Remote sensing for crop improvement: From research to industry

Sebastien Prud'homme, Marie-Hélène Tixier, Justin Blanc, Alexis Comar, Frédéric Baret

In the age of the genotype, phenotype is all the rage!

Phenotyping is king!

But what about real impact in plant breeding?

Plant breeding

Phenotyping, biotech & plant breeding

Digital breeding is not digital farming

Questions:

- How is it possible to apply HT phenotyping?
- Which traits do we need to focus on?
- The key is identifying the desirable characteristics.
- Phenotyping for discovery

100-500 genotypes

Which traits?

Which genes?

Biodiversity

New traits

Issues for impact

Cost

Flexibility

Precision

Regulation

Strong effect
Grain Yield (q. ha⁻¹)

- Drought impacts RUE by direct effects on photosynthesis.
- We identified genetic variability for early vigour, stay green, senescence speed and start of leaf expansion.
- During leaf expansion, drought reduces leaf area (accelerated senescence).
- Grain yield can be reduced by the effect of drought on most of these factors:
  - Area
  - LAI
  - Qcab
  - Chlorophyll

- Drought reduces Green leaf duration (accelerated senescence).

- We will consider only LAI and Qcab for the current study.

**Case study: drought response in maize**

**Research for new traits**

- Precise are necessary
  - A list of measurements around biomass/cultivar distribution and use are destruction and for vaccine consumption.

- Precise can be estimated directly from spectral reflectance measurements as NDVI (Normalized Difference Vegetation Index)
  - Chlorophyll content can be measured indirectly or indirectly (calculated) from spectral reflectance measurements as NDVI (Normalized Difference Vegetation Index).

**Objectives**

- Evaluate the precise potential of vegetation indices and discriminate by high throughput phenotyping tools.
- Develop models for estimating these indices and select the most relevant traits.

**Use of field phenotyping platforms**

- Collaboration with HIPPER & INRA-CAPTE
  - Common biomass: correlation highly
  - Precision measuring instrument: 1200x520, 2 or more images
  - Hyperspectral: 6 configurable bands (450-950 nm)

**Material**

- Field: Le Mans area, France
  - Plot: 15,000, 1 replication: 2 rows x 6 m, 2 replicates, 2 microplot

**Extraction of Biophysical traits**

- Use of PROSAIL: Estimation of LAI and Qcab from multispectral reflectance measurements
  - The cost function integrates a priori constraints
  - The solution is found by identifying the set of variables in the LUT model that minimize the cost function.

**Extraction of Biophysical traits**

- Estimation of LAI and Qcab from measured multispectral reflectances.
  - Use of a look-up tables provided by the model (C dataset: 5000 with real data).
  - The solution is found by identifying the set of variables in the LUT model that minimize the cost function.

**Analysis of NDVI dynamics**

- Timing of the phenotyping flights
  - Five dates across the whole cycle, at important physiological points, to generate informative time series of data

- Strategies to find traits
  - Calculation of slopes, time, area under the curve.

- We identified genetic variability for early vigour, stay green, senescence speed and start of leaf expansion.
Analyses of biophysical traits

- Correlations between NDVI, LAI, (QTL)
  - Optimal conditions (better in drought)
  - Variation across the dates of the flights
- Lower leafabilities
  - The relationship with NDVI are not linear (semi-logarithmic)
  -船舶 with the dates of the flights (seem to be linear)
  - The plants continue to grow near the NDVI values.

When compared to yield

- Analysis
  - Regression analysis (backward, forward and stepwise) with yield gives significant results
- Regarding NDVI
  - Scanned, NDV images seem to be a major parameter explaining 26-30% of yield variance in both optimal and drought conditions.
  - Variance can be also significantly associated in both conditions.
  - Plant growth is not in our conditions.

- Regarding biophysical traits (area under the curve):
  - 25 to 30% of yield variance is explained by biophysical traits calculated from the commercial plant (for drought conditions).
  - The late onset of leaf senescence (stay green) and a higher senescence rate contribute to significant increases in maize yields.

Preliminary Gwas analysis

- Use of the data in gwas analyses
  - A part of QTLs for NDVI identified in Dell’Acqua et al., 2015 (PAV) for Plant Height and Grain Yield.
  - We can also derive that PROSAIL model is a model. It can be improved.

Take home messages (1)

- Main results
  - Higher density (stand) speed and management rate increase a part of yield genetic variance
  - Correlation with yield is quite weak, leafabilities can be improved especially for biophysical traits
  - NDVI is point-fundamentally but green senescence effects
  - NDVI traits may be more promising but availability is low
  - Breeding selection efficiency ($R^2$) is still too low - not available by breeders yet (Falconer, Mackay 1996).

- Problems
  - NDVI traits is a proxy for drought conditions. Homogeneity and calculation of available water capacity across the flights
  - Market calculation allows to reduce the number of flights.

- On-going
  - More work on the biophysical genomics, LAI (Chromolith content) to increase correlations with agronomic traits
  - PROSAIL is a model. It can be determined. It is on-going.
  - Are we seeing a new that stems growth based on ground-based real data (two through plant phenotyping).

Estimation of LAI

- Correlation between manual measurements and UAV estimates
  - NDV vs LAI using a line through method extracting the following, canopy structure characteristic from 250m x 250m images taken from the ground.
  - During the final development stage, LAI estimated from NDV-LAI is significantly underestimated.

- Hypothesis
  - Problems during flowering - ndvi are not green and leaves area may be due green part. Big differences
  - PROSAIL model is developed for a market vessel. There is a new result that deviates from the assumption
  - LAI dynamics can be characterized using a semi polynomial curve and modeled by aggregation of functions.

Modelling Leaf Area in Maize

- Development of a new leaf area model
  - Based on dynamics of leaf appearance, dynamics of leaves appearance and dynamics of senescence in determining LAI at any time
Validation of our model

- We can use a leaf area model to compare with LAI measures extracted from true color images.

Next steps
- Improve PROSAIL with a better estimation of the 3D architecture of the plant and take account the male ear.
- Our LAI model will be used on some genotypes to identify the time points with problem, and then, to smooth the curve and extract data from reflectance measurements (UAVs).

Phenotyping for discovery works:

- It is important to focus on the development of method, trait by trait.
- Then, to identify the time points with problem, and take account the male ear.
- Clear need of development to increase accuracy (heritability).
- Development shall include or be driven by end users.

Phenotyping for discovery works:

- Hard work but it may work!
- Impacts on breeding may be multiple.

Analytical breeding - mid term:

- Analytical breeding: mid term
- Consist of the use of secondary traits to complement phenotypic selection or replace yield.
- Development of new traits to be used in breeding (stay green, senescence, temperature of the canopy).
- Associate remote sensing + modelling will be necessary.
- Development shall include or be driven by end users.
- UAVs+ ground system+ IOT+ human's eyes are probably the ultimate toolkit for the near future!