# UAV- based imagery for phenotyping in breeding and physiological pre-breeding of wheat at CIMMYT

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IWYP

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# CIMMYT Global Wheat Program locations in Mexico


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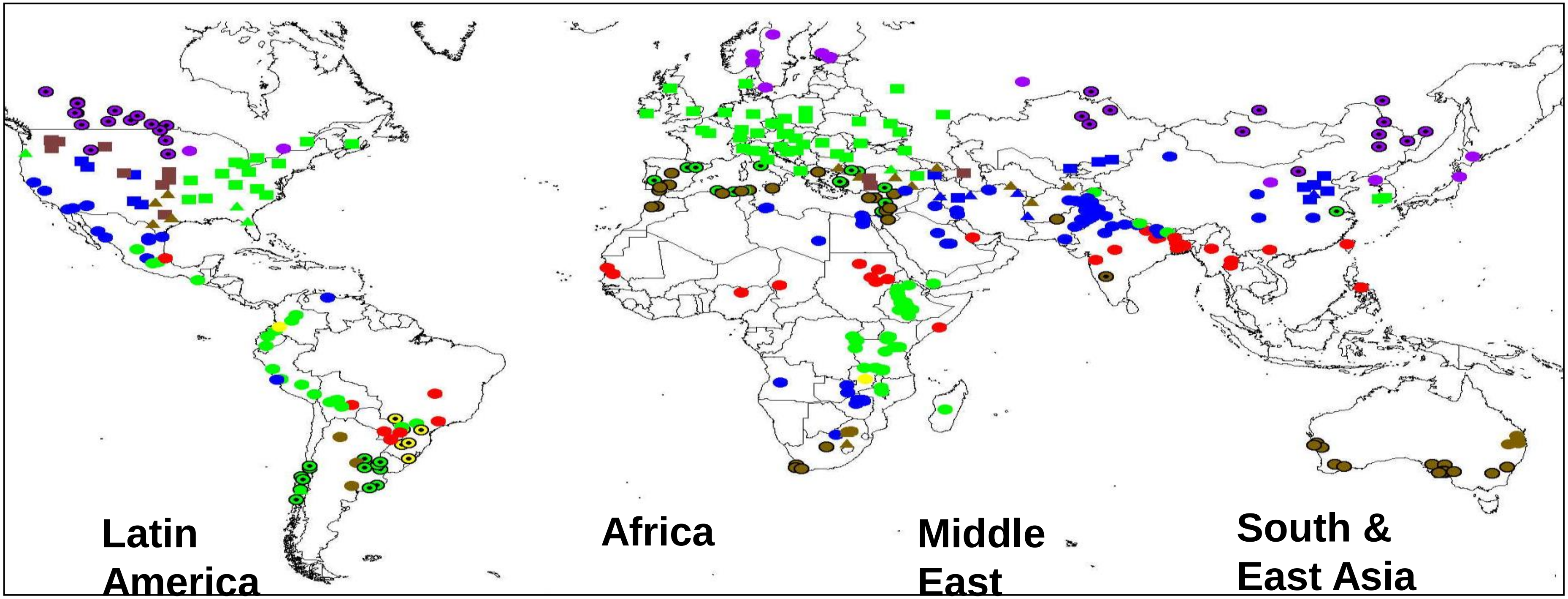
# International Wheat Improvement Network (IWIN)

## Coordinated by CIMMYT since 1960s




CIMMYT distributes 1,000 new wheat genotypes annually targeted to a range of environments

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# HTP in our Wheat Program

## Wheat breeding program

**Objectives:**
- Reducing breeding time
- Improving selecting efficiency
- Phenotype under diverse environment

**Traits:**
- Yield
- Phenology
- Disease resistance

**RS parameters/information:**
NDVI, Canopy temperature, RGB

## Wheat physiological pre-breeding

**Objectives:**
- Evaluation of physiological and morphological properties of the plants.
- Exploration of the available genetic resources.
- Selection of parents and progeny.-

**Traits:**
- Yield
- Phenology
- Biomass
- Photosynthesis (RUE, light interception)
- WUE
- Plant height

**RS parameters/information:**
NDVI, Canopy temperature, RGB, Water index, 3D structure, Surface model, PRI, Fluorescence, SRI, full spectrum analyzes

# HTP in the wheat breeding program

1st year yield trial(~10,000 lines) → 2nd year Multi-environment yield trial (~1000 Lines)

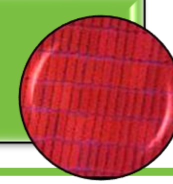
**Pedigree Information**

**Genotyping**

- GBS markers (KSU)
- 10,000 lines each year for 4 years

**High throughput phenotyping**

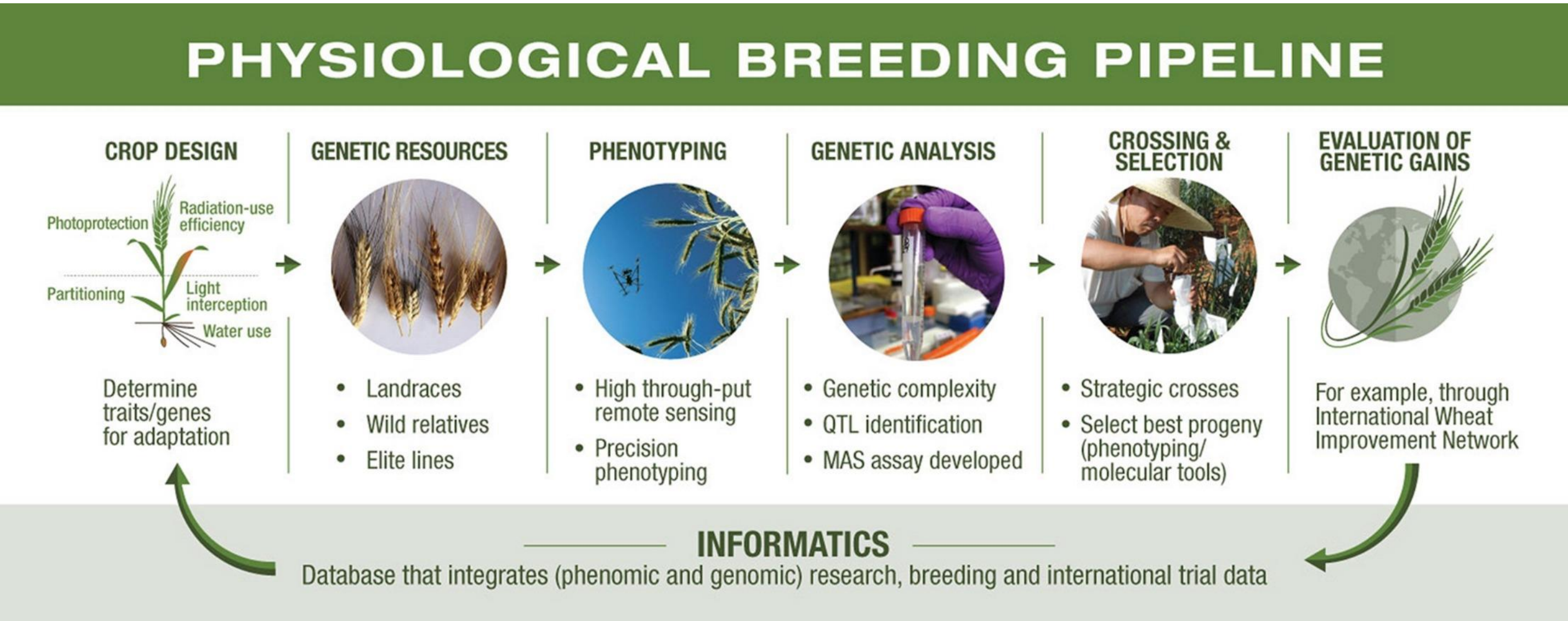
- Aerial & UAV phenotyping
- Thermal and hyperspectral camera



**Modelling & performance prediction**

# Physiological pre-breeding

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



# Physiological pre-breeding

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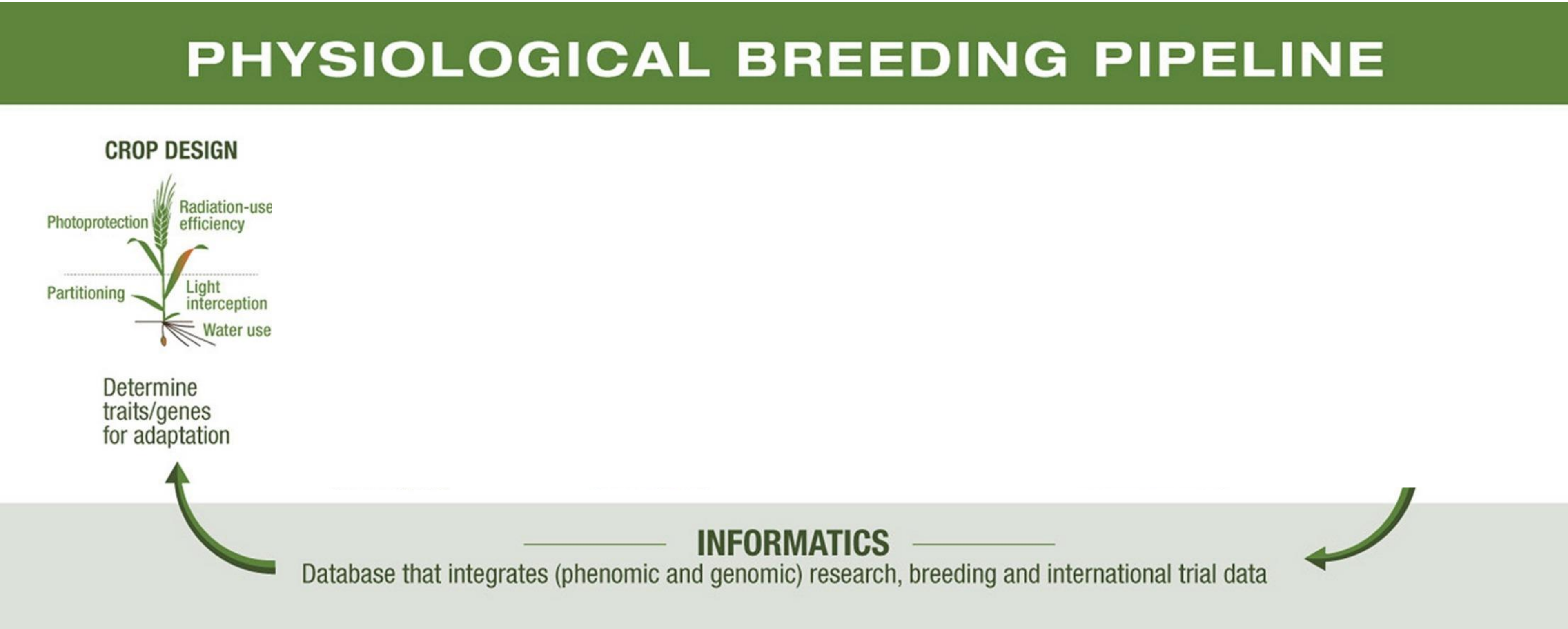


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# Physiological breeding as strategy for genetic gain: use of conceptual models

## 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

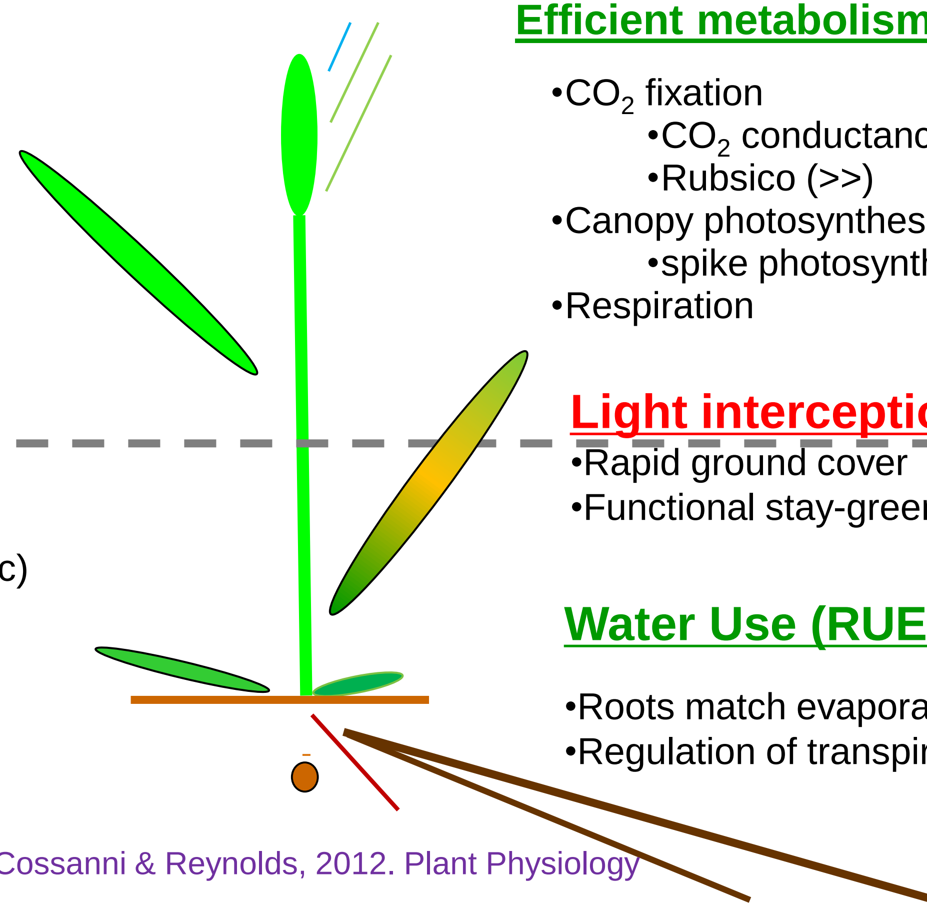
•Antioxidants

### 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

# Conceptual Model of Drought-Adaptive Traits

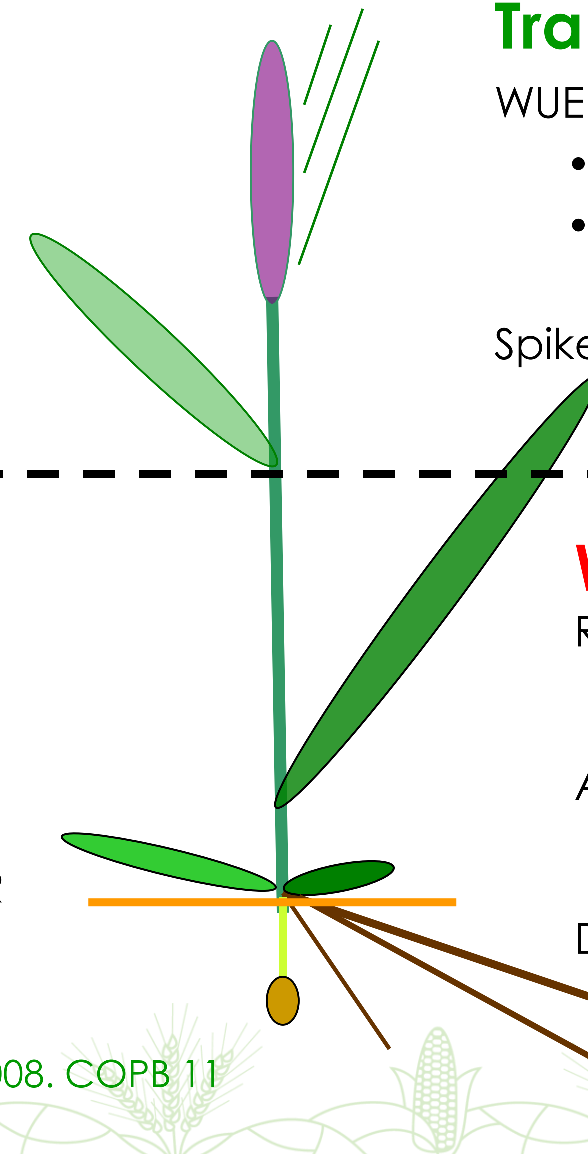
YIELD = WU x WUE x HI

## Photo-Protection

Leaf morphology
- wax/pubescence
- posture/rolling

Pigments
- chl a:b
- carotenoids

Antioxidants
- various candidates



## Transpiration Efficiency

WUE of leaf photosynthesis
- low 12/13C discrimination
- PGR signals (ABA, ethylene, etc)

Spike/awn photosynthesis

## Partitioning (HI)

Partitioning to stem carbohydrates

Harvest index
- Rht alleles
- Avoid grain abortion (PGR signals)

## Water Uptake (WU)

Rapid ground cover
- Leaf area
- Coleoptile length/seed size

Access to water by roots
- $\Psi$ leaf (spectrometry)
- IR thermometry

Dehydration avoidance
- osmotic adjustment

Reynolds M.P. and Tuberosa R., 2008. COPB 11

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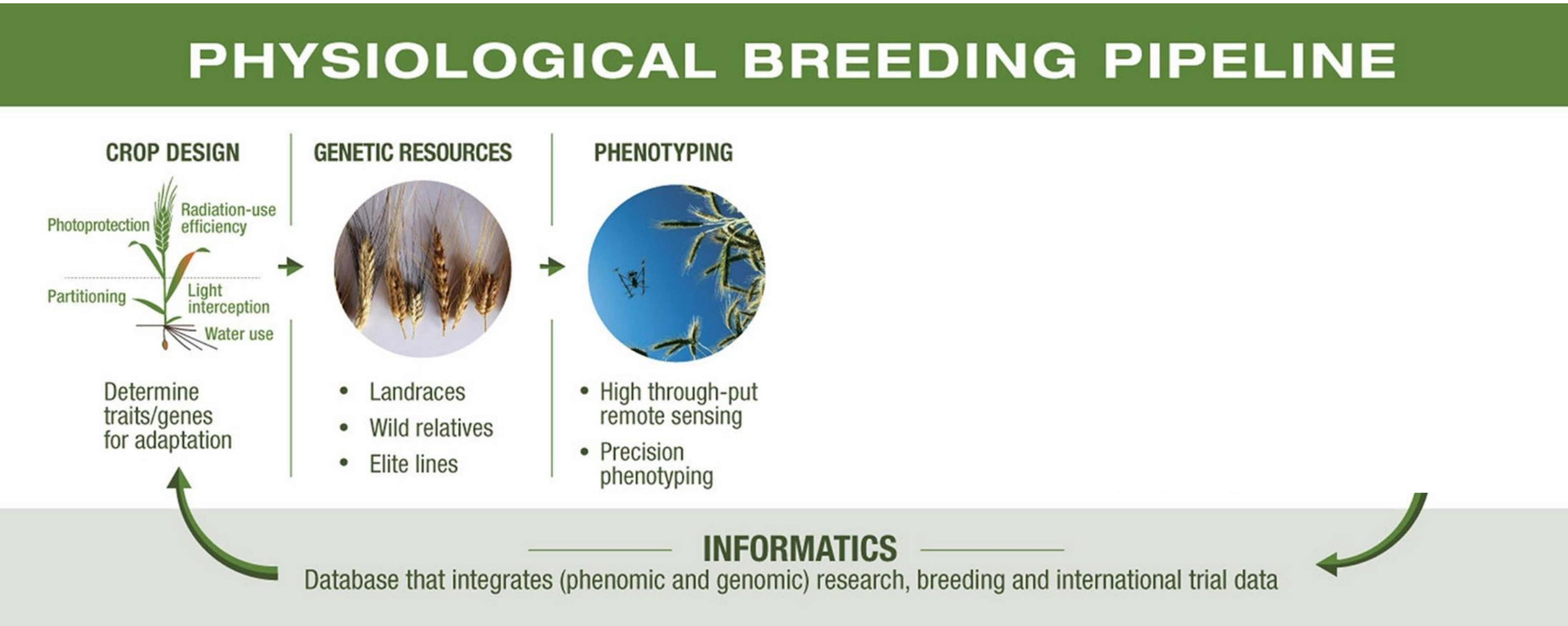
# Physiological pre-breeding

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

**70,000 wheat genetic resources screened under drought and heat, Sonora, Mexico, 2011-2013**

# Physiological pre-breeding

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

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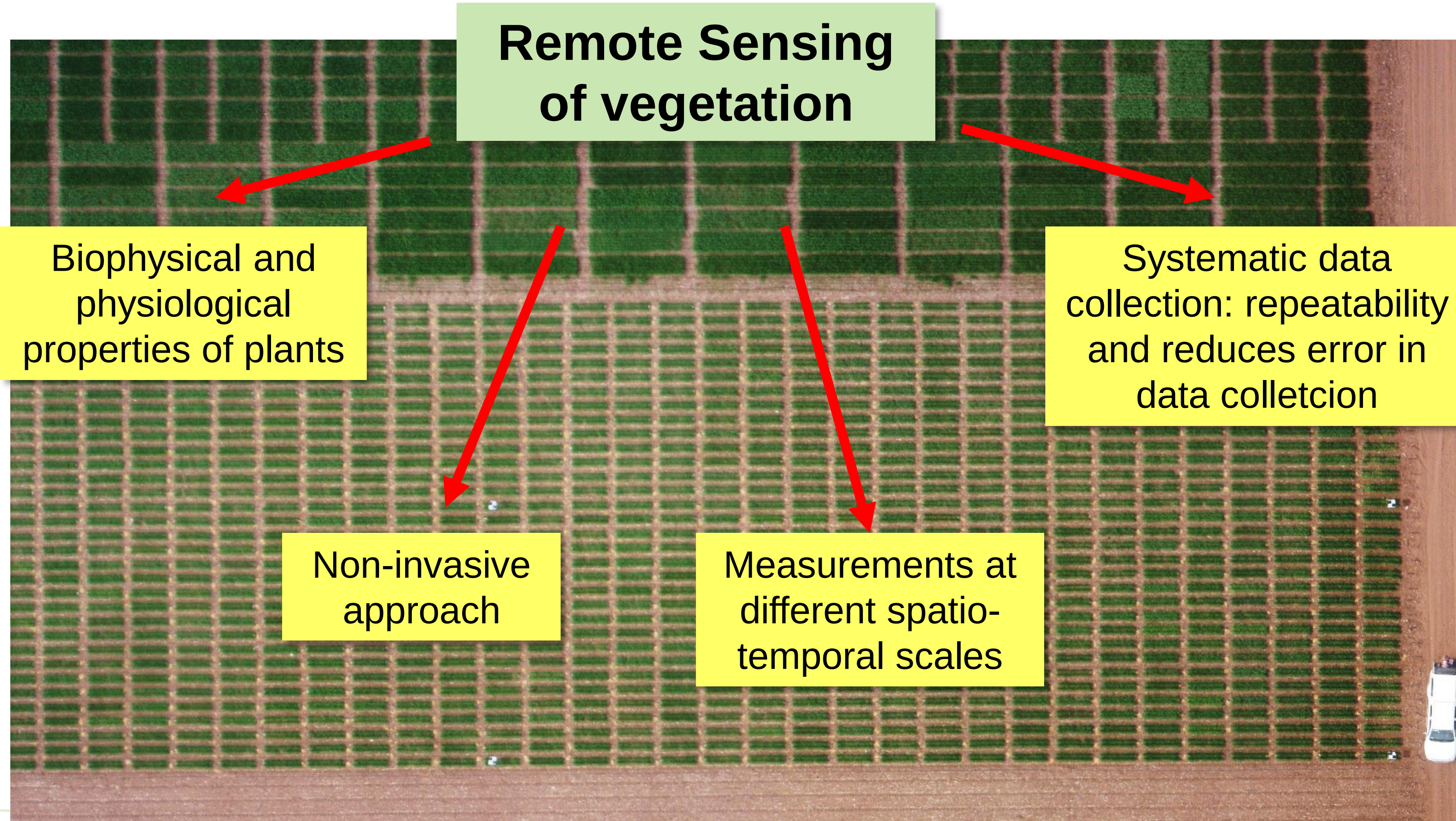
# The potential of RS/UAVs for field plant phenotyping



# Our aerial platforms and sensors

| Drones | NDVI and vegetation indices | Thermography | RGB y 3D |
| --- | --- | --- | --- |

***Falcon 8***
AscTec, Germany
Max. payload: **0.8 kg**

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

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

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

***eBee***
*senseFly*, Switzerland
Max. payload: **0.15 kg**

***RedEdge, MicaSense***
Bands: 475, 560, 668, 840, 717 nm
Main products: **NDVI, SR**
GSD at 30m: 2.0 cm/pixel

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

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

***Matrice 200***
DJI, China
Max. payload: **1 kg**

***2p multispec, Slantrange***
Bands: 532, 570, 650, 850 nm
Main products: **PRI, NDVI**
GSD at 30m: 1.3 cm/pixel

***Matrice 600***
DJI, China
Max. payload: **6 kg**

***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

## Hyperspectral

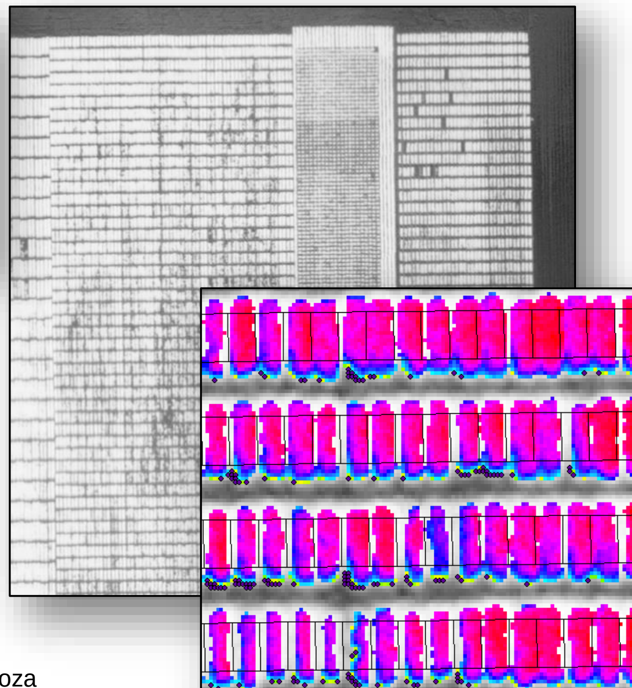
***Micro-Hyperspec, Headwall Photonics***
*Range: 600 – 1700 nm*
*n. bands: 267*
GSD at 30m: 1.8 cm/pixel

GSD= Ground Sample Distance

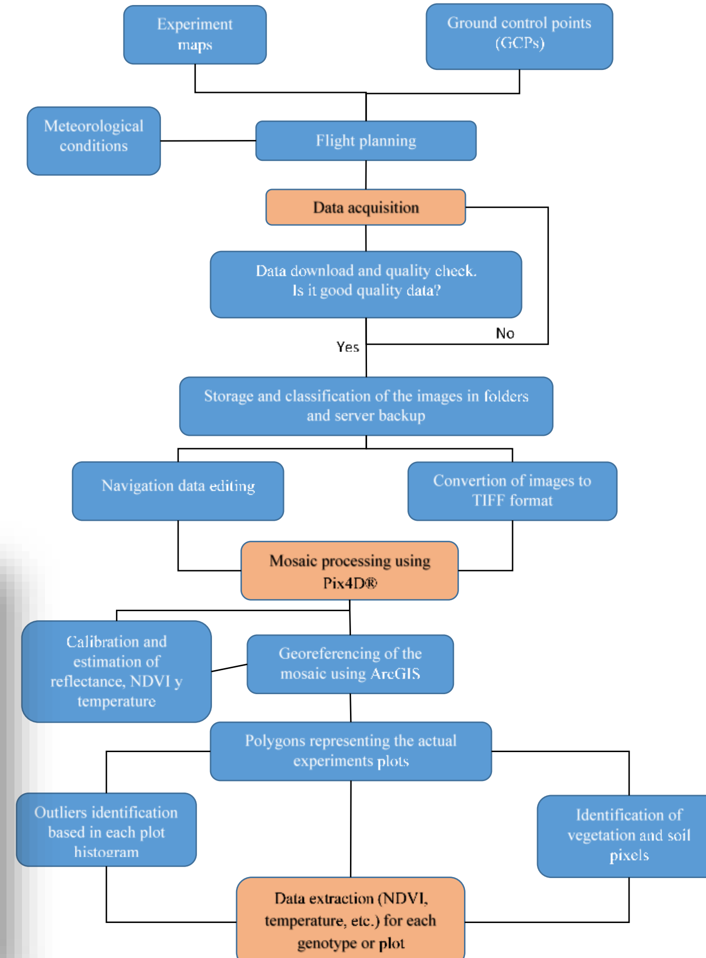
# Towards the automation of a UAV-based HTP platform

Georreferenciation of our experiments

Semi-automatic data extraction

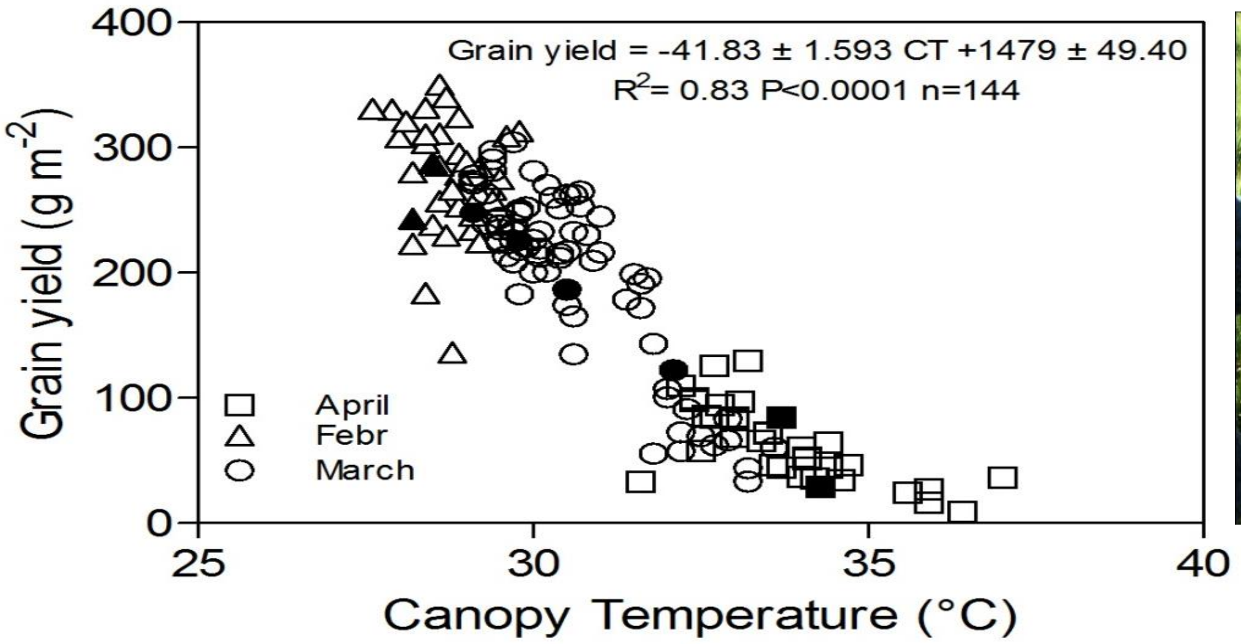


Images generated by J.M. Mendoza




Definition of a processing scheme

# Canopy temperature shows consistent association with yield under drought and heat

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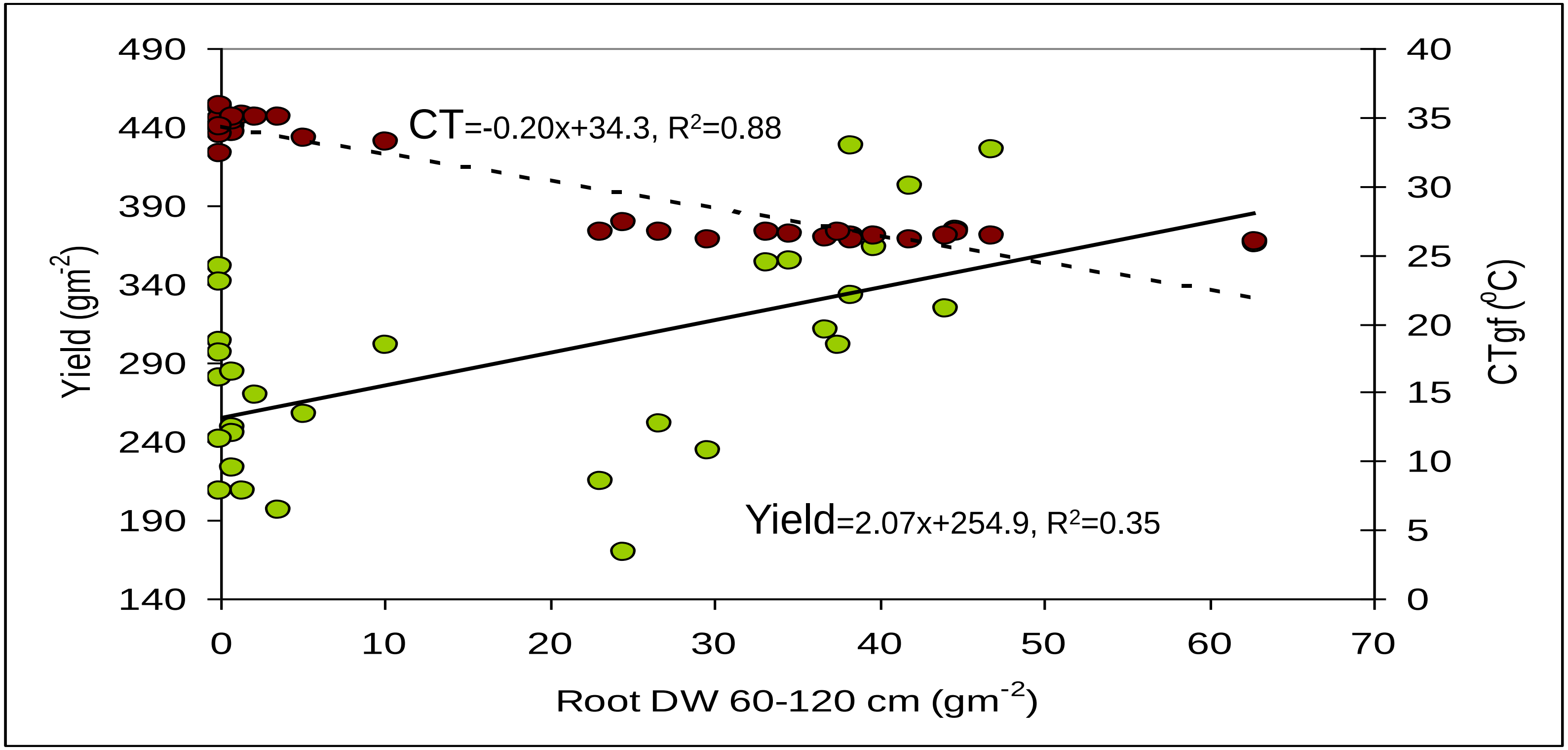
# Deeper roots under drought confer stress adaptation




Lopes MS and Reynolds MP, 2010. Partitioning of assimilates to deeper roots is associated with cooler canopies and increased yield under drought in wheat. *Functional Plant Biology* 37:147-156

Pinto & Reynolds, 2015. Common genetic basis for canopy temperature depression under heat and drought stress associated with optimized root distribution. *TAG:* 128

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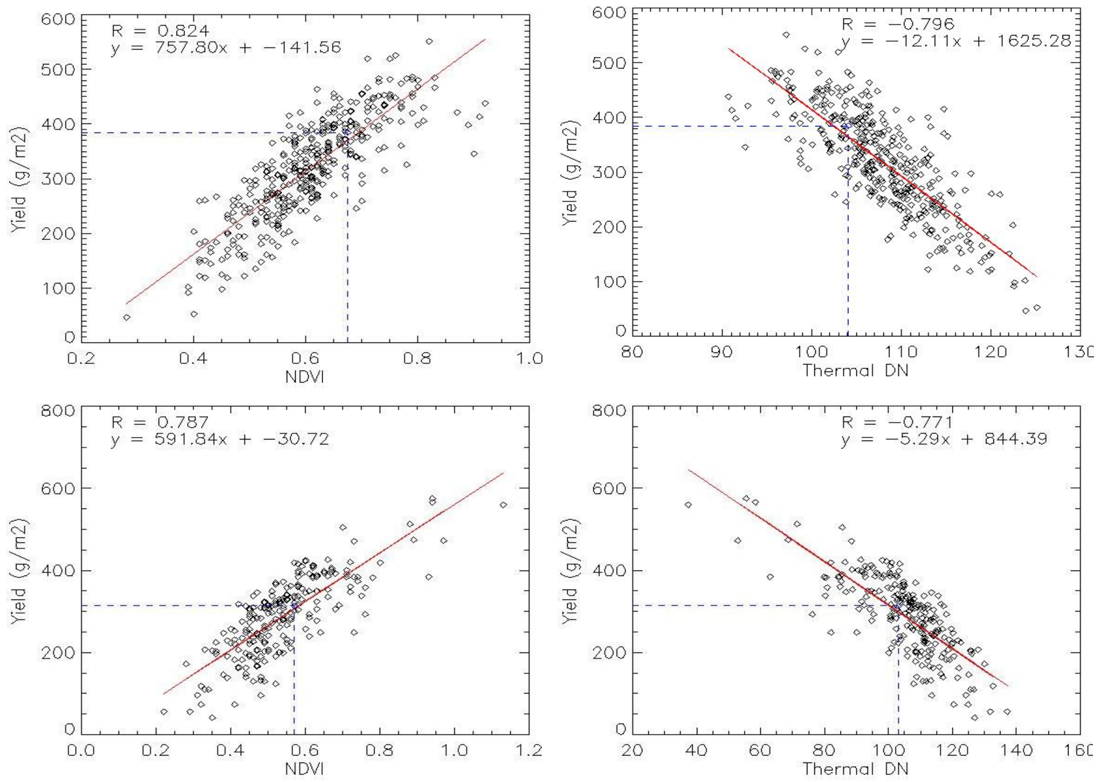
# Yield prediction using NDVI and canopy temperature

Heat

Bread wheat

Durum wheat

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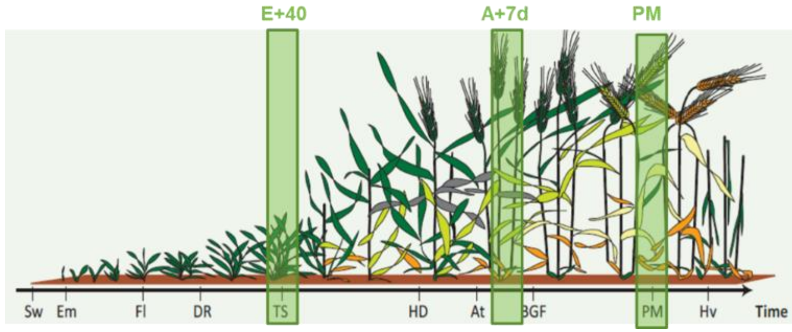
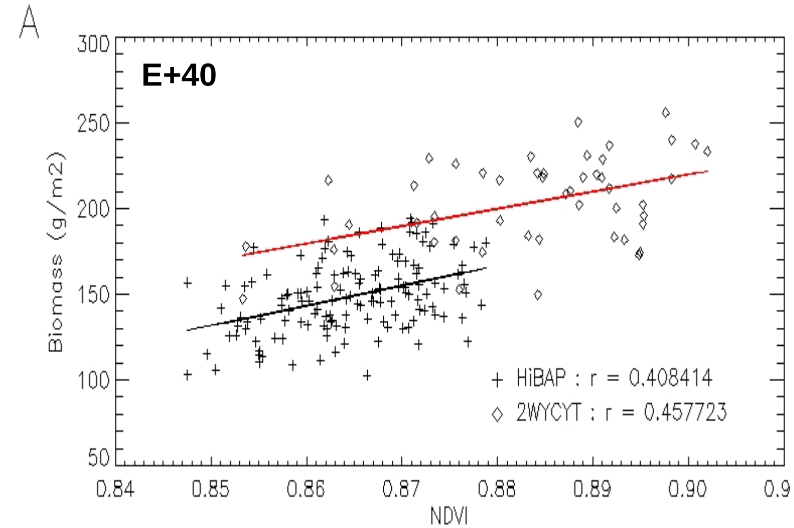
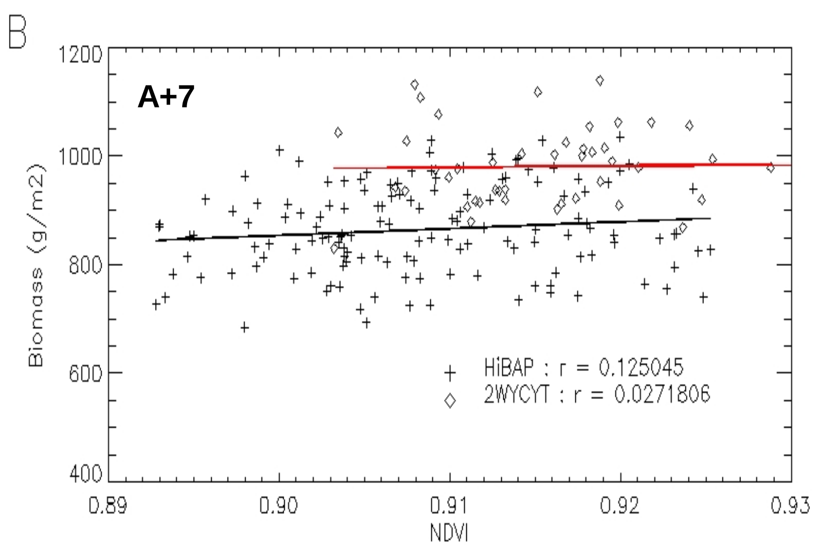
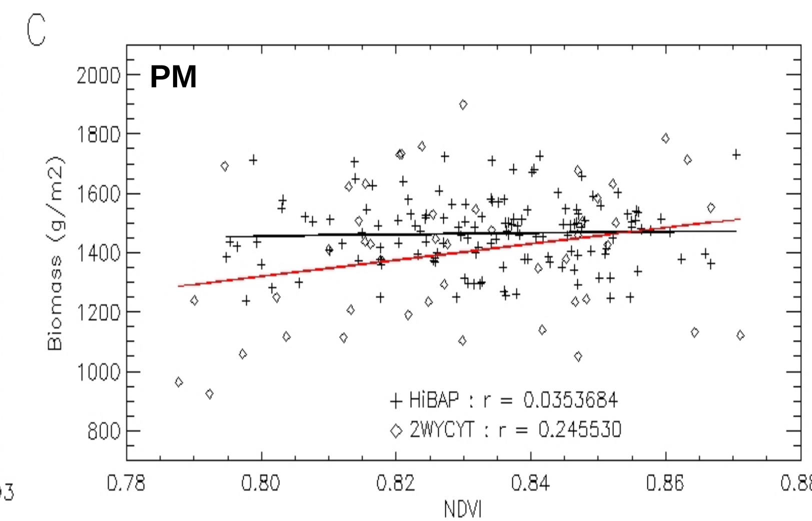
# Biomass prediction at different phenological stages using NDVI

HiBAP, 2nd WYCYT



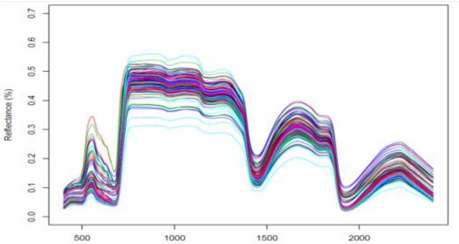



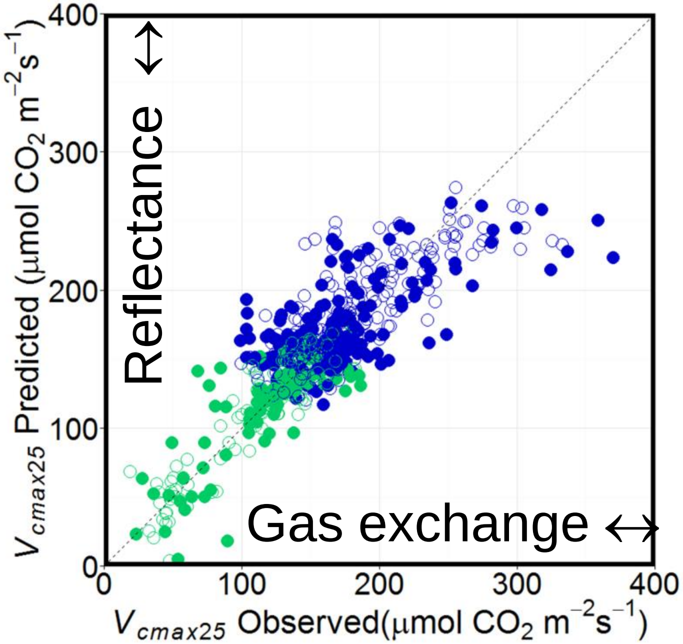



# Increasing Photosynthetic capacity and efficiency: Leaves

## Hyperspectral Reflectance (2 min)


## Gas Exchange: *A/Ci* curve (30-45 min)

**(Silva-Perez et al.)**

Australian National University

CSIRO

ARC Centre of Excellence for translational photosynthesis

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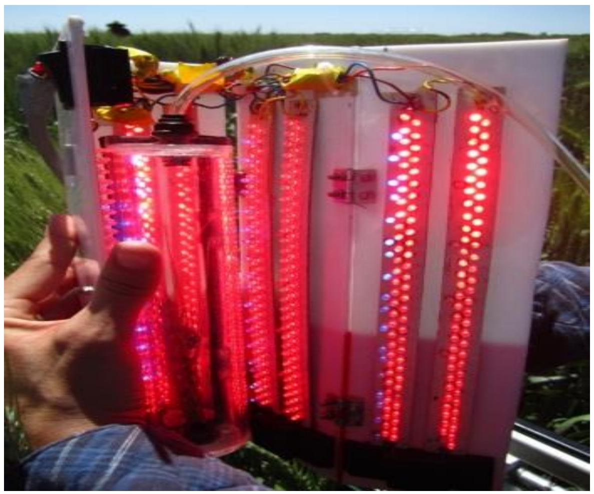
# Genetic variation in spike photosynthesis

**Direct Measurements with LI-6400XT**



***Indirect Measurements with …***

***Textile (inhibition treatment)***

On 95 sisters of *T. Turgidum (Atil)* x *T. Dicoccum*

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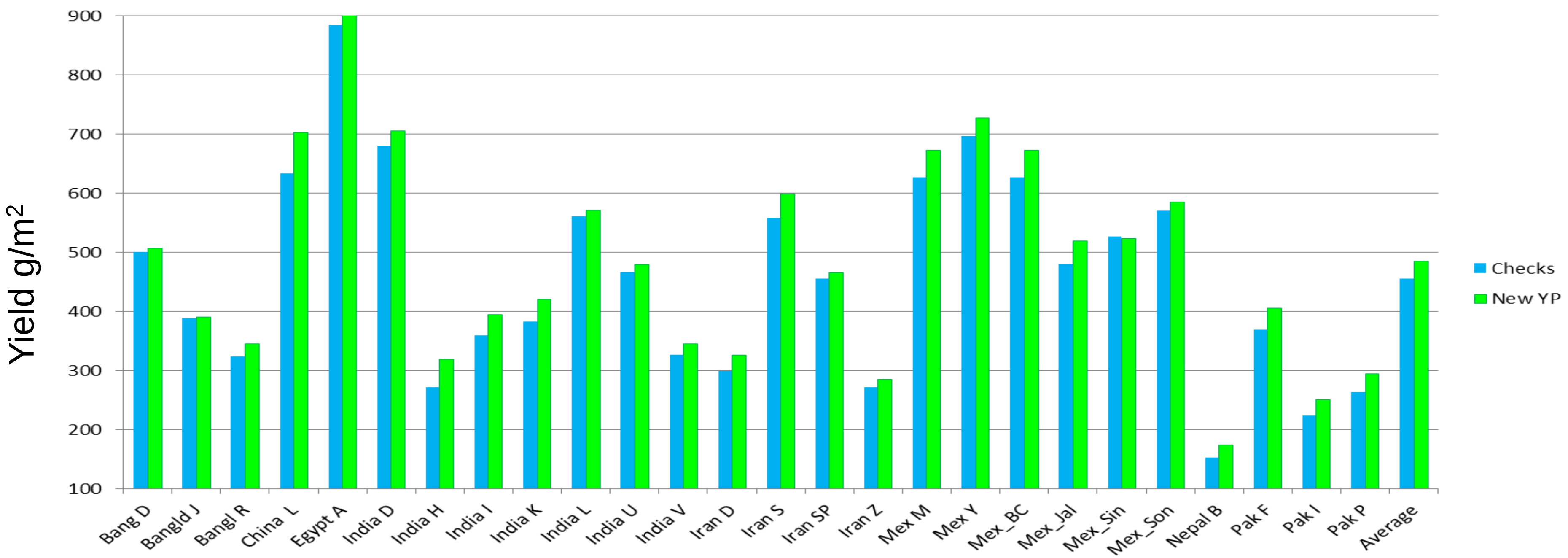
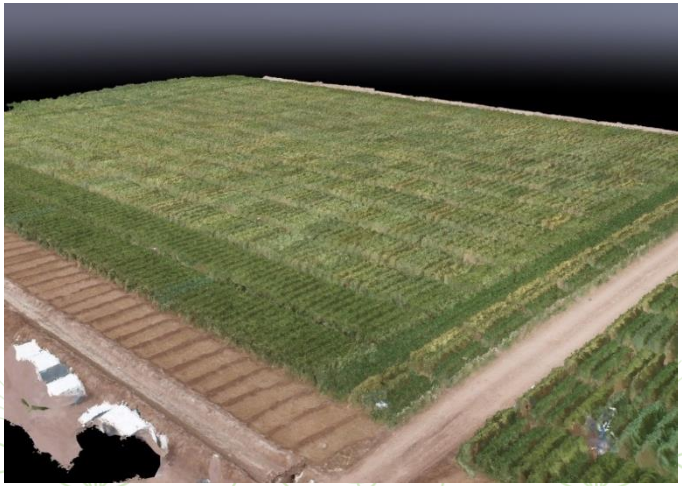
# Mean yields of 35 new PT lines v 7 elite checks: (average 7% advantage of new lines)

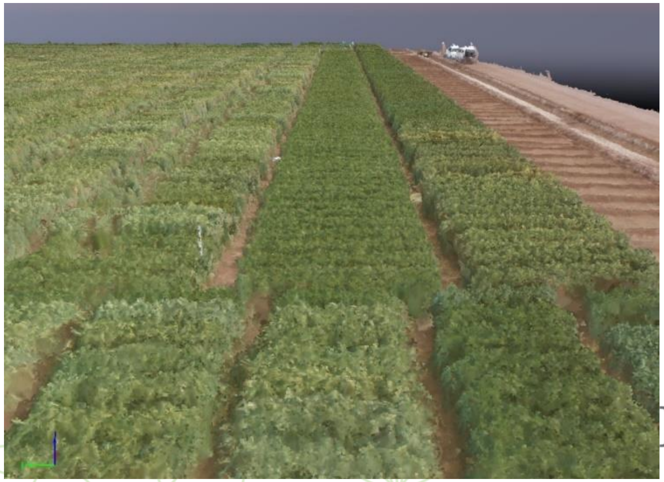



2nd WYCYT, 2014

# Ongoing developments and challenges

- Digital Surface Model (multiangular RGB imagery):
  - Biomass estimation
  - Structural parameters of the canopy (e.g. plant height)
- Biomass estimation through the use of relevant vegetaton índices (e.g. wáter index)
- Phenology: combining different RS parameters and RGB imagery.
- Spike density: RGB imagery
- Radiation Use Efficiency: vegetation indices, spectral reflectance (multivariate stats) and sun-induced fluorescence





# Conclusions

- Remote sensing tools provide the unique opportunity to measure integrative complex traits at different stages of crop genetic improvement.
  - Parental selection for strategic crossing
  - Early generation/progeny selection
  - Genetic resource screening

- These approaches have already delivered genetic gains in yield internationally (Reynolds and Langridge, 2016)

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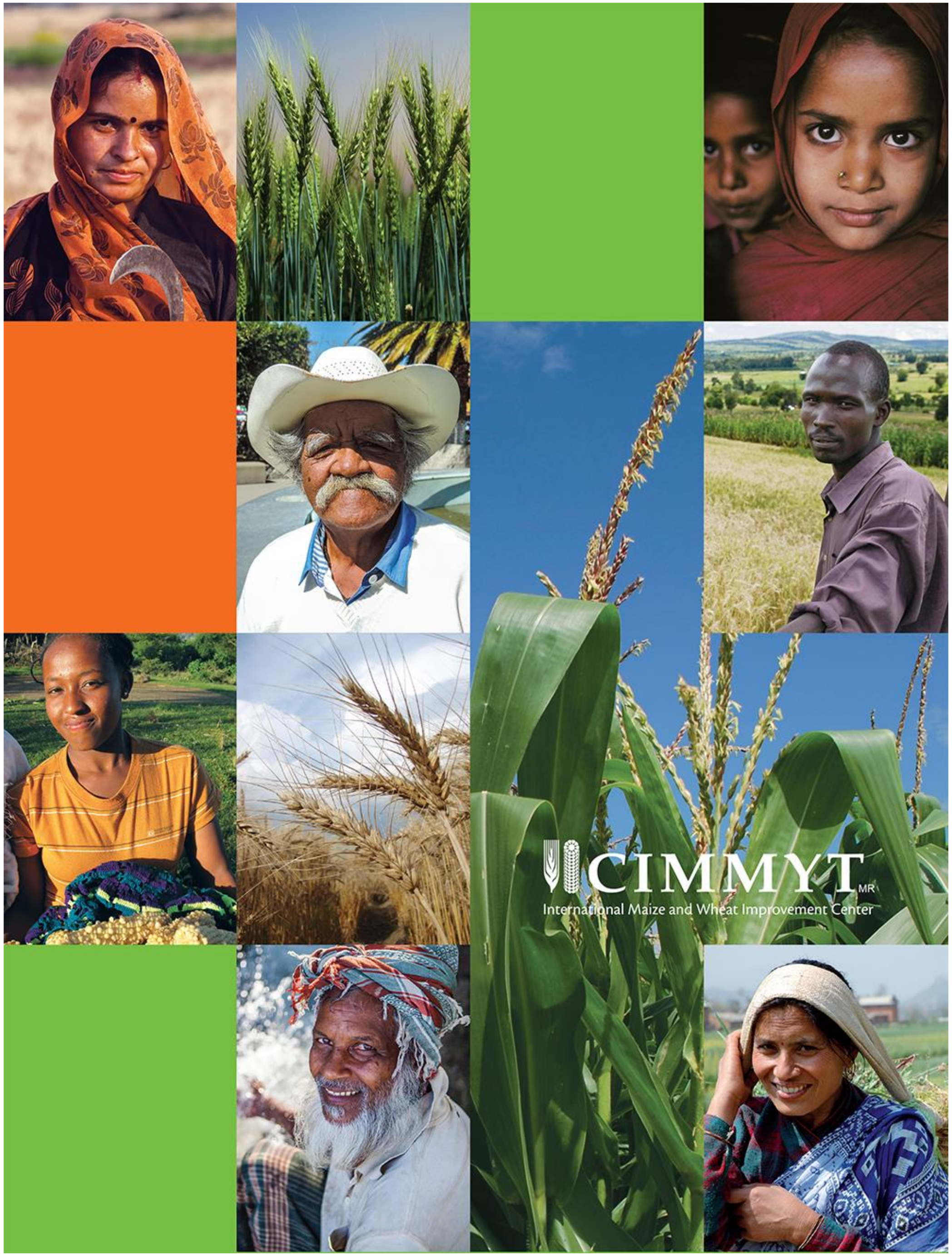


# Thank you for your interest!