UAV-based high-throughput phenotyping for wheat breeding and physiological pre-breeding

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The need of CIMMYT for high-throughput phenotyping (HTP)

- GWP in Obregon:
  - Breeding, pre-breeding and research
  - >100,000 plots (200 Ha)
  - Phenotyping different traits for:
    - Early selection
    - Disease resistance evaluation
    - Physiology research
    - Physiological breeding
    - Exploration of genetic resources
    - Progeny evaluation
- International research collaborations:
  - e.g. IWYP Hub
- Regional offices, NARS, research institutions: evaluation of genotypes distributed by CIMMYT (IWIN)
Using UAVs for plant phenotyping under field conditions

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

Disadvantages:
- Regulations
- Accidents
- Limited payload
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

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

RGB y 3D

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

Hyperspectral

- **Micro-Hyperspec, Headwall Photonics**
  - Range: 600 – 1700 nm
  - n. bands: 267
  - GSD at 30m: 1.8 cm/pixel
Towards the automation of a UAV-based HTP platform

Georeferencing our experiments

Semi-automatic data extraction

Images generated by J.M. Mendoza
Good agreement between ground and aerial measurements.

UAV measurements of CT and NDVI show better heritability than ground-based measurements in HiBAP.
Objective: Improve abiotic stress adaptation and yield potential in a changing climate
Dynamics of NDVI as adaptive trait

NDVI is related to green matter

Indicator of growth-related mechanisms for adaptation to different environments
SRIs for estimation of RUE under yield potential

Estimation of light interception related traits using spectral indices and RGB imagery

Water indices for estimation of in-season biomass

Hyperspectral imagery

*SRIs = Spectral Reflectance Indices
Canopy temperature: Related to physiological processes and their interaction with the environment.
Canopy temperature as adaptive trait

Canopy temperature:
Related to the interaction of few environmental factors and plant physiology.

Lopes MS and Reynolds MP, 2010.
Pinto & Reynolds, 2015.
Root phenotyping: finding a RS approach

- Canopy temperature is associated to root capacity under drought and heat
- Evaluation of root biomass and root:shoot ratio of fully developed roots subjected to stress.

Thermography

Spectrosocopy

Graphs showing correlation of canopy temperature vs root biomass at different depths and days after emergence.
Estimating structural traits using image analyses

Structural parameters such as plant height and plot volume, using RGB imagery
QTL associated with spectral indices under yield potential and heat

- SRIs identified for indirect selection for yield: 11 for YP and 9 for HS
- Common indices across phenological stages: EVI in YP and NDVI/PRI in HS

- Marker-trait associations: 14 regions in 9 chromosomes
- 2 common genomic regions between yield and SRIs in 5A and 6A

Liu et al 2019
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
Ongoing developments: challenges and “whish list”

• Parameters/indices for inderic 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

• Calibration/validation
• Automatic image processing
• Data quality check
• Data management.
Conclusions

• CIMMYT needs efficient HTP approaches to assist breeding, pre-breeding and research targeting for improvement of genetic gain in yield and plant adaptation to stress.

• UAVs and remote sensing offer a good tradeoff between accuracy, cost and throughput needed for phenotyping GWP trials and exploring the genetic resources available.

• The challenge is big and resources are limited. We encourage and welcome groups to collaborate with us.
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