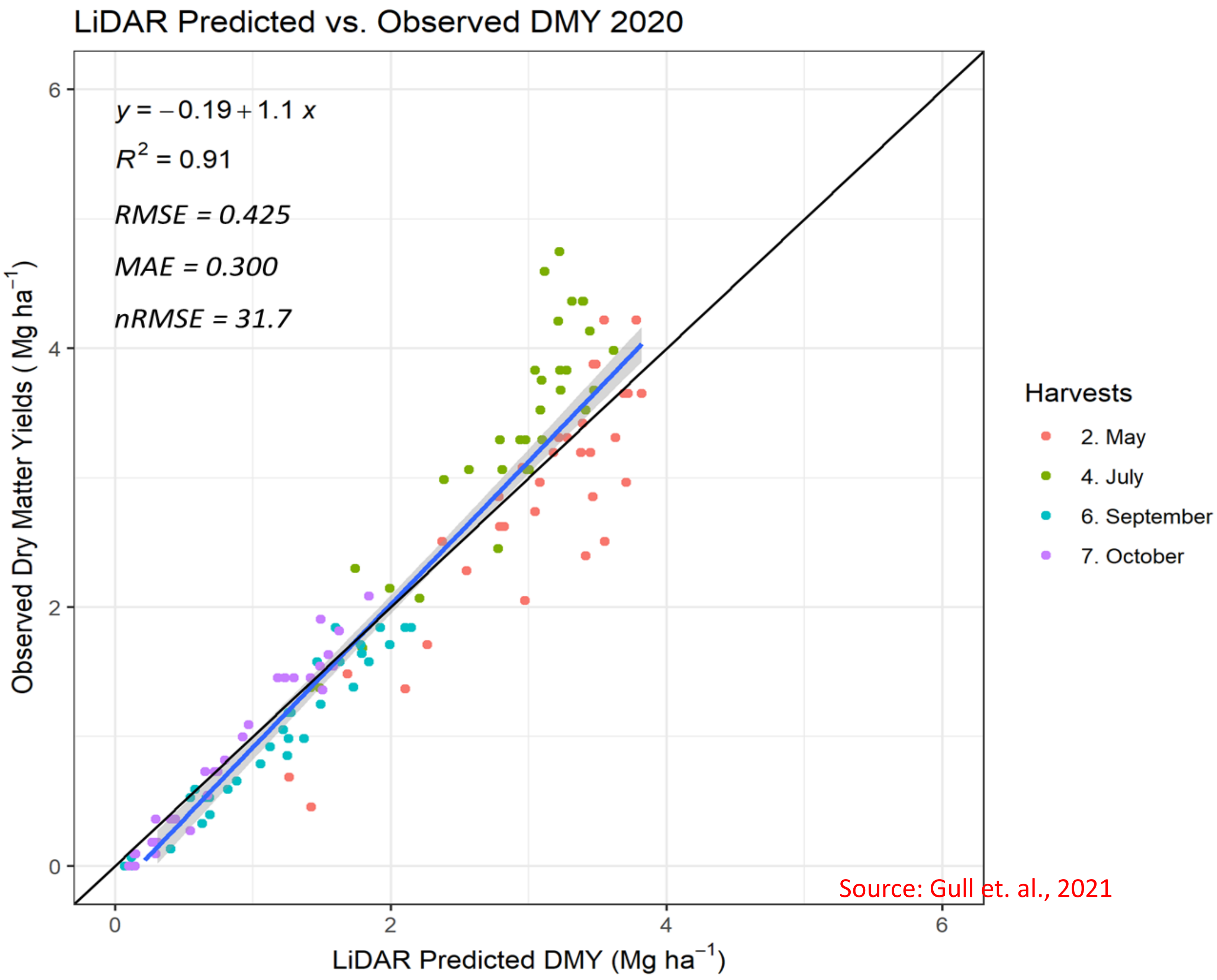
n= 252

Yield (Mg/ha) = -0.071 + 8.198 * PH

- LiDAR



Source: Gull et. al., 2021



Source: Gull et. al., 2021

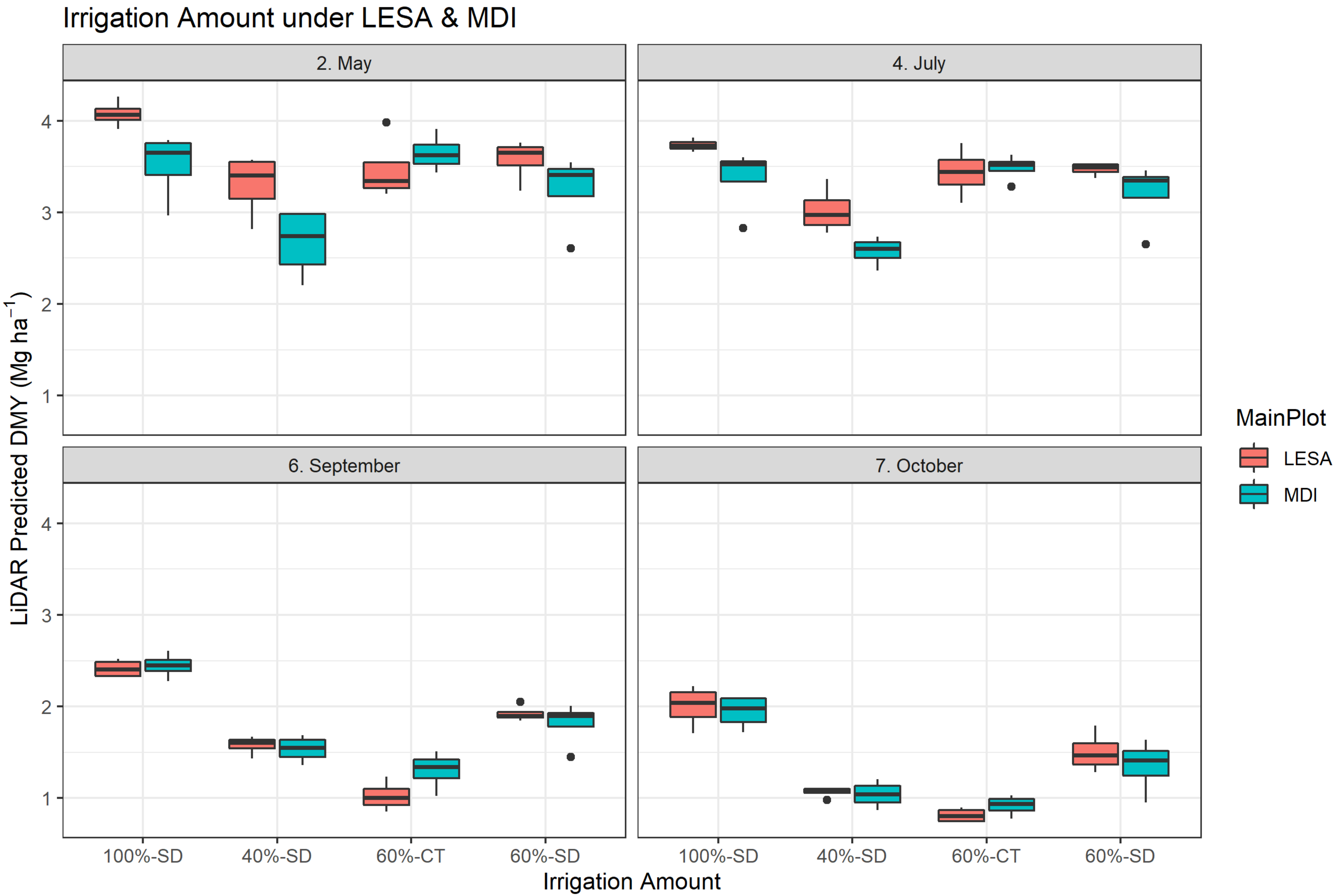
- LiDAR

Predict Machine Harvest

Area= 4 ft × 30 ft

n= 124

• LiDAR

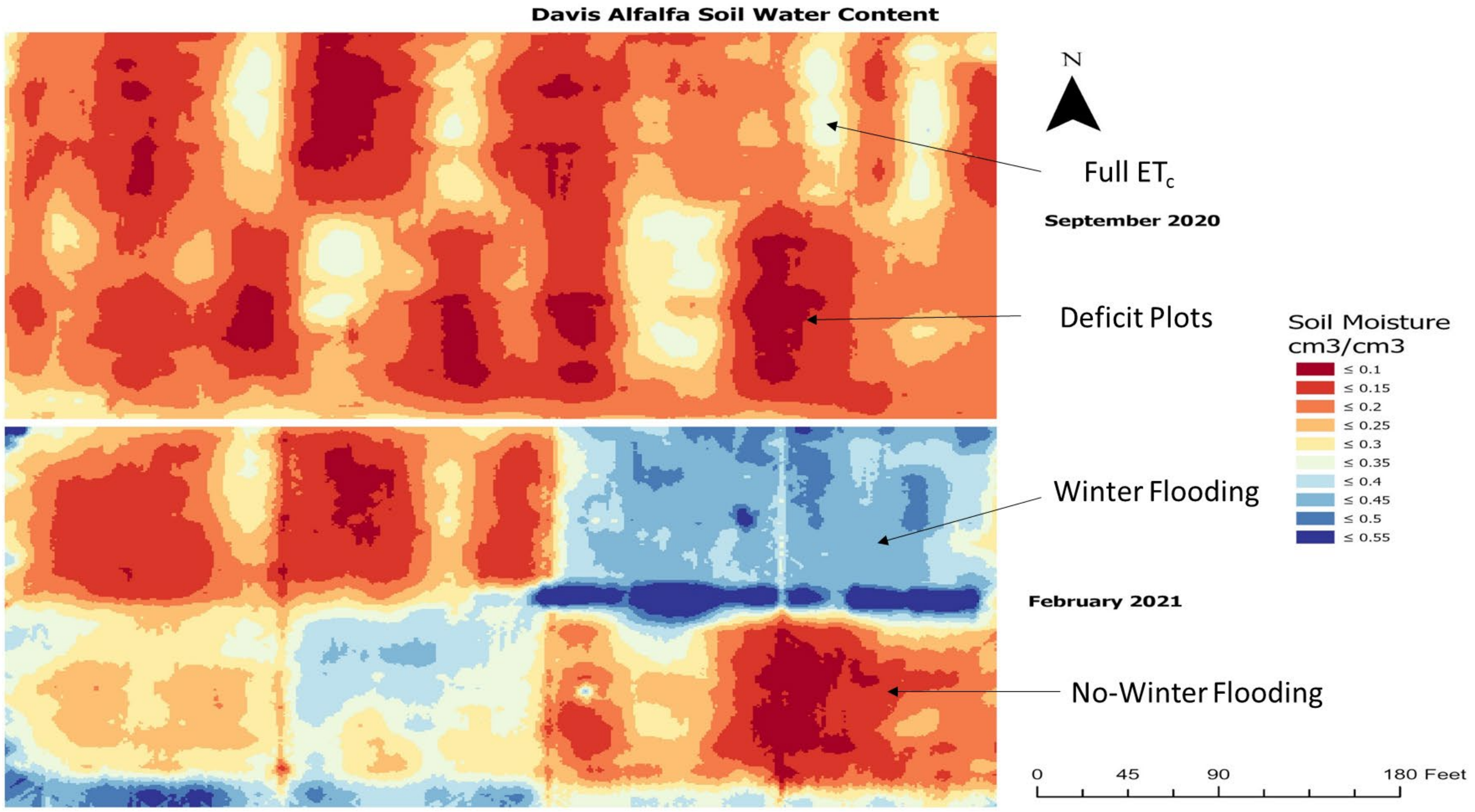


Source: Gull et. al., 2021

Predict Whole Plot

Area= 30 ft × 120 ft

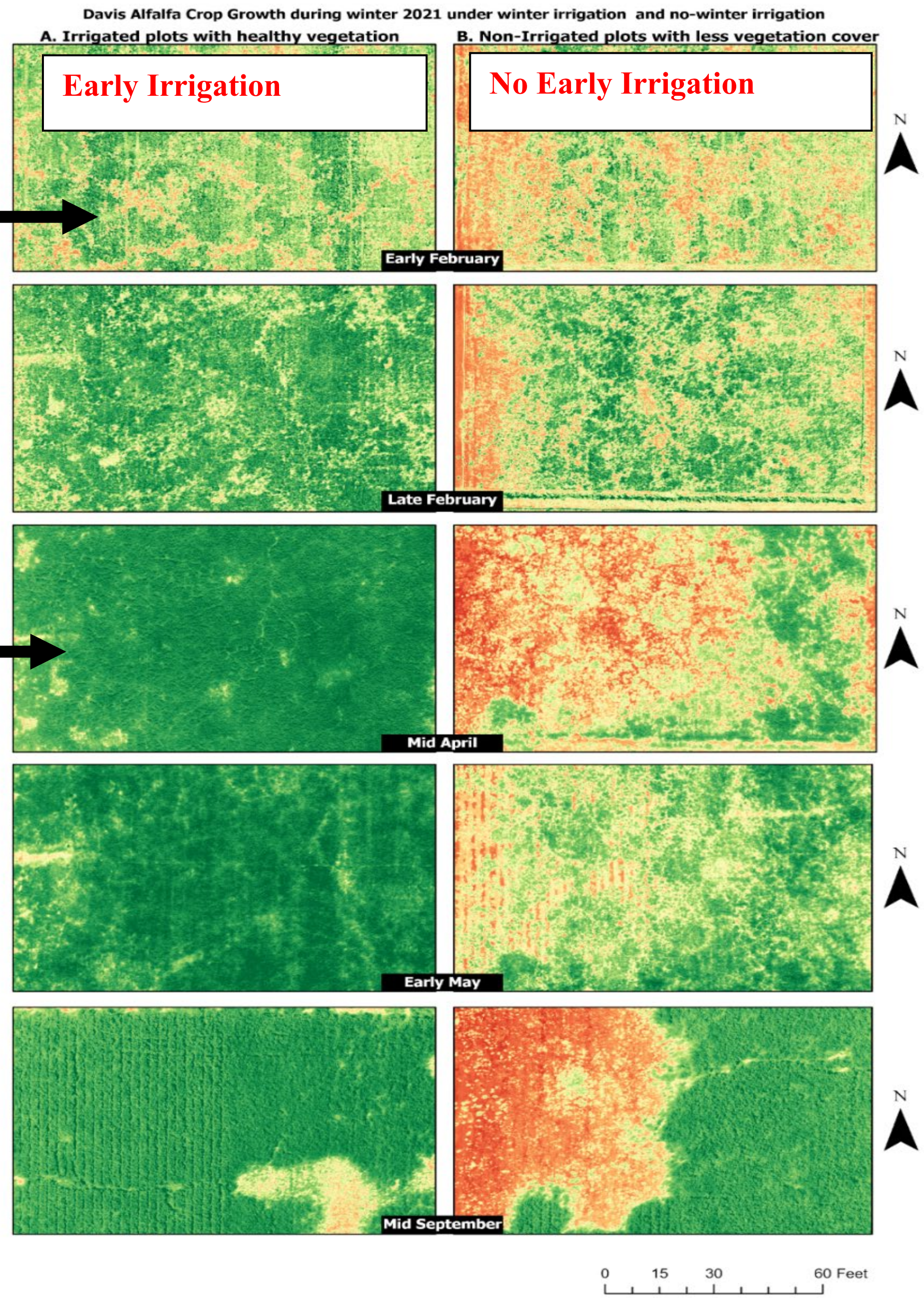
n= 190


Davis Alfalfa Soil Water Content
N
Full ET_c
September 2020
Deficit Plots
Soil Moisture cm3/cm3
≤ 0.1
≤ 0.15
≤ 0.2
≤ 0.25
≤ 0.3
≤ 0.35
≤ 0.4
≤ 0.45
≤ 0.5
≤ 0.55
Winter Flooding
February 2021
No-Winter Flooding
0
45
90
180 Feet

Importance of Early Irrigation:

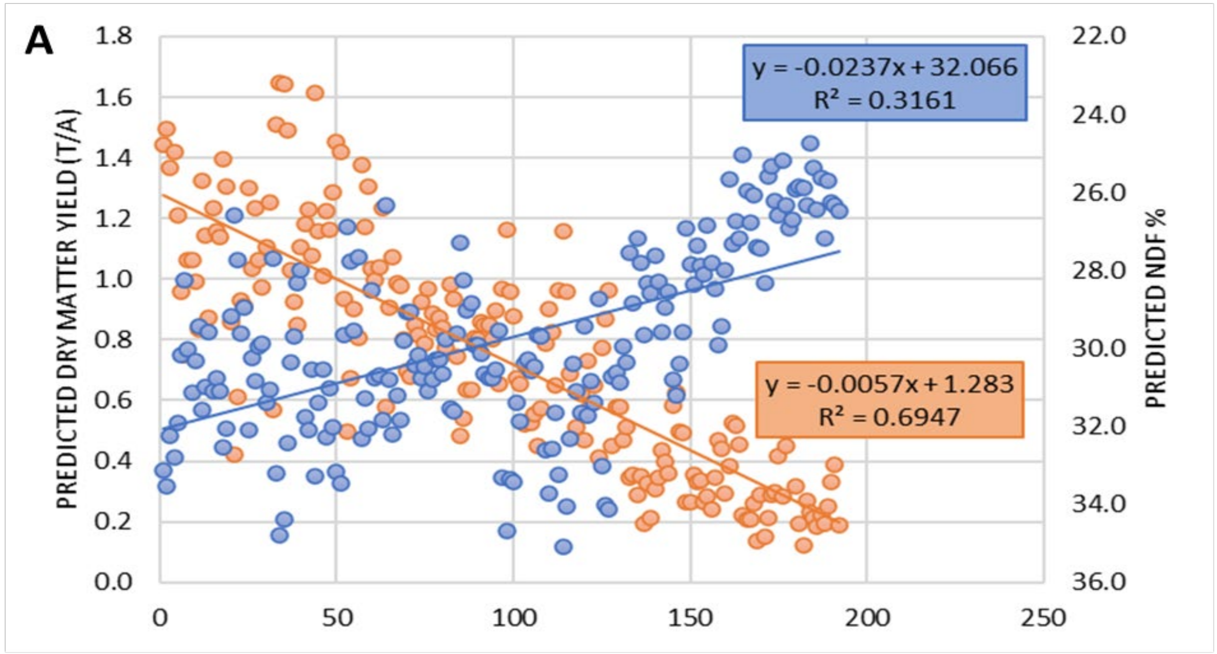
Irrigation:

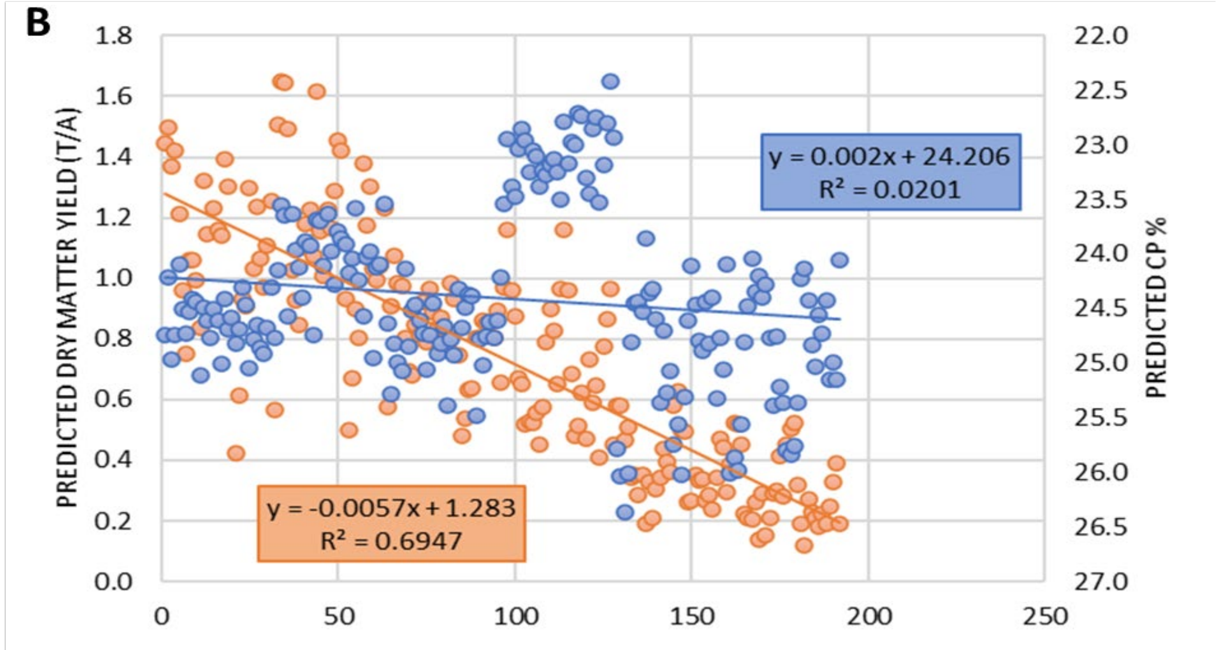
Irrigation:



Forage Quality

- Multispectral





Source: Gull et. al., 2021

Conclusions:

- Both LEPA/LESA sprinklers and Mobile Drip Systems have the capability of improving WUE of alfalfa. MDI Improved subsoil infiltration.
- Deficits targeting 40% of ETc resulted in yields 78-80% of full irrigation.
- Both multispectral cameras and LiDAR have the capability of spatially predicting alfalfa yield.
- Less accuracy in prediction of quality.
- Vigorous tested equations could predict yield effects over larger areas, taking into account sources of field variation
    - Traffic effects
    - Soil Variation
    - Imprecise irrigation techniques
    - Pest Impacts
- Utility: diagnosing problems, more vigorous yield evaluations of varieties in larger areas

Acknowledgments:

Alfalfa
NAFA
U.S. Alfalfa Farmer Research Initiative

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United States Department of Agriculture
National Institute of Food and Agriculture

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College of Agricultural and Environmental Sciences

University of
AGRICULTURE
Faisalabad-Pakistan

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