High Throughput-Phenotyping at CIMMYT: Experiences and needs

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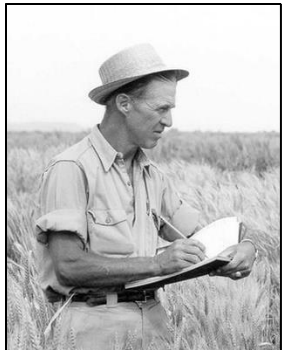
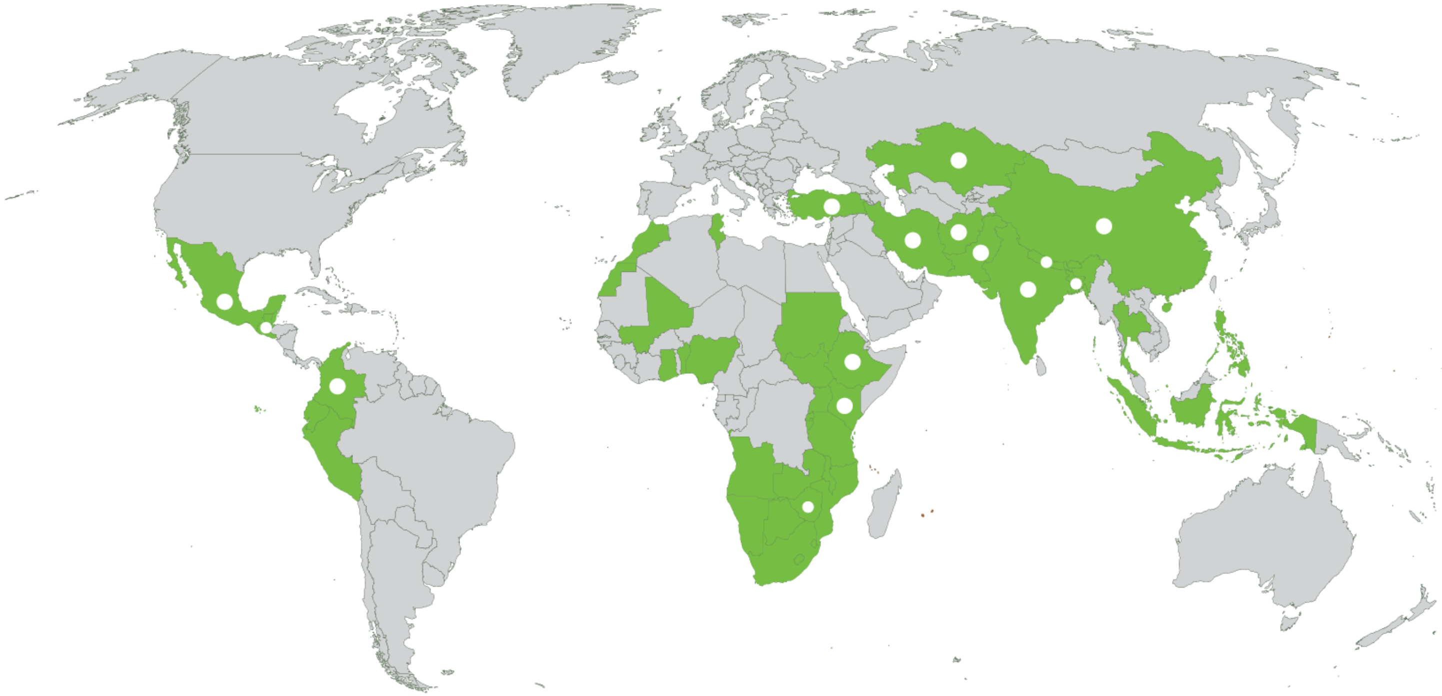
2021 R. F. Baker Plant Breeding Symposium
Predicting in the Future of Plant Breeding

CIMMYT around the world

1,200 staff from over 50 countries!

CIMMYT works mainly in the developing world, aiming at improving livelihood by promoting more productive and sustainable maize and wheat agrosystems.


Dr. Norman Borlaug



Countries with offices:

Afghanistan
Bangladesh
China
Colombia
Ethiopia
Guatemala
India
Iran
Kazakhstan
Kenya
Mexico
Nepal
Pakistan
Turkey
Zimbabwe

Projects in over 40 countries

CGIAR

Consultative Groups for International Agricultural Research

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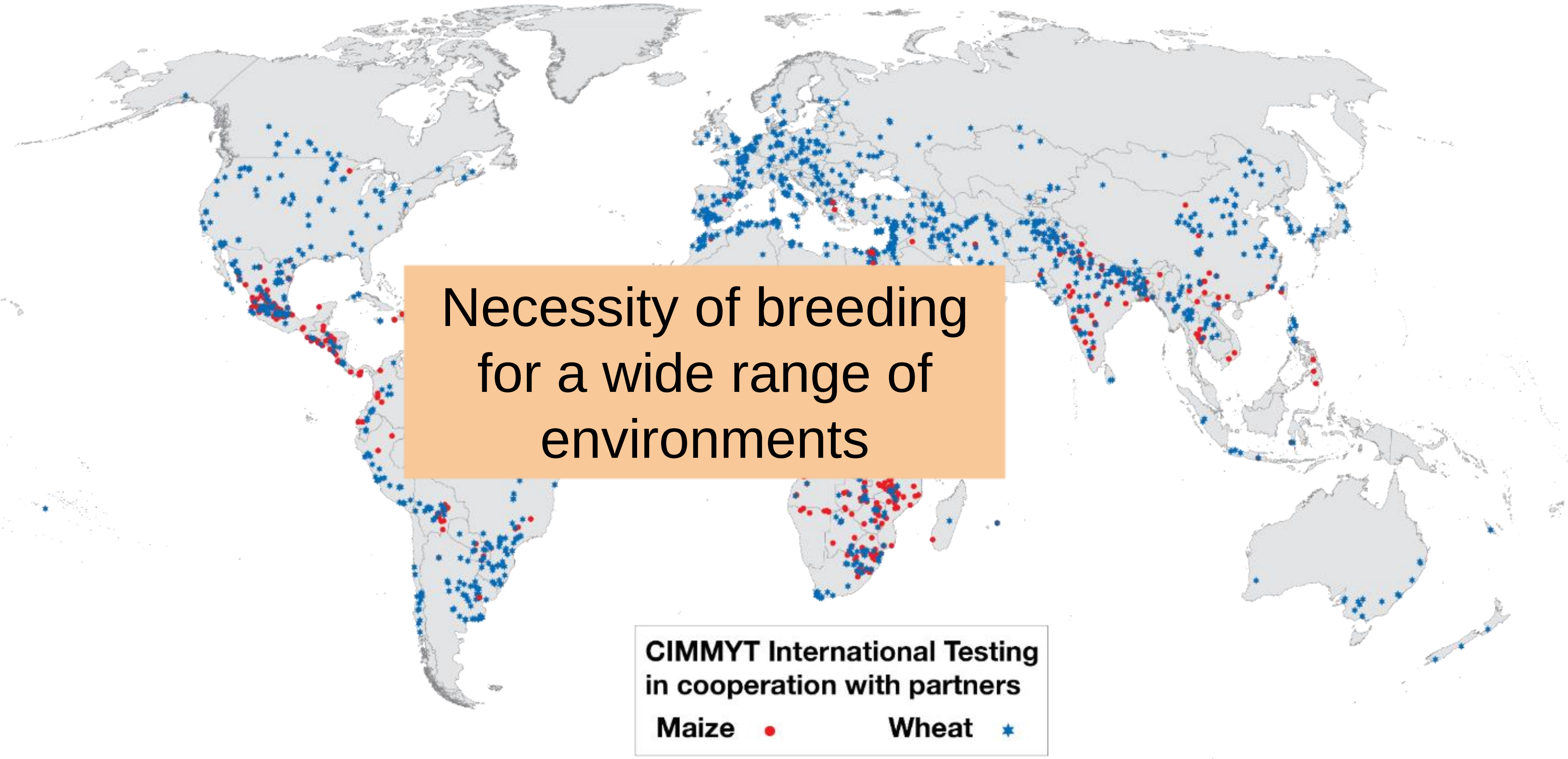
Global seed distribution network



Necessity of breeding for a wide range of environments

50% of maize and wheat in the developing world is based on CIMMYT varieties

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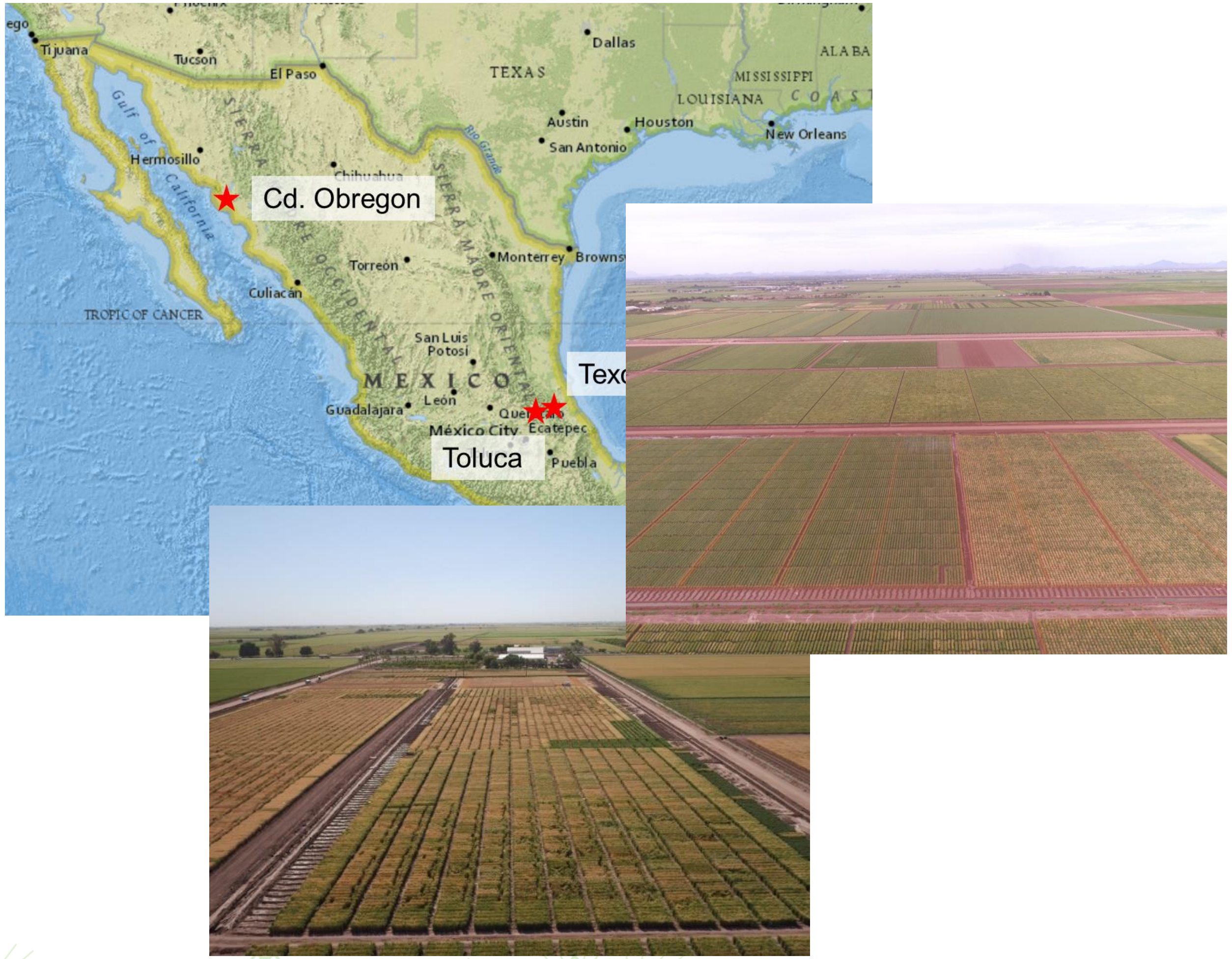
Where everything starts: the experimental sites of the Global Wheat Program

- <u>Cd. Obregon</u>, Toluca, Texcoco:
  - Breeding, pre-breeding and research for <u>different environments</u>
  - International research collaborations
  - >100,000 plots (>250 Ha)
  - Phenotyping different traits for:
    - Early selection
    - Disease resistance evaluation
    - Physiology research
    - Physiological breeding
    - Exploration of genetic resources
    - Progeny evaluation



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Plant phenotyping: a cornerstone in breeding programs

Plant phenotyping: quantitative description of plant's anatomical, ontogenetical, physiological and biochemical properties

Walter et al. 2015, Plant Methods

Agronomic traits:
- Yield
- TKW
- Phenology
- Plant height
- Disease resistance
- Biomass

High-throughput phenotyping

Genomic selection models

Pedigree

Genomic

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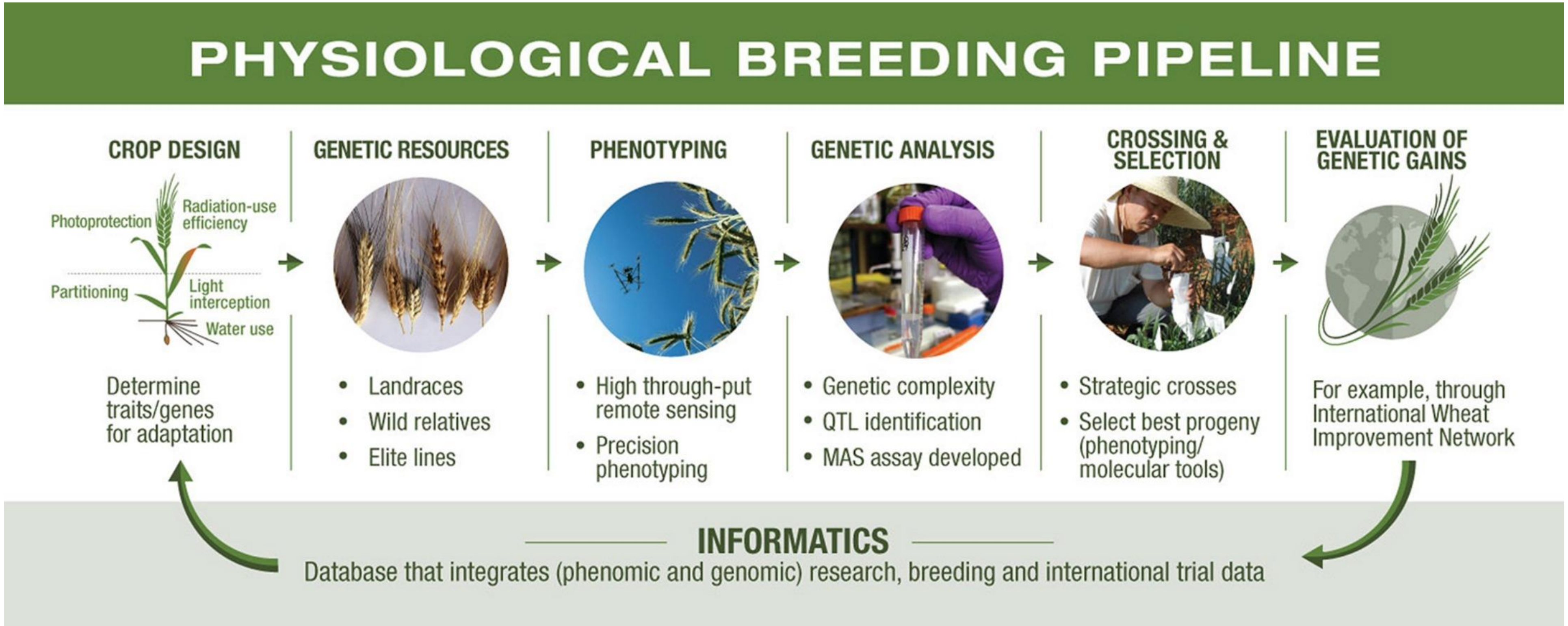
Physiological pre-breeding

Objective: Improve abiotic stress adaptation and yield potential in a changing climate



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Physiological breeding as strategy for genetic gain: use of conceptual models

YIELD POTENTIAL

YIELD = LI x RUE x HI

HEAT

YIELD = LI x RUE x HI

DROUGHT

YIELD = WU x WUE x HI

Conceptual Model of Heat-Adaptive Traits

YIELD = LI x RUE x HI

Photo-Protection (RUE)

•Leaf morphology (display, wax)
•Down regulation
•Pigment composition
- Chl a:b
- Carotenoids

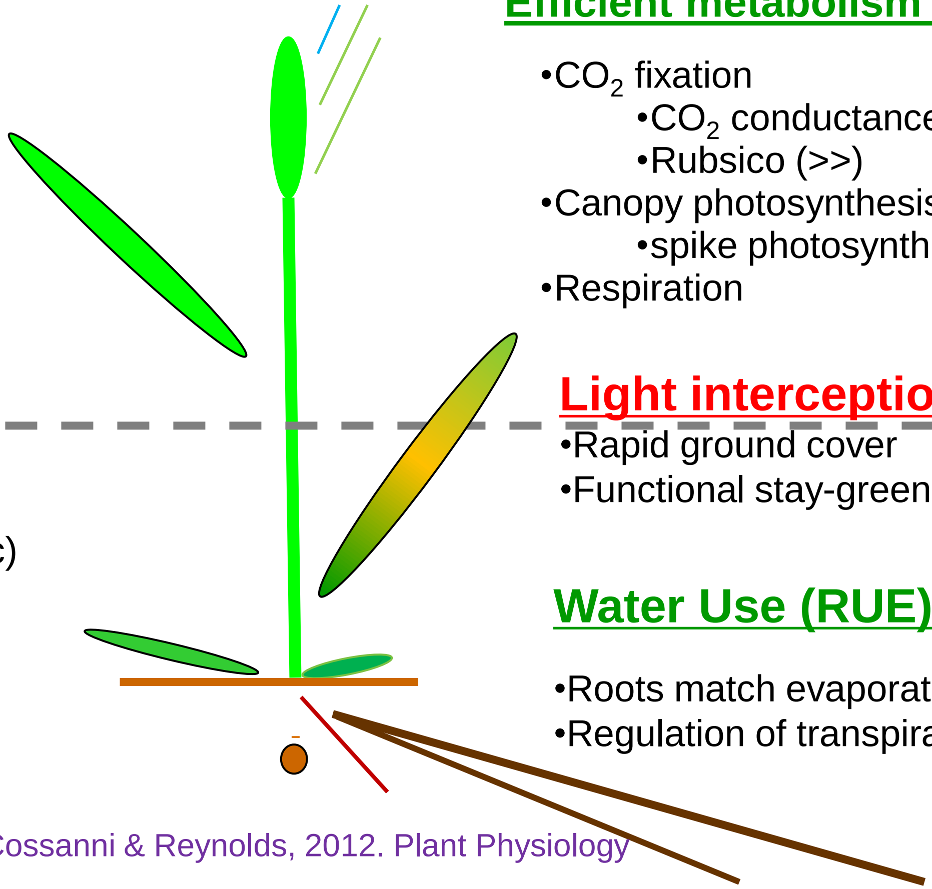
•Antioxidants

Efficient metabolism (RUE)

•CO_2 fixation
- •CO_2 conductance
- •Rubisco (>>)

•Canopy photosynthesis
- •spike photosynthesis

•Respiration



Light interception (LI)

•Rapid ground cover
•Functional stay-green

Partitioning (HI)

•Spike fertility (meiosis, pollen, etc)
•Stress signaling (e.g. ethylene) regulating
- •senescence rate
- •floret abortion

•Grain filling (starch synthase)
•Stem carbohydrate storage & remobilization

Water Use (RUE)

•Roots match evaporative demand
•Regulation of transpiration (VPD; ABA)

Cossanni & Reynolds, 2012. Plant Physiology

Traits considered in strategic crosses (to date):

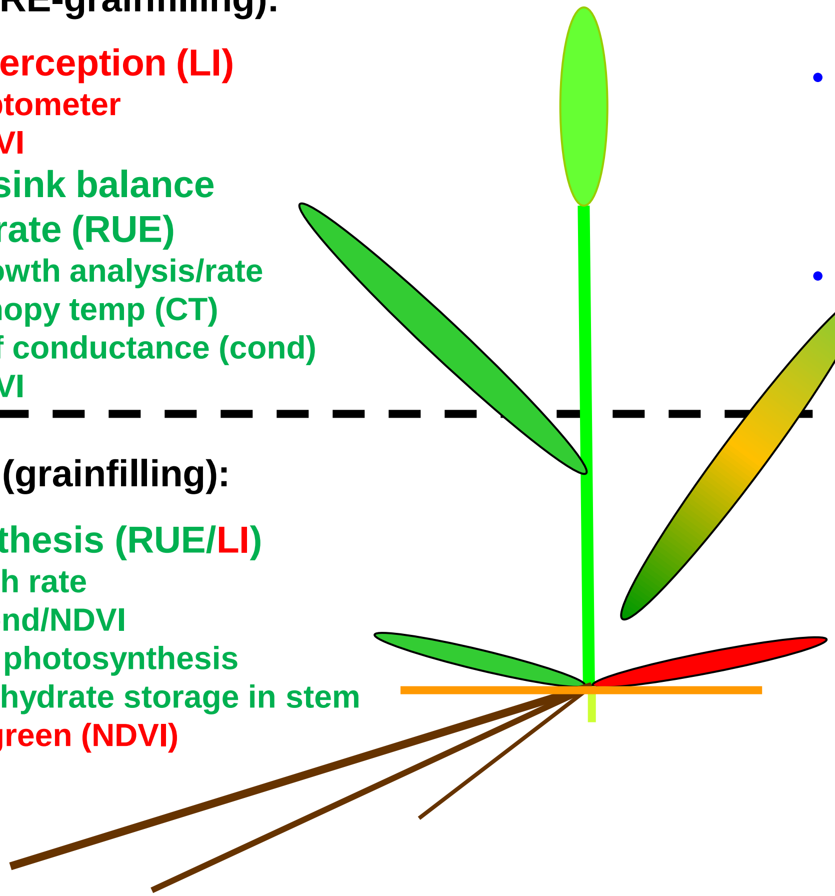
YIELD = LI x RUE x HI

SOURCE (PRE-grainfilling):

- Light interception (LI)
  - ceptometer
  - NDVI
- Source:sink balance
- Growth rate (RUE)
  - Growth analysis/rate
  - canopy temp (CT)
  - leaf conductance (cond)
  - NDVI

SINK (PRE-grainfilling):

- Spike fertility
  - grain number
  - kernel weight potential
  - spike index
  - Internode partitioning
- Development pattern
  - long juvenile spike phase
  - *Ppd/Vrn/Eps* constellation



SOURCE (grainfilling):

- Photosynthesis (RUE/LI)
  - growth rate
  - CT/cond/NDVI
  - spike photosynthesis
  - carbohydrate storage in stem
  - stay green (NDVI)

SINK (grainfilling)

- Harvest Index
  - tiller survival
  - grain growth rate
  - fruiting efficiency
- Adaptation to density

Breeding friendly phenotyping

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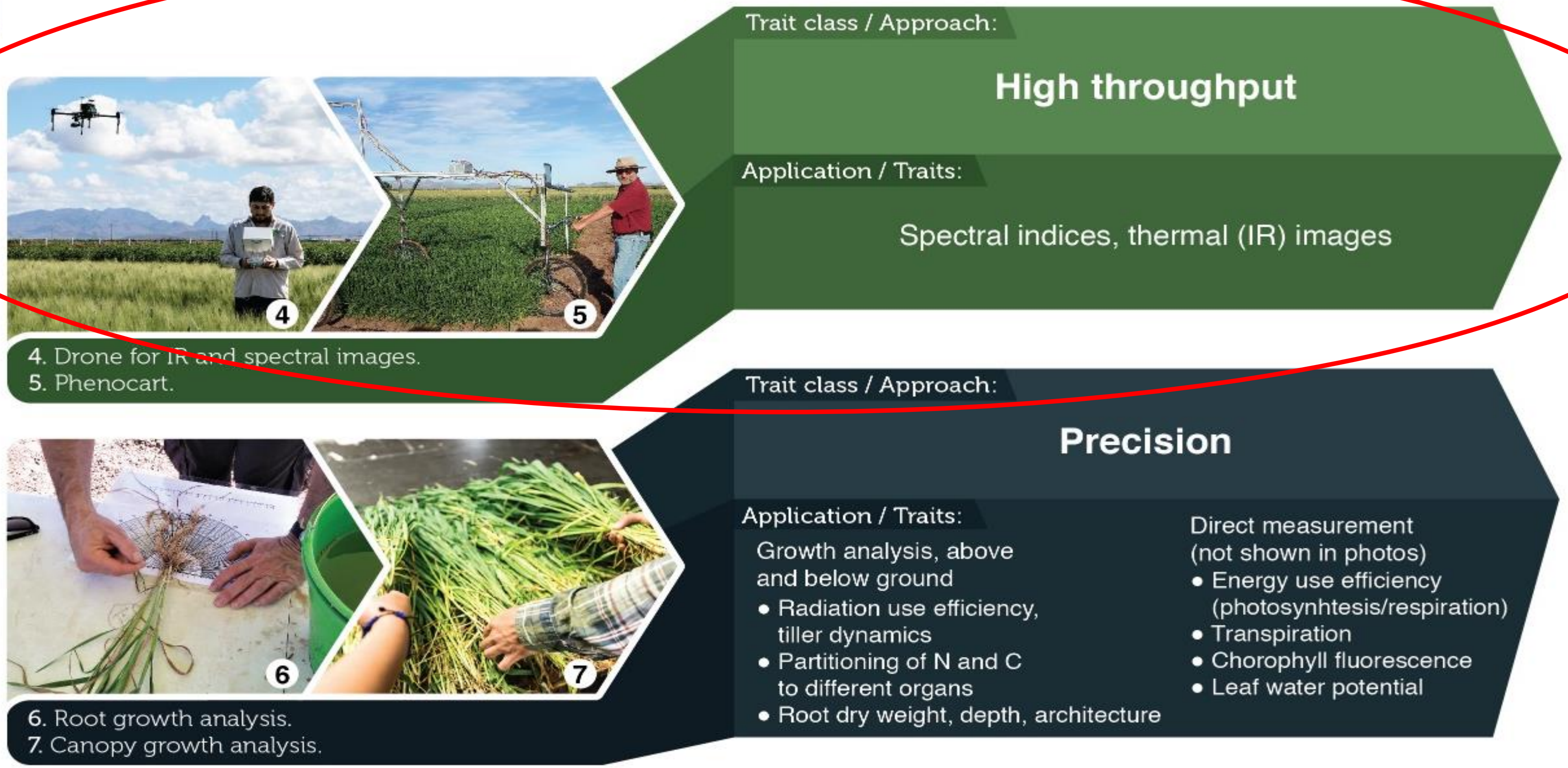
Breeding friendly phenotyping in GWP

Reynolds et al. 2020

Breeding friendly phenotyping in GWP



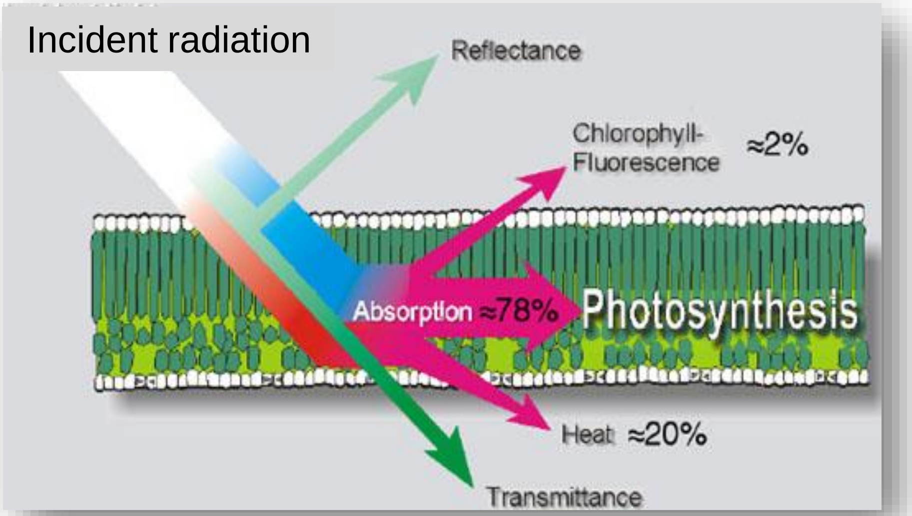
Reynolds et al. 2020

RS and sensors for HTP under field conditions

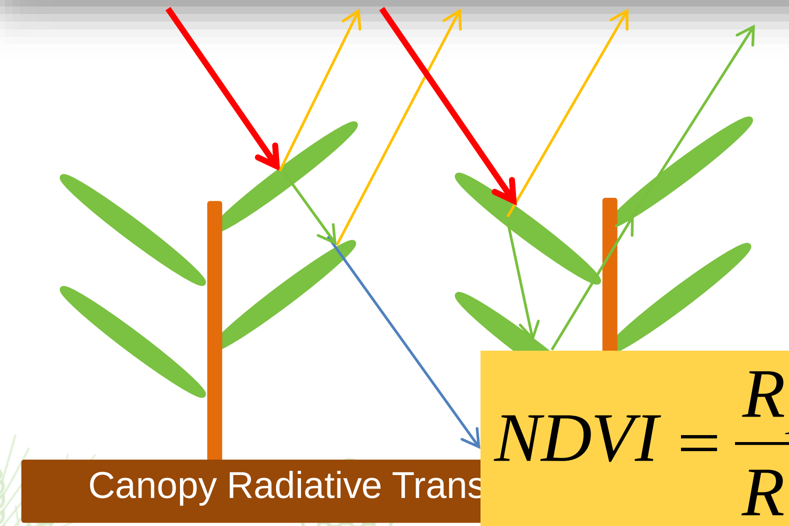
Advantages:

- •Non-invasive
- •Multipe spatio-temporal dimensions
- •Fast
- •Systematic data collection (reduced errors and allows automation)
- •It can potentially be cost effective

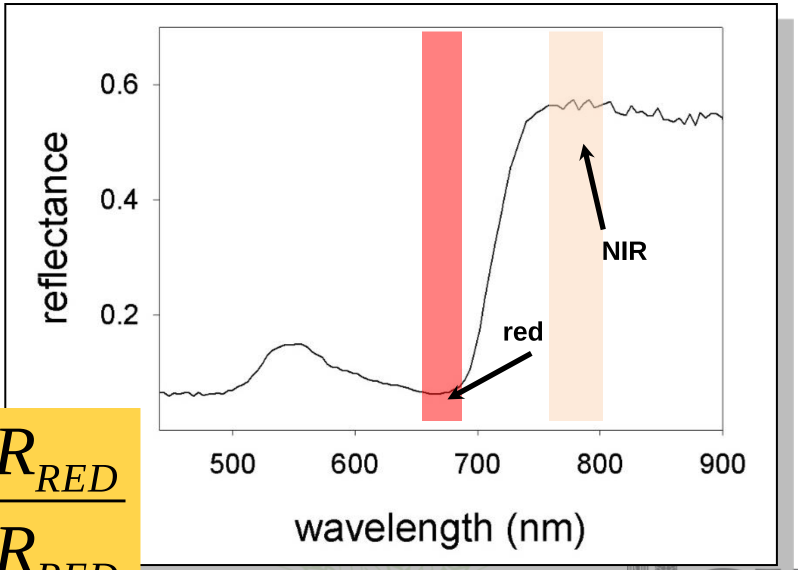
1) Spectroscopy for plant phenotyping



Spectral patterns of absorption, transmission and reflection of photons are primarily determined by plant pigments, constituents and structure



$$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$$



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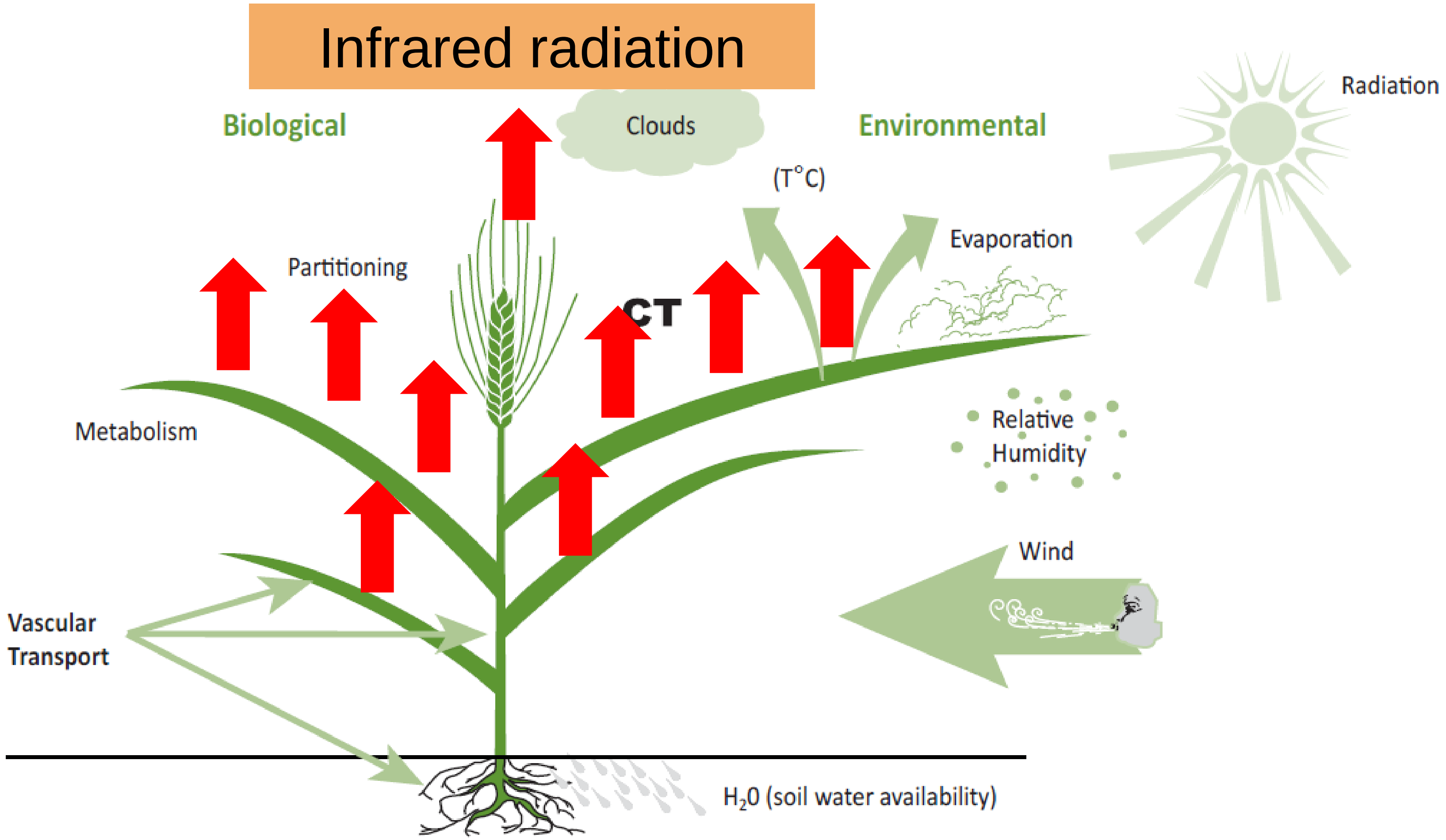
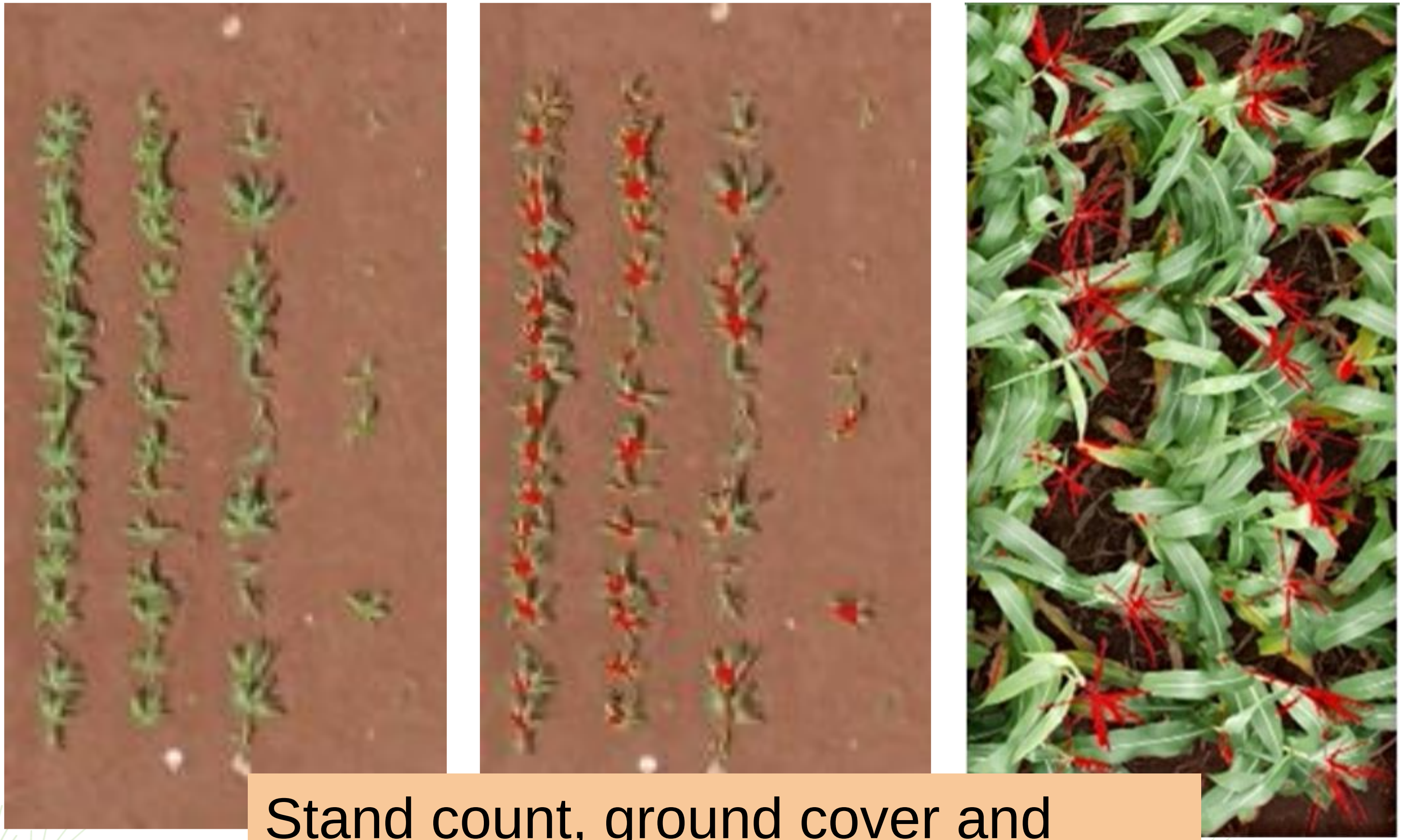
2) Thermography: plant temperature as an indicator of physiological status



3) Methods for object identification and classification + photogrametry



Stand count, ground cover and phenology using RGB imaging

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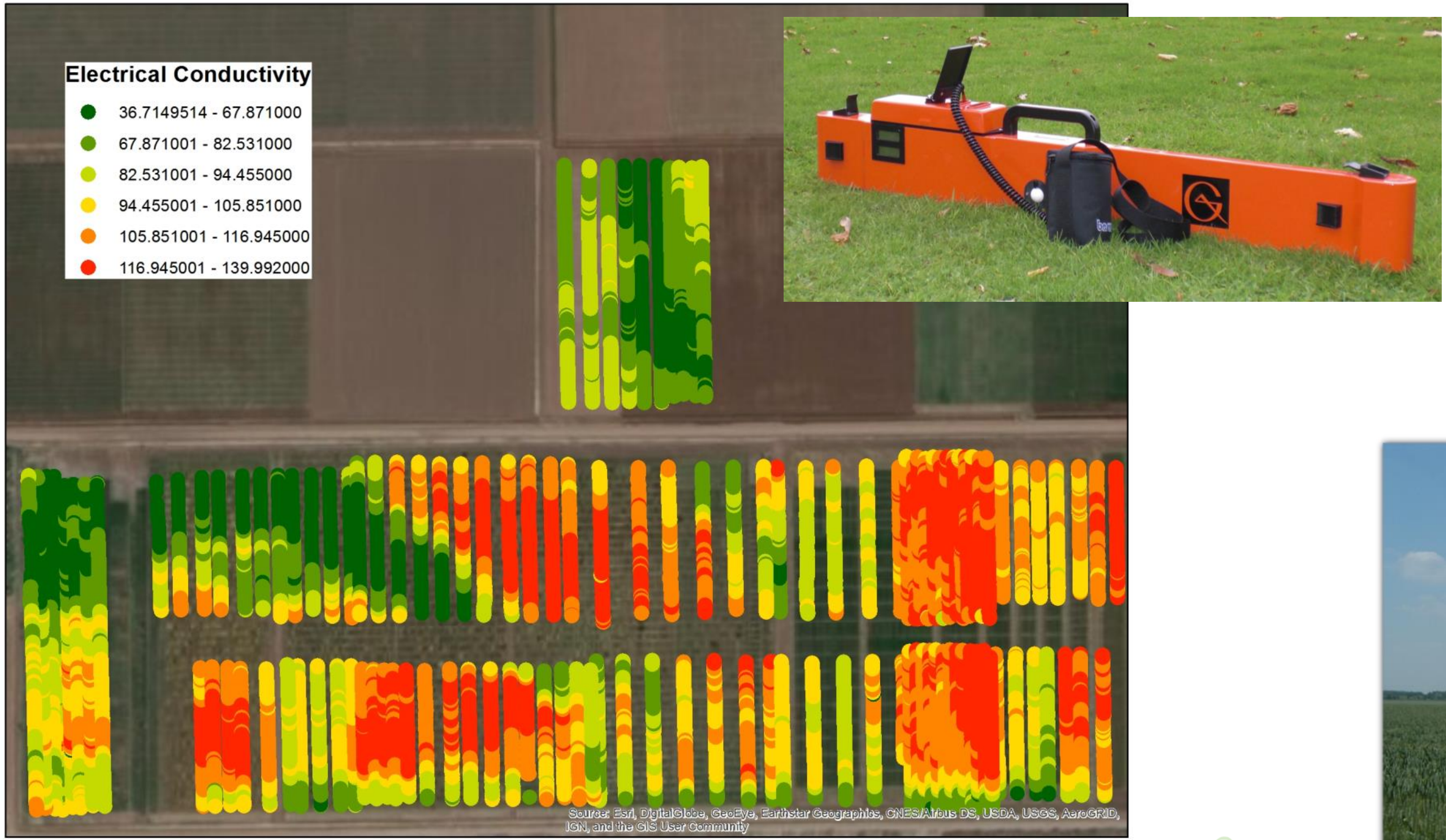
4) Envirotyping



- Soil characterization
- Weather characterization
- Field management

Platforms and sensors

Sensors and platforms: aerial phenotyping at GWP

Drones

Matrice 200
DJI, China

Max. payload: **1 kg**

Matrice 600
DJI, China

Max. payload: **6 kg**

eBee
senseFly,
Switzerland

Max. payload: **0.15 kg**

NDVI and vegetation indices

RedEdge, MicaSense
Bands: 475, 560, 668, 840, 717 nm

Main products: **NDVI, SR**
GSD at 30m: 2.0 cm/pixel

2p multispec, Slantrange
Bands: 532, 570, 650, 850 nm

Main products: **PRI, NDVI**
GSD at 30m: 1.3 cm/pixel

ADC-Lite, Tetracam
Bands: 560, 660, 830 nm
Main product: **NDVI**
GSD at 30m: 1.1 cm/pixel

Mini-MCA 12 ch, Tetracam
Bands: 445, 550, 670, 680, 700, 710, 720, 760, 780, 800, 900, 970 nm

Main products: **NDVI, WI, SR, RARS**
GSD at 30m: 1.6 cm/pixel

Thermography

Zenmuse XT, DJI/FLIR
Range: 8-14 µm
GSD at 30m:
4 cm/pixel

TAU 640, FLIR
Range: 8-14 µm
GSD at 30m:
2 cm/pixel

RGB y 3D

Zenmuse X5, DJI
GSD at 30m:
0.8 cm/pixel

NEX 5, SONY
GSD at 30m:
0.9 cm/pixel

Hyperspectral

Micro-Hyperspec, Headwall Photonics
Range: 600 – 1700 nm
n. bands: 267
GSD at 30m: 1.8 cm/pixel

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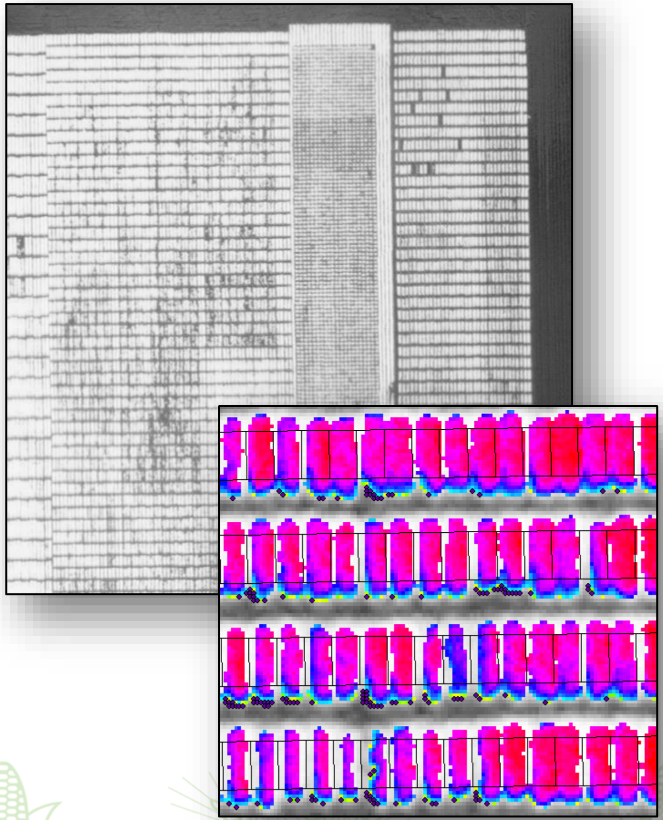
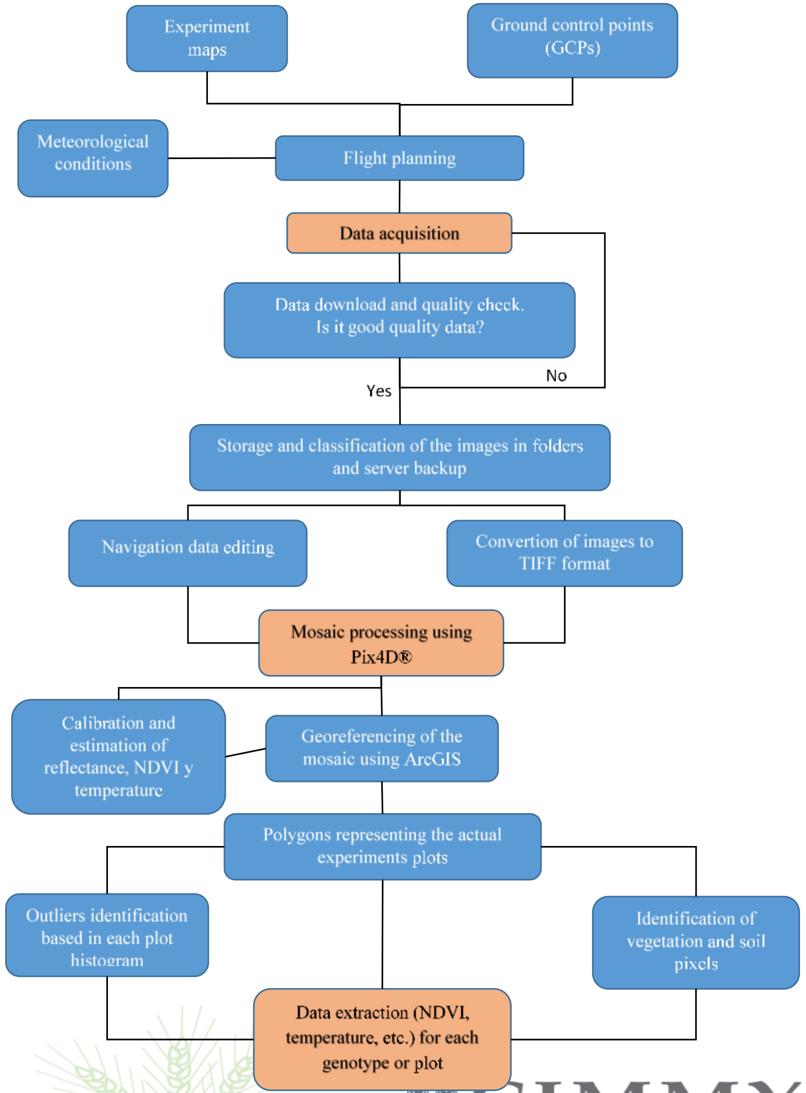
Towards the automation of a UAV-based HTP platform

Georreferencing our experiments

Images generated by J.M. Mendoza

Semi-automatic data extraction





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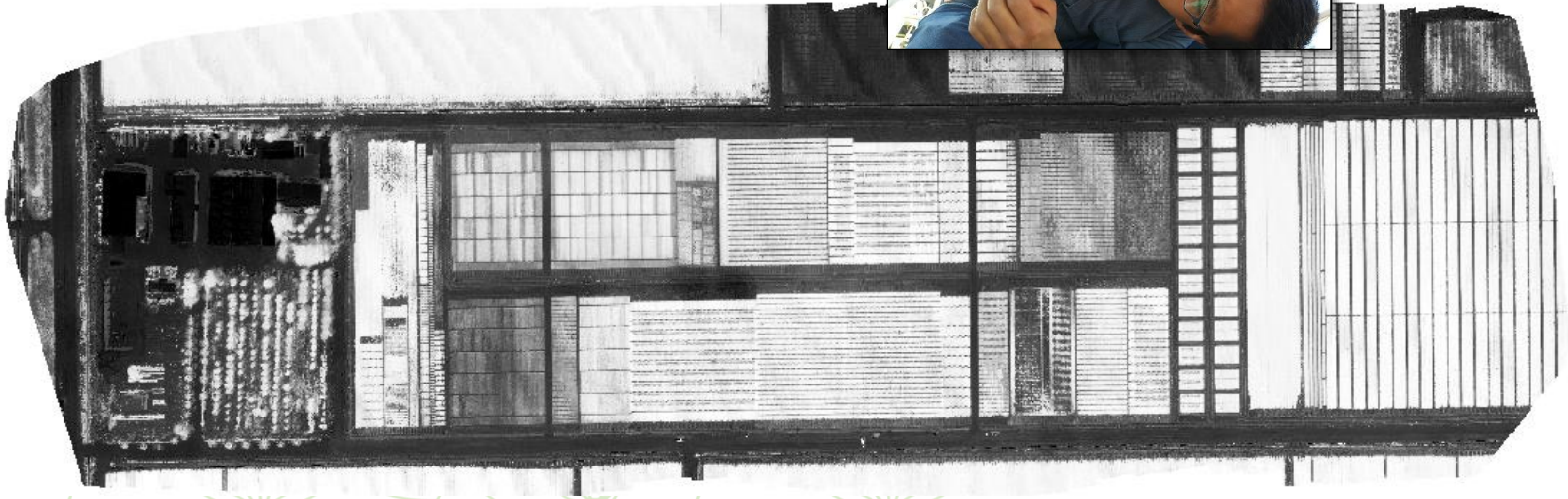
Moving from UAV to manned aircraft

Multispectral and thermal cameras:

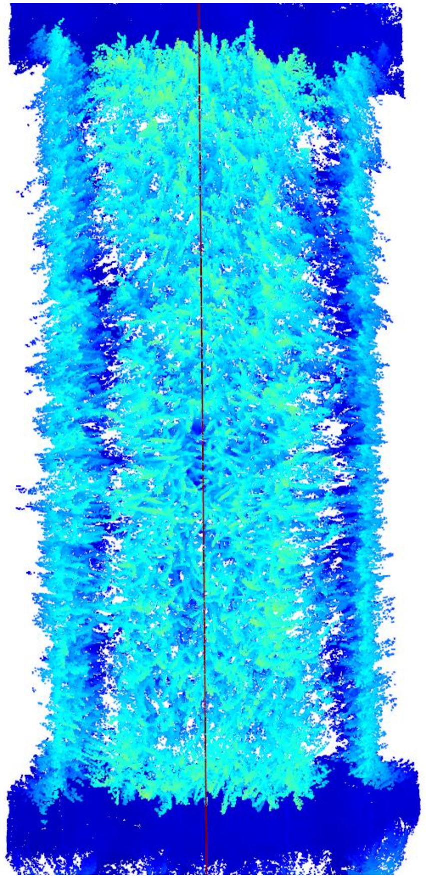
- NDVI
- MCARI
- Chlorophyll Index (green)
- Chlorophyll Index (Red-Edge)
- LAI (Prosail)
- CAB(Prosail)
- FAPAR (Prosail)
- QPAR
- Canopy Temperature
- Biomass index
- Plant height

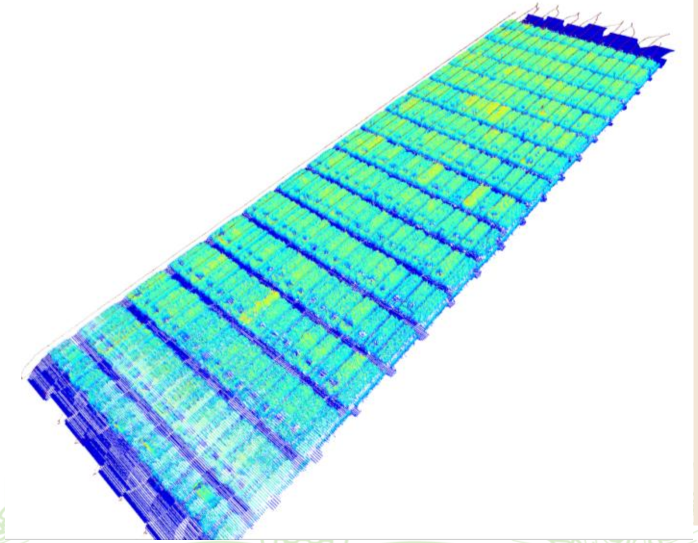
(Collaboration with HIPHEN)

Flights every 7-10 days



New platforms for ground phenotyping





Development of a terrestrial vehicle for integrated measurements of different sensors:

- LIDAR: structural traits such as plant height and biomass.
- Thermal sensors
- Multispectral cameras and hyperspectral sensors
- RGB digital cameras
- NDVI and PRI sensors

New platforms for ground phenotyping

Dataset for the:
The Global Wheat Head Detection Challenge

Collaboration with private sector for developing a phenotyping rover based on Deep Learning

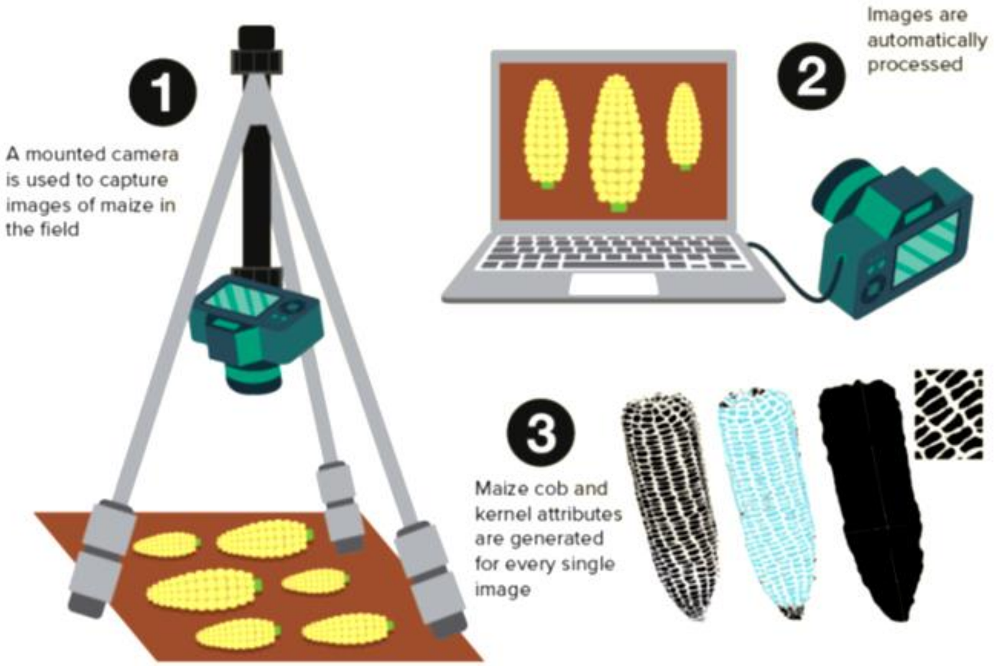
Evaluating some key physiological traits

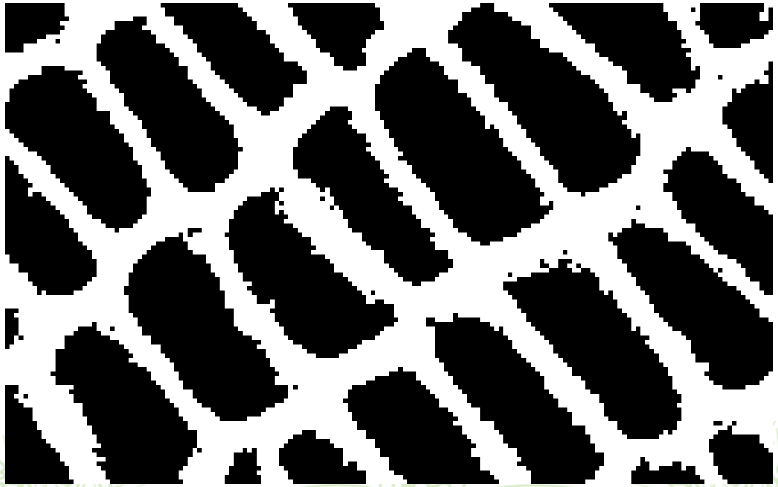
Digital RGB images

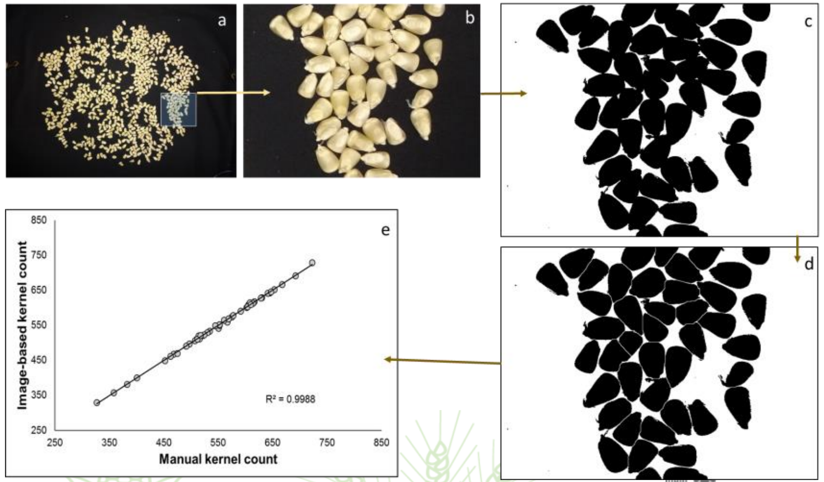
Using RGB imaging for spatial distribution and structural properties of the vegetation

Calculating the vegetation ground cover using.

Maize Ear Phenotyping







Makanza et al, 2018

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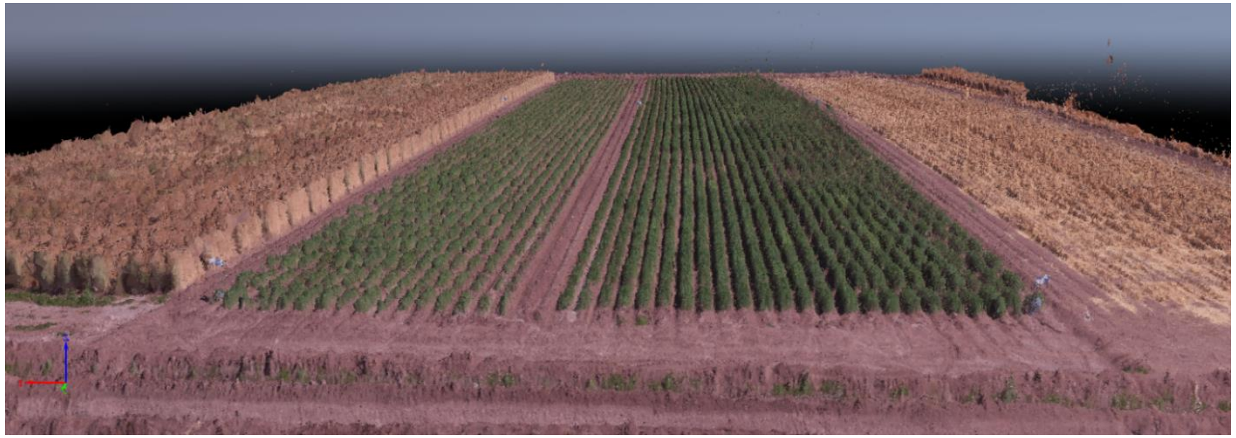
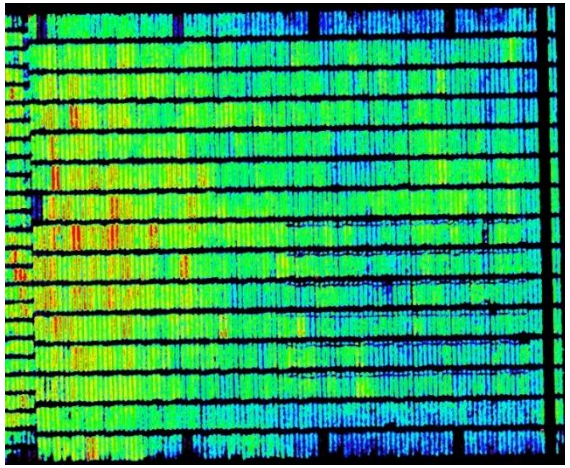
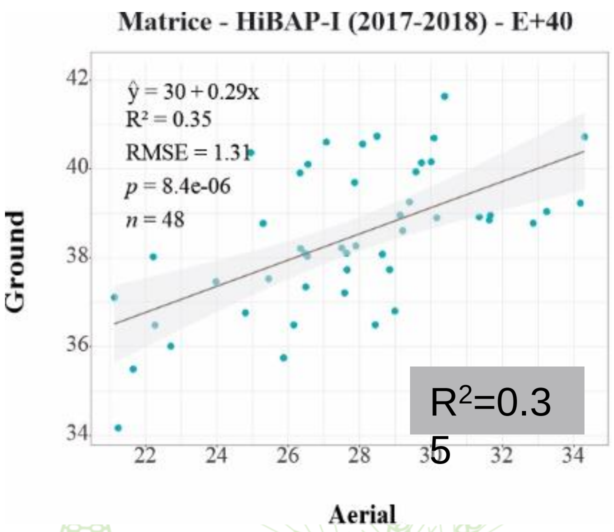
RGB photogrammetry for reconstruction of 3D model of canopy surface



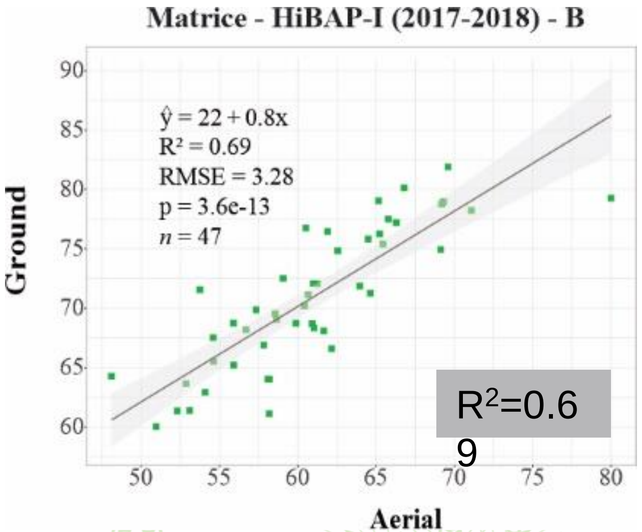


- Good estimations of plant height.
- Prospects for estimation of biomass using plot volume as proxy

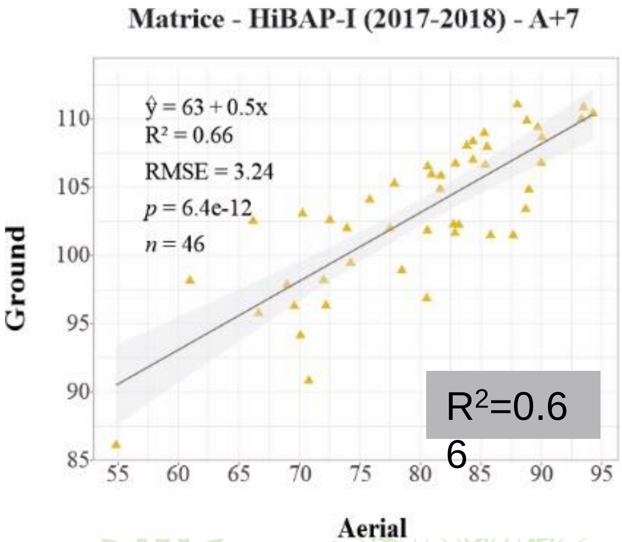
Volpato et al. (2021)



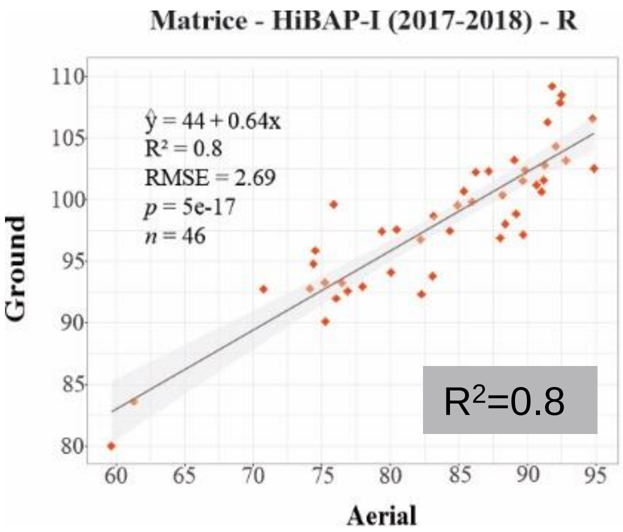
40 days after emergence



Booting



7 days after Anthesis



Physiological maturity

Estimation of RUE under yield potential

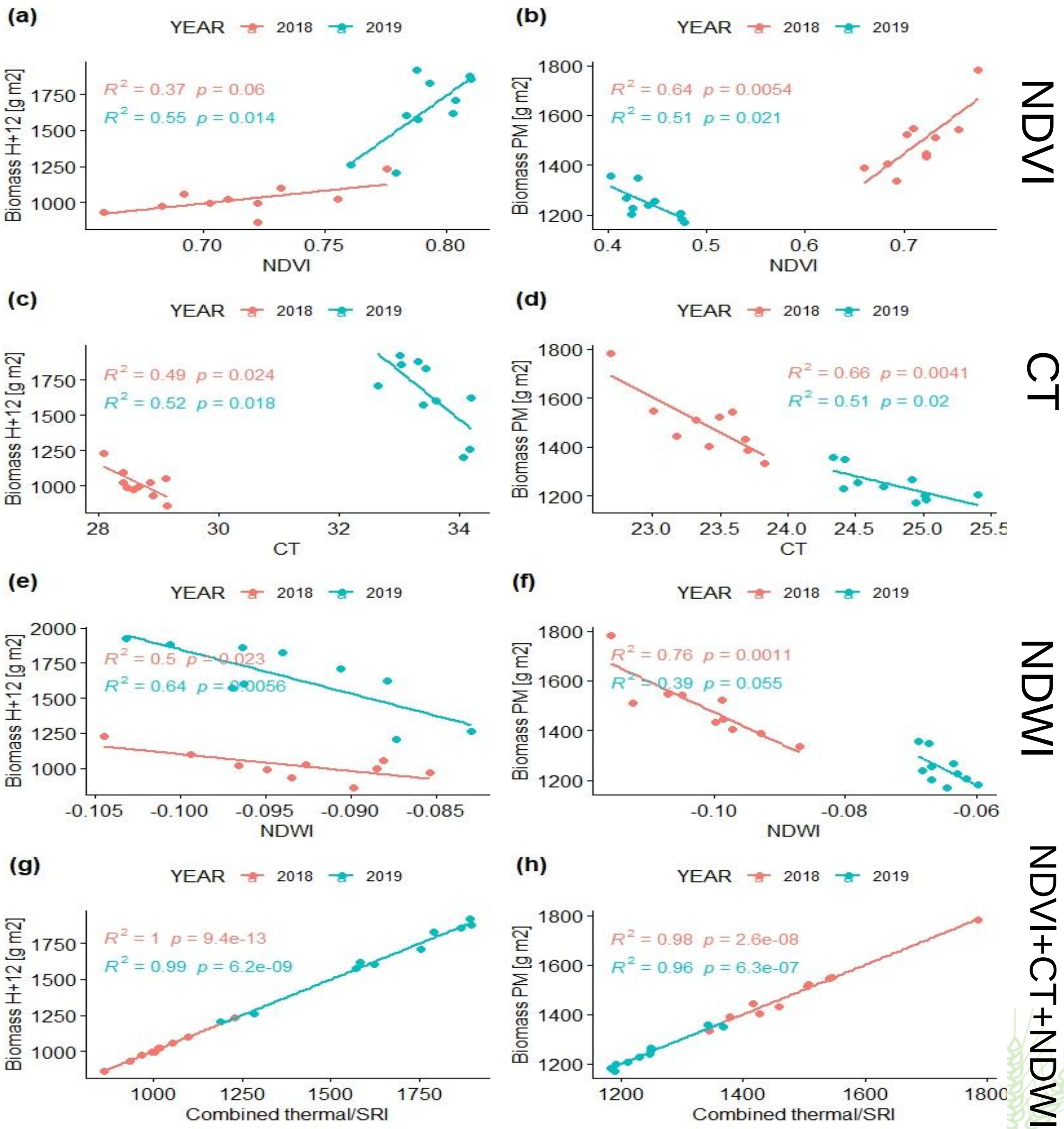
Trait	Growth stage	RS variables used in the best models	R^2	RMSE
IPAR	E+40	NDVI, GNDVI, MCARI	0.95	3.21
	A+7	NDVI	0.92	11.99
	PM	NDVI	0.92	20.93
Biomass	E+40	CRI, CUR, NDVI, TCARI	0.63	16.06
	A+7	NDWI, CT, CT	0.66	51.73
	PM	CT, NDVI	0.61	74.17
RUE	pre Grain Filling	NDVI, NDWI	0.42	0.17
	grain filling	SPAD, CT, EVI, RGR	0.79	0.15
	Total	SPAD, CRI, CT, NDVI	0.94	0.04

- IPAR: chlorophyll-related indices (e.g. NDVI)
- Biomass:
  - E+40: **Pigment-related indices** (TCARI and CRI)
  - A+7: **NDVI + normalized water index** (NDWI) **+ canopy temperature** (CT)
- RUE:
  - Vegetative stage: **NDVI + NDWI**.
  - Grain filling: **CT + chlorophyll-related indices**

$$RUE = \frac{BM_{acumulated}}{IPAR_{accumulated}}$$

Robles-Zazueta et al. (2021)

Estimation of shoot biomass



- <u>Canopy temperature (CT), NDVI and water indices (NDWI) </u>tested as estimators of biomass measured 12 days after heading (BM_H+12) and at physiological maturity (BM_PM)

- **NDVI** showed the lowest prediction capacity across dates.
- **CT** showed high correlation with both BM_H+12 and BM_PM, particularly in early grain filling
- **NDWI** also showed a robust and high correlation with biomass when measured during grain filling.
- The **multiple linear model** combining the three RS variables measured during grain filling resulted in the highest correlations with BM_H+12 and BM_PM

Next step: to build and validate similar model for a larger population and across years: HIBAP

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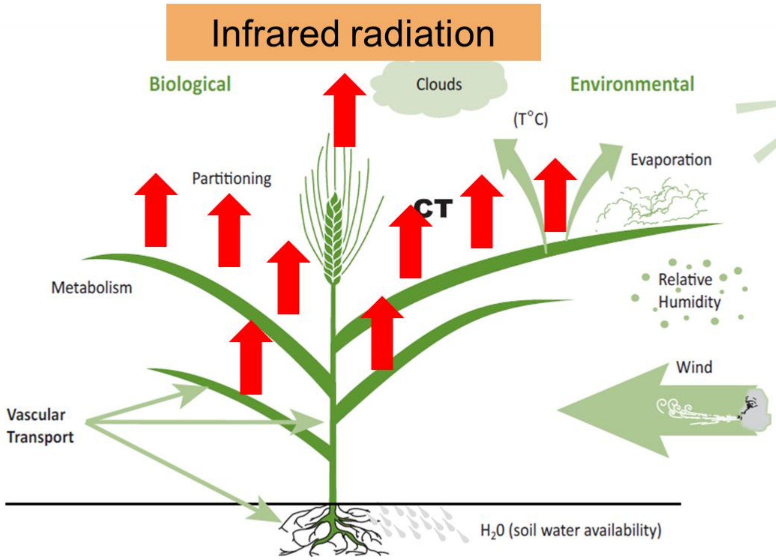
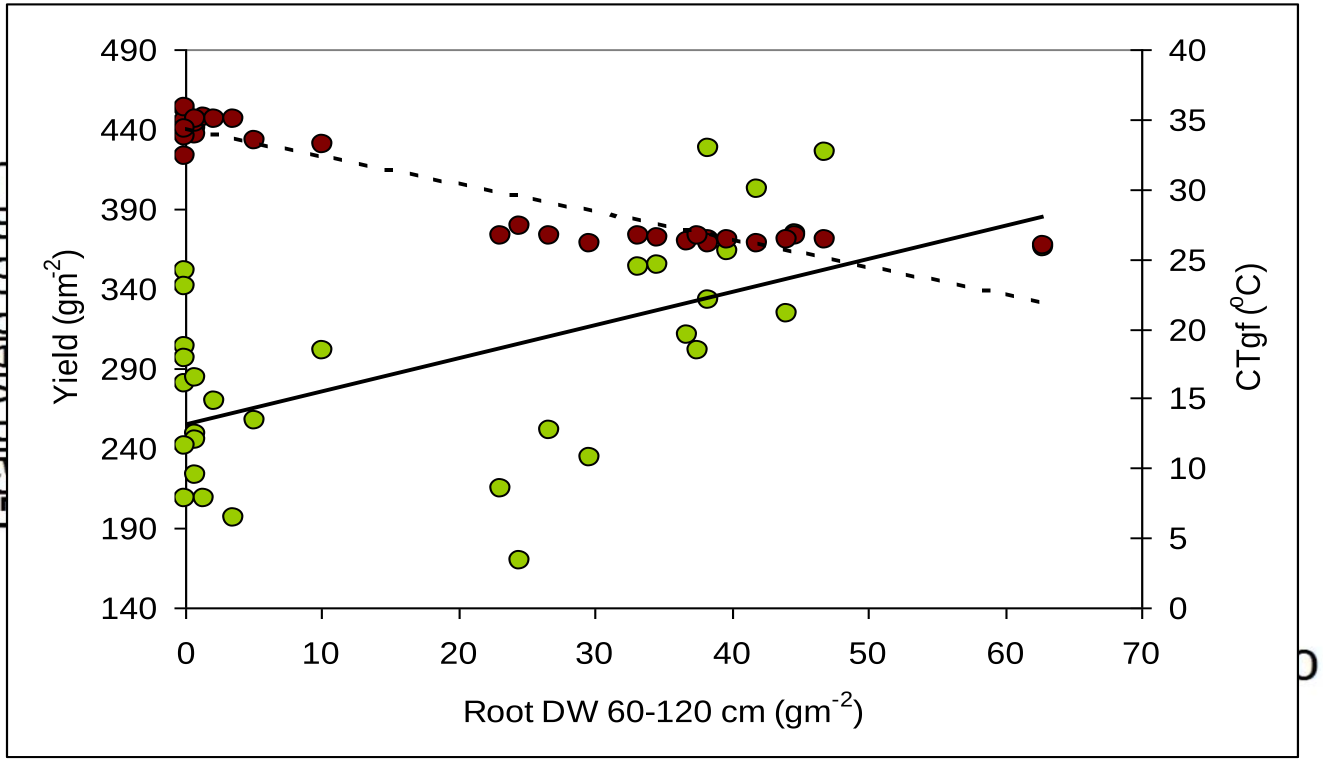
Robles-Zazueta et al. (2020) *In preparation*

Canopy temperature: a possibility for phenotyping root capacity

Canopy temperature:

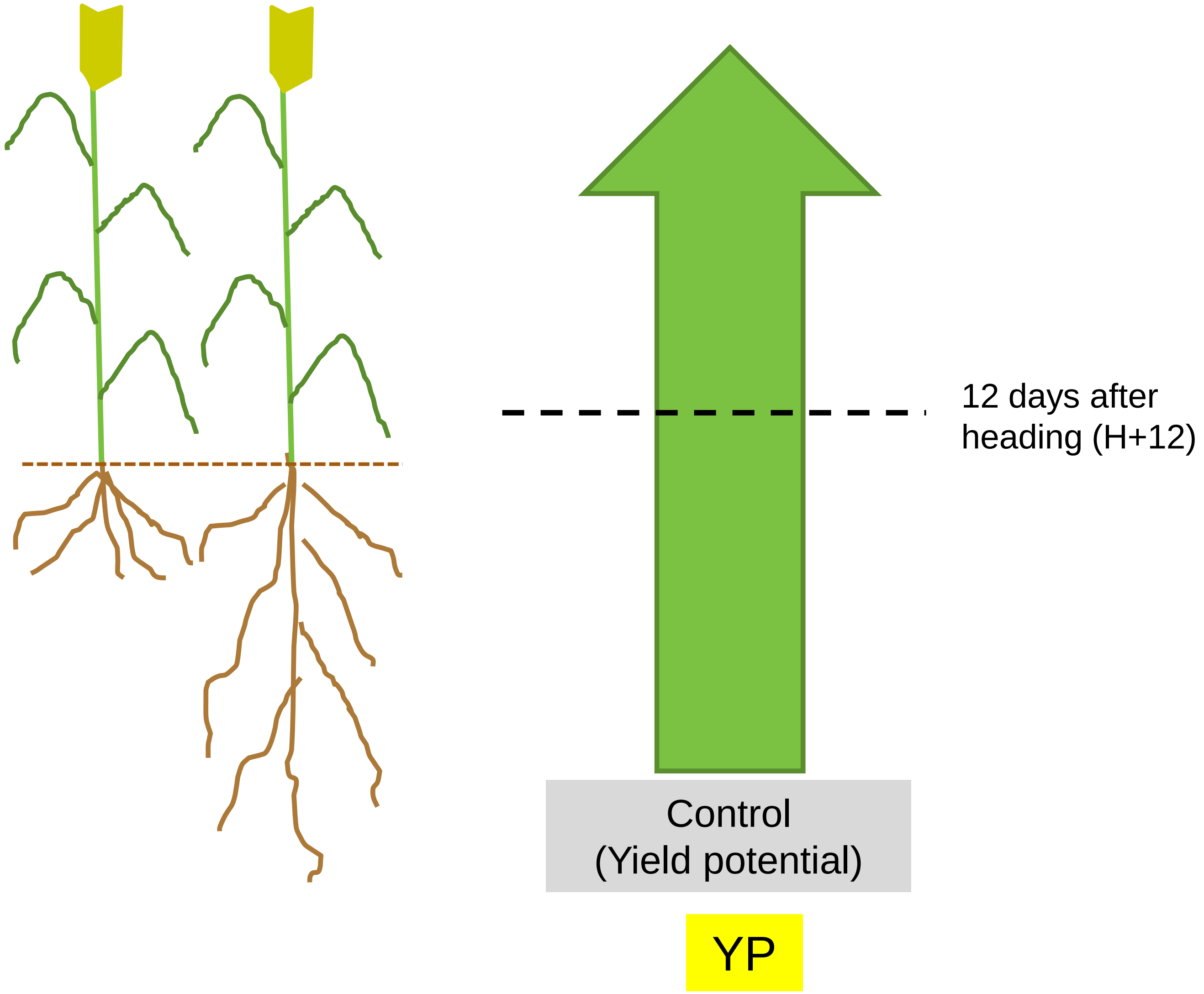
Related to the interaction of few environmental factors an plant physiology.





Lopes MS and Reynolds MP, 2010.
Pinto & Reynolds, 2015.

Field experiment: imposed stress where canopy temperature and water reflectance indices would reflect root capacity



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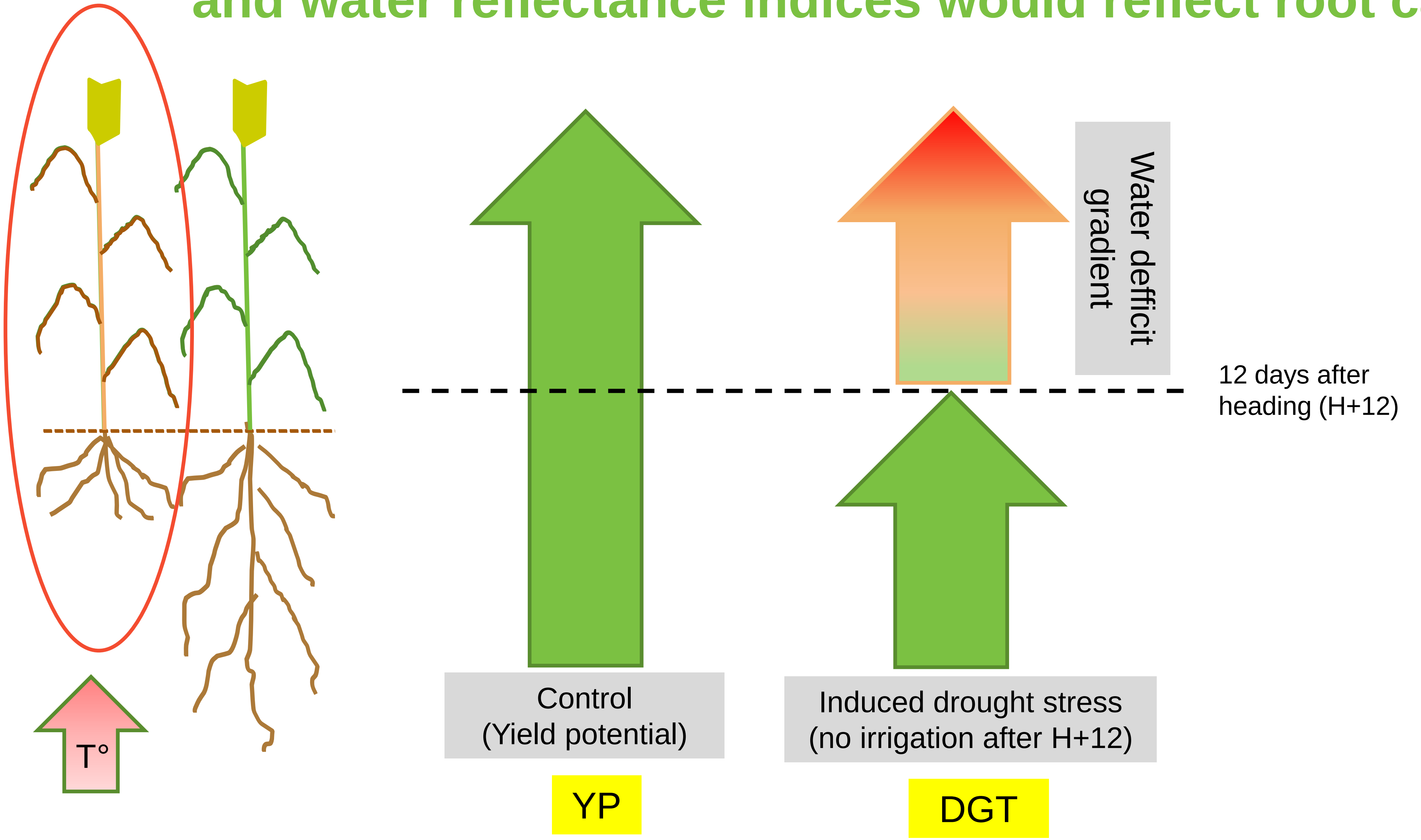

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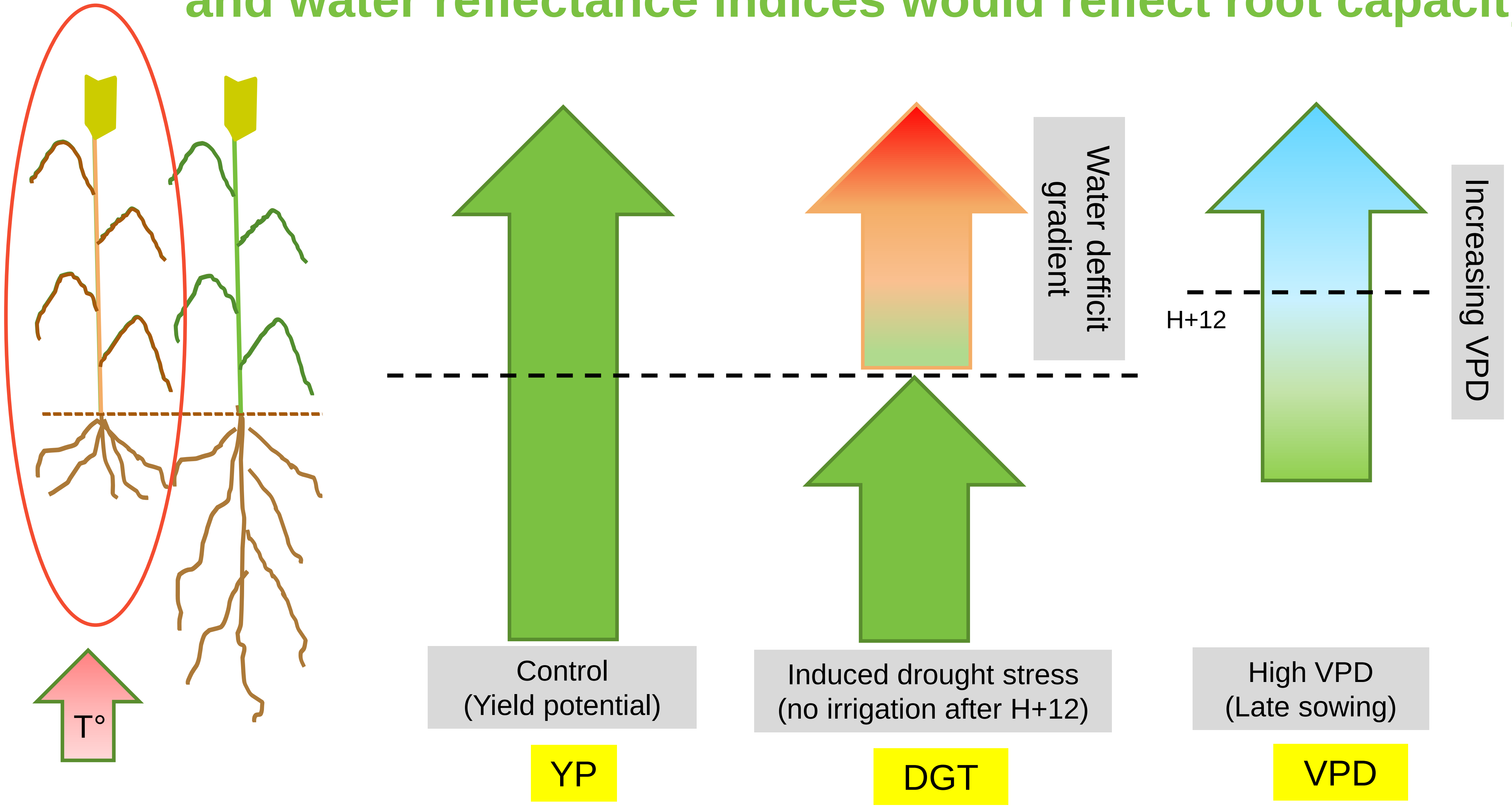
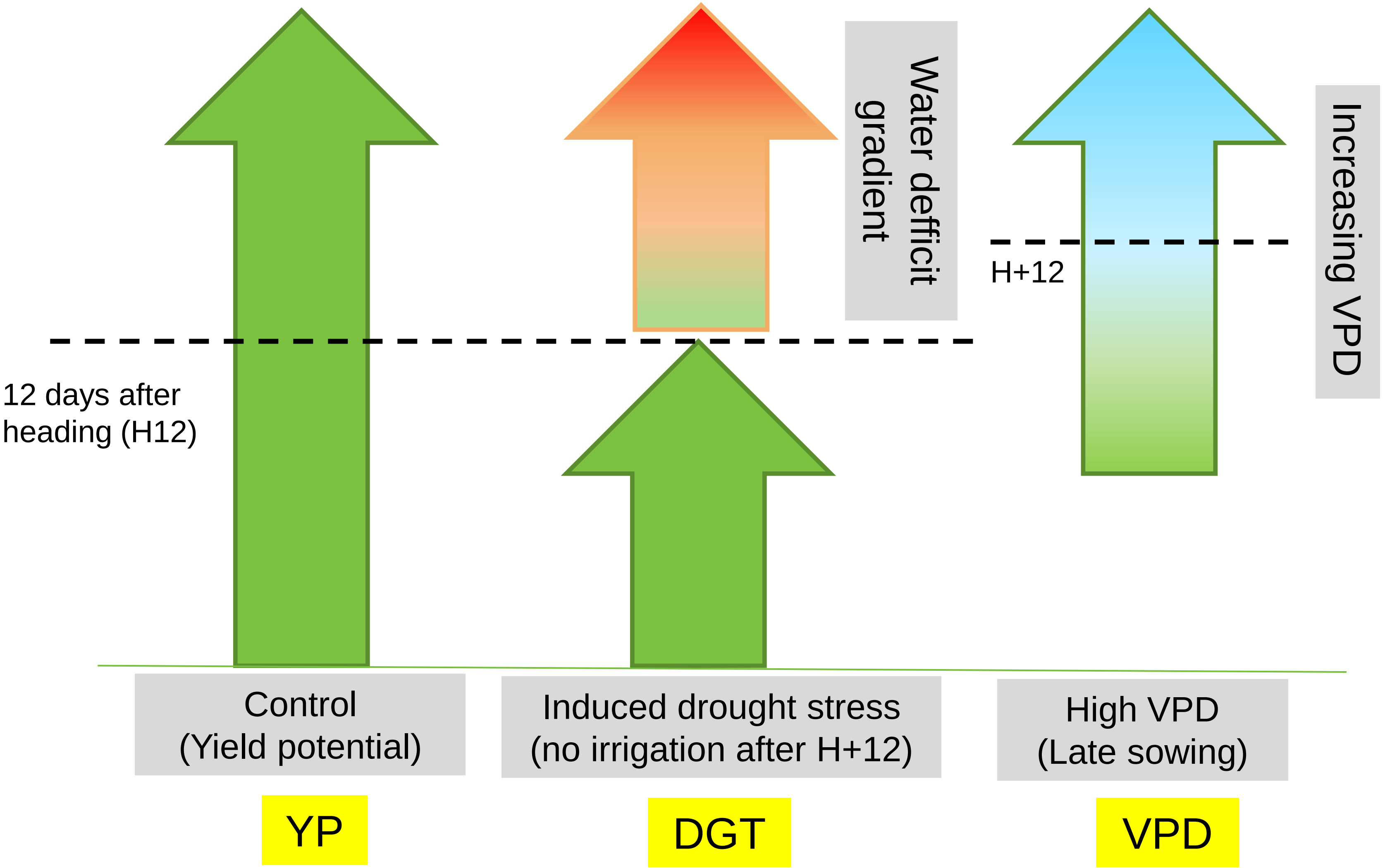


Field experiment: imposed stress where canopy temperature and water reflectance indices would reflect root capacity

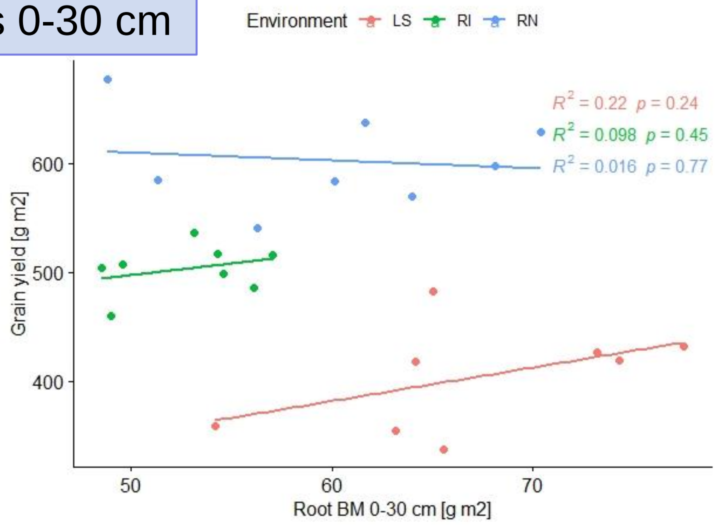


- 10 lines
- 4 beds (0.8 x 5 m) per plot
- 3 reps
- 2 cycles: 17-18 and 18-19

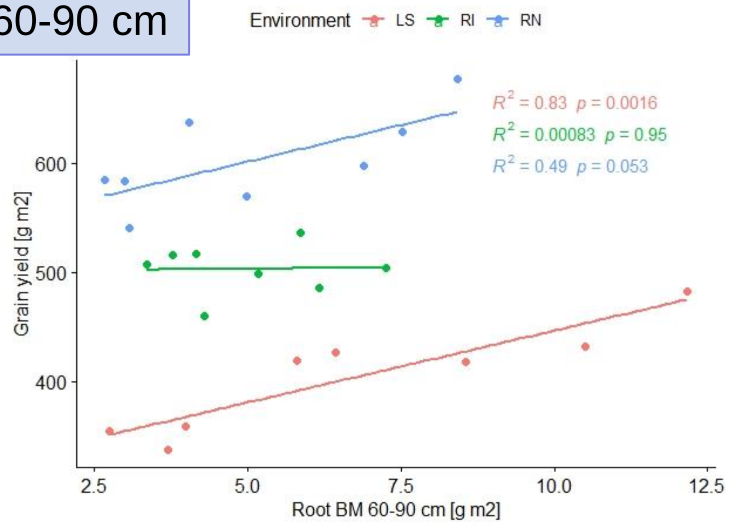
Root traits vs grain yield (2018)

Root biomass vs yield

Roots 0-30 cm



Roots 60-90 cm



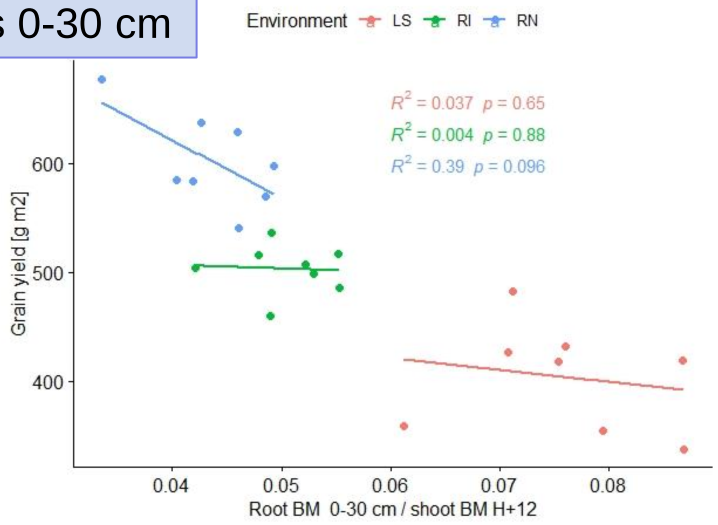
YP

DGT

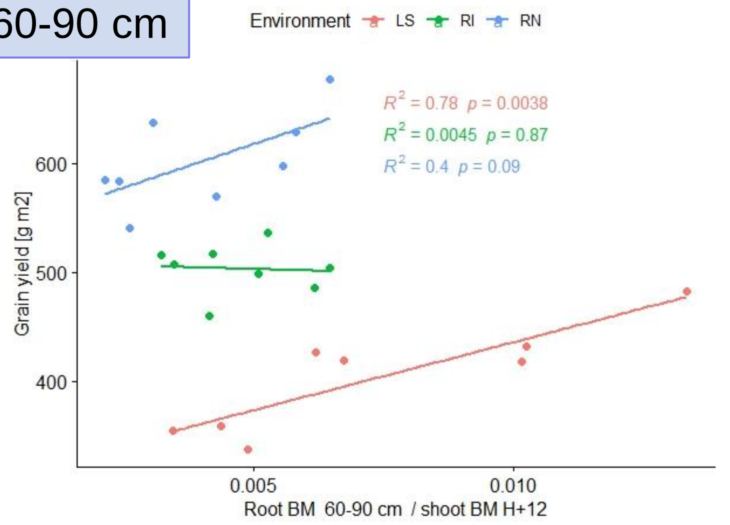
VPD

Root : shoot vs yield

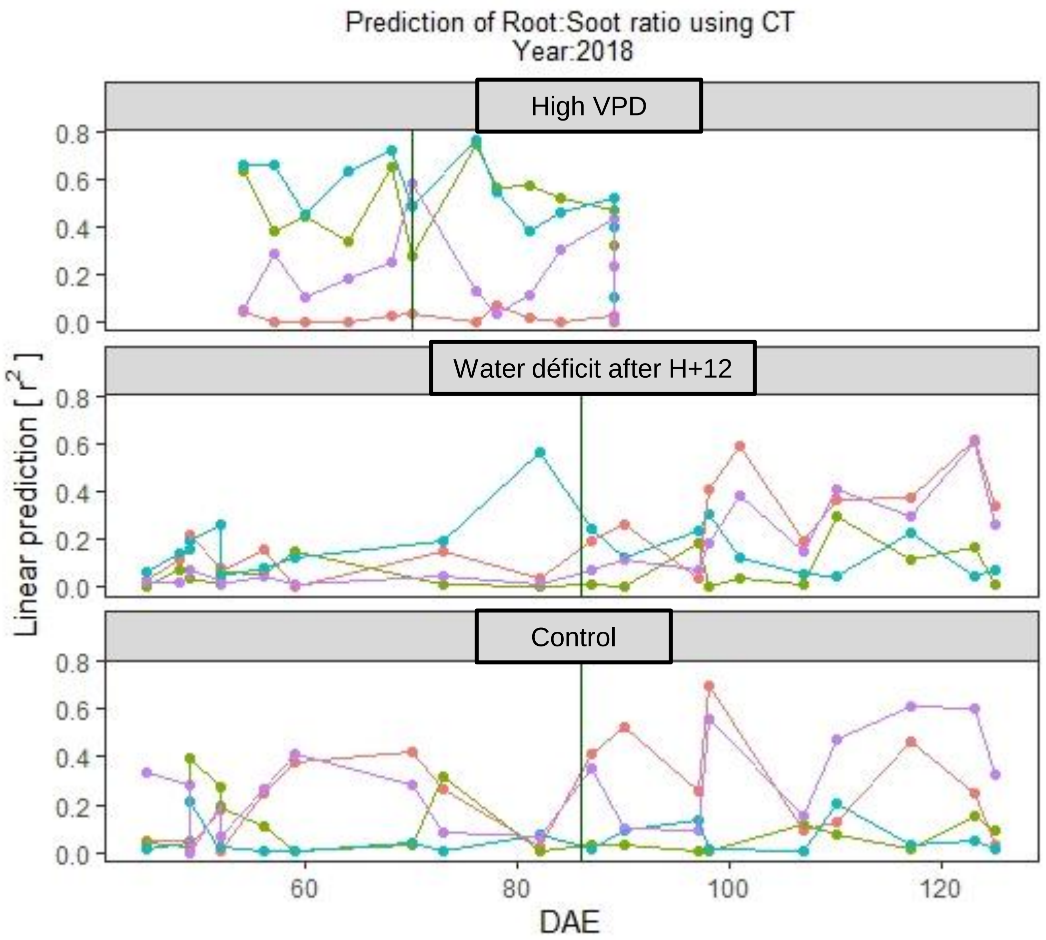
Roots 0-30 cm



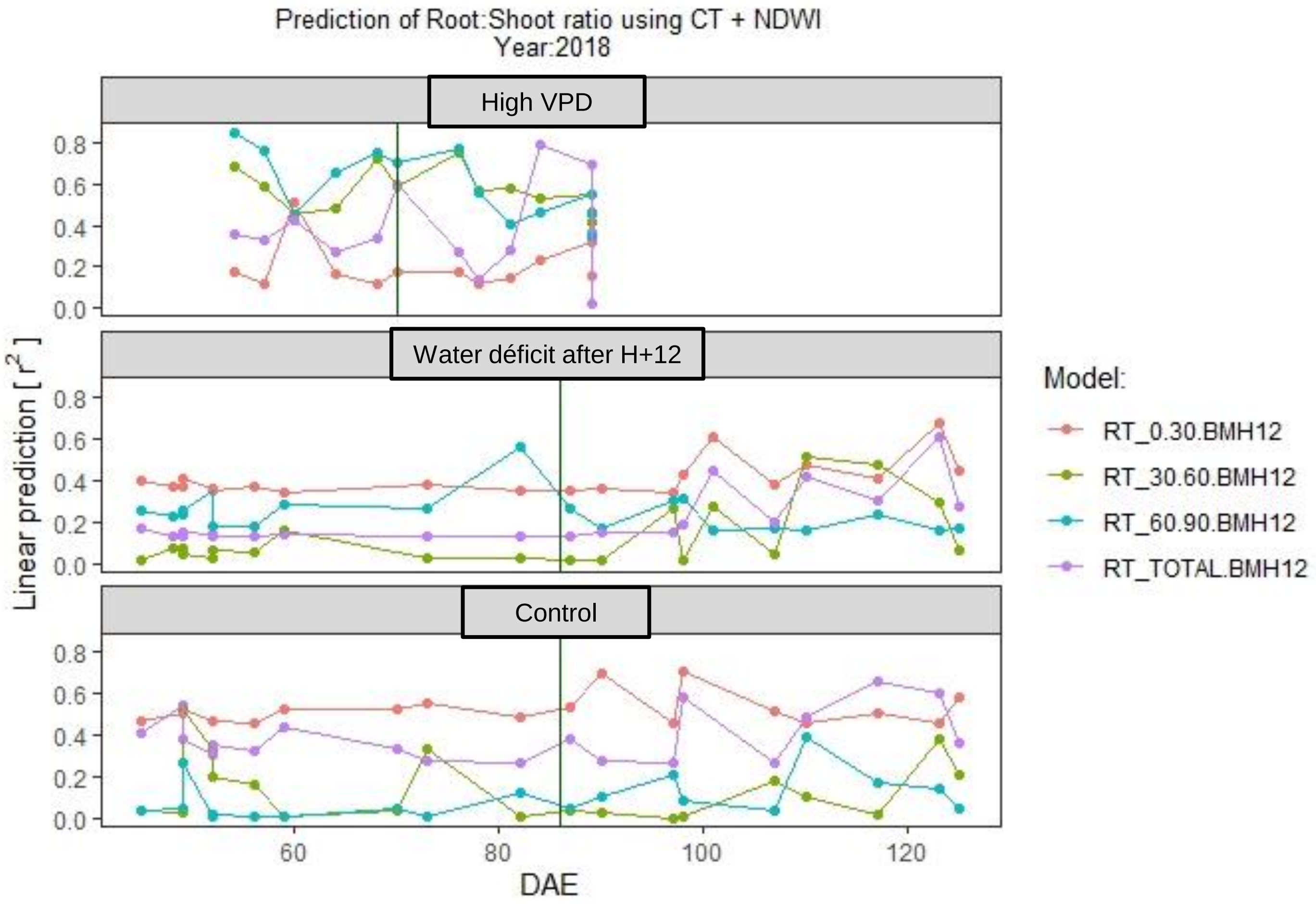
Roots 60-90 cm



Canopy temperature and water reflectance indices as indicators of root:shoot ratio



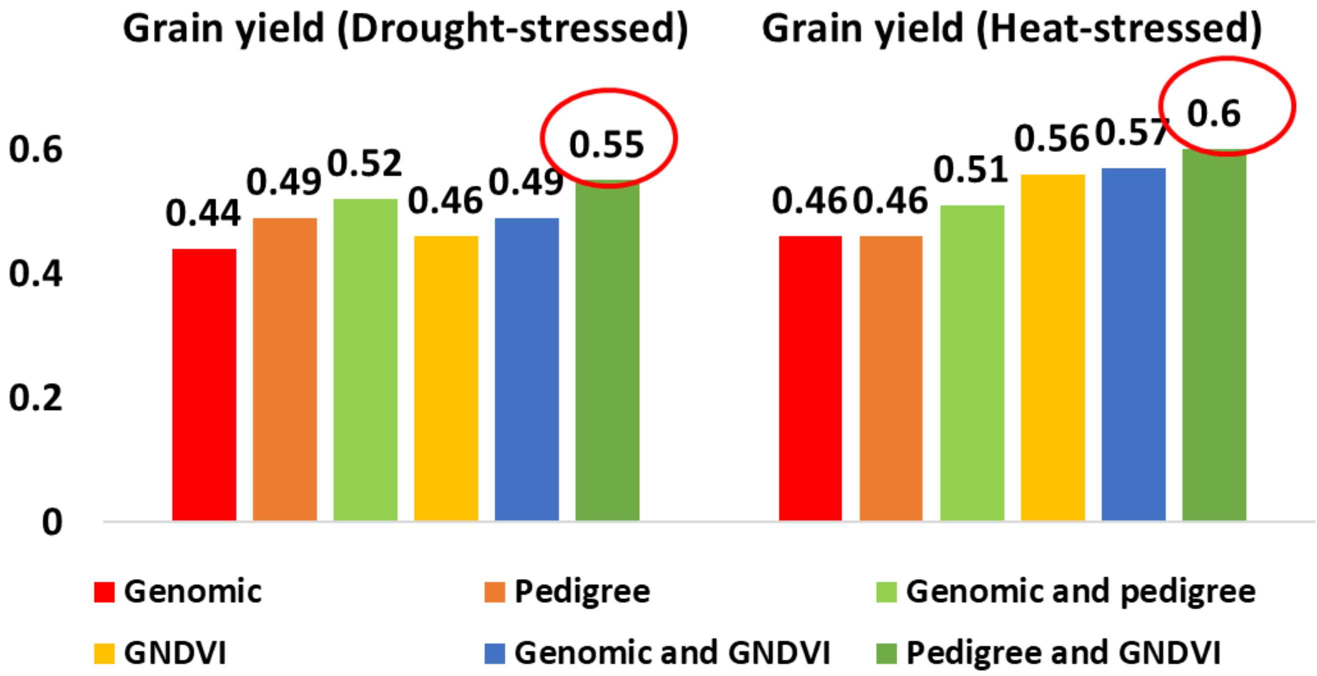
CT as predictor



CT + NDWI as predictors

HTP for improving genomic selection models

- Measuring NDVI and CT on YT and EYT
- Measurements on 3 cycles
- DGGW and Feed the Future Innovation Lab for Applied Wheat Genomics projects



NDVI for complementing genomic and pedigree selection models.

Juliana et al 2018

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What is next…

Ongoing developments: challenges and "whish list"

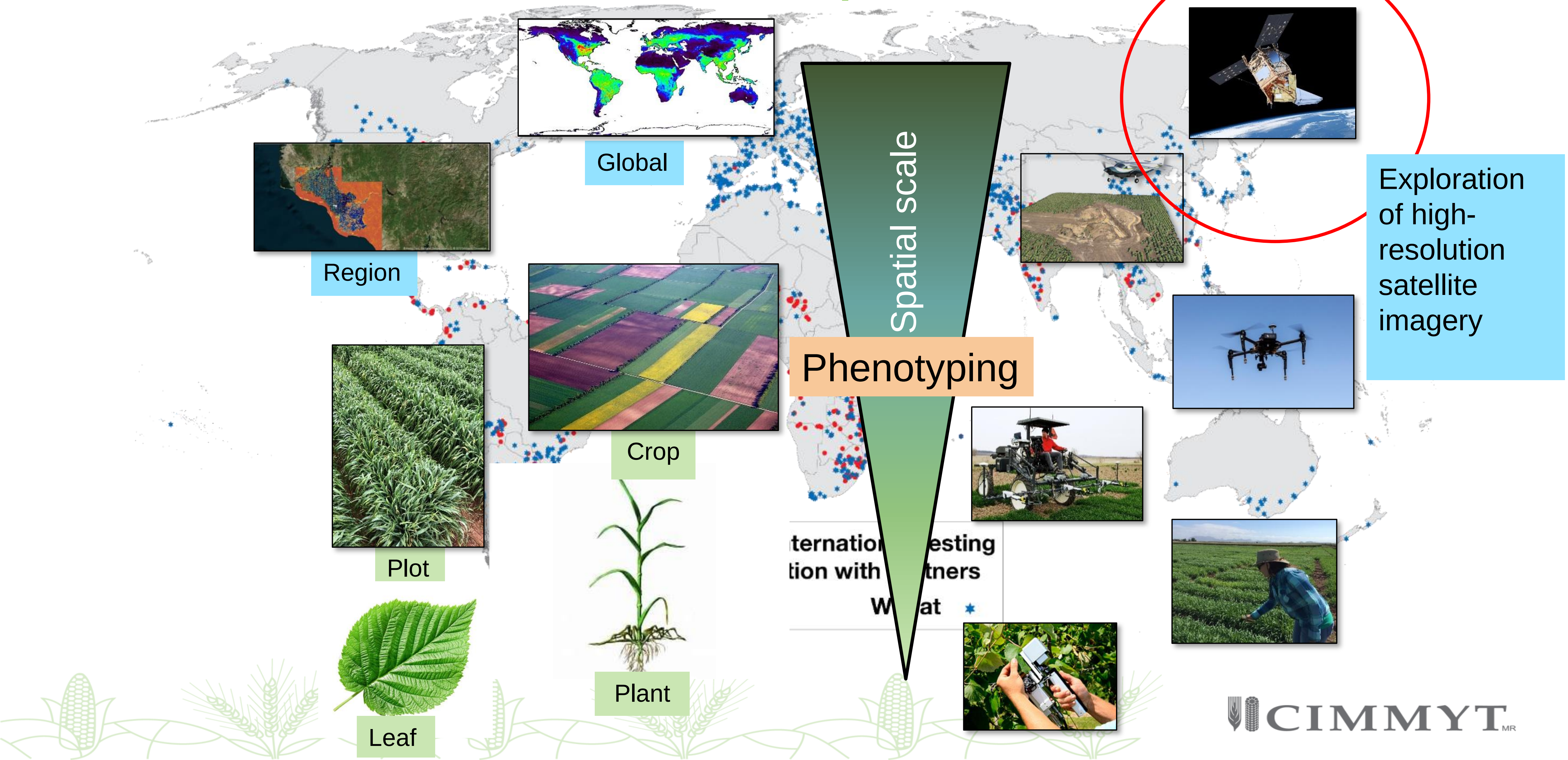
- Automatization and up-scaling of routine aerial of multispectral and thermal images (Collaboration wth HIPHEN)
- Ground-based imaging systems for Deep-learning
- Improving environment characterization

Calibration/validation
Automatic image processing
Data quality check
Data management

Parameters/indices for indirect estimations of:

- Biomass (water index, 3D point cloud)
- Structural traits (3D reconstruction, radiative transfer models)
- Water use efficiency
- Radiation Use Efficiency (hyperspectral, fluorescence)
- Phenology (heading detection)
- Spike density
- Disease screening and early detection

Challenges for MET in wheat: characterizing the GxExM component



Acknowledgments CIMMYT

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Gilberto Thompson
Rodrigo Rascon

SIP:

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Lorena Gonzalez

CIMMYT

Donors & collaborators

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International Wheat Yield Partnership
Research to Deliver Wheat for the Future

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Thank you for your interest!