Phenomics at Scale: Driving Advances in Crop Breeding and Smart Farm Management With Insights From Diverse Sensor Platforms and Technologies

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Introduction

The world’s largest agricultural sensing platform - $20M DOE/BMGF Investment

Senior Research Scientist at the Danforth Plant Science Center
**Phenomics** is an area of biology concerned with the measurement of phenomes (a phenome is the set of physical and biochemical traits belonging to a given organism) as they change in response to genetic mutation and environmental influences.

- Wikipedia

Systematic measurement of any and all observable traits aka phenotypes

Genotype x Environment x Management = Crop Phenotype
Current scales of field-level crop phenotyping
TERRA-REF Team
TERRA-REF: Roles and Capabilities

Data standards, storage systems, computational workflows for TERRA collaborators and the community

Genotype x phenotype trait associations, selections, advancement of high yielding energy sorghum lines

Outputs and Deliverables

Reference Datasets for TERRA collaborators and the community

Data standards, storage systems, computational workflows for TERRA collaborators and the community

Genotype x phenotype trait associations, selections, advancement of high yielding energy sorghum lines

Germplasm

Energy sorghum germplasm selected by Clemson and TAMU
Advanced sensor technologies on the TERRA-REF field scanner platform

- hyperspectral (350nm-2500nm)
- thermal infrared
- NDVI / PRI
- 2D RGB
- stereo RGB
- PSII fluorescence
- 3D laser
- environmental sensors
AUTOMATED FEATURE DETECTION

PLANT ARCHITECTURE TRAITS
- Panicle Size
- Height

EMERGENCE
- Stereo RGB

PANICLE DETECTION AND QUANTIFICATION
- 3D Laser Scanner
- Stereo RGB

PREDICTIVE MODELS
e.g. terminal growth based on early season data

Zongyang Li, Roman Garnett, David LeBauer, Solmaz Hajmohammadi, Robert Pless
TERRA-REF Data Products

Full field 3D laser scan
Merged point cloud data colorized from height map.
*Ground level is shown in blue and pixels in red indicate plants that are 2m in height*

3D reconstruction time series of crop plots over a season
Individual plots scanned 3x/week with 3D scanner. Reconstructions allow for measurements of plant architecture (plant height, leaf area, etc.), growth rate, developmental stages

Solmaz Hajmohammadi  Robert Pless
Grain Sorghum Genomics Toolbox: a TERRA Partnership

Phenotyping at DDPSC

App development at WUSTL

Sequencing at HudsonAlpha

Phenotyping at UA Maricopa

Phenotyping in Senegal (CERAAS), Mali, and Ethiopia (EIAR)

Phenotyping at ICRISAT-IN

Phenotyping at Montpellier
What's missing?

Root Zone Phenotyping
Remote Phenotyping

- Physically robust
- Collect data 24/7, irrespective of good weather, or an operator
- Collect, transmit and analyze data in real time - no latency for analysis
- Customizable and modular - collect data **within and above** the plant canopy for any crop
- A platform that can accommodate new sensors **as they come online**
- Accessible from anywhere in the world
- Base station for a gridded network of sensors or autonomous data collection vehicles (aerial and ground based)
- Has a suite of validated, lower resolution sensors that tested with 90% accuracy against state of the art sensors

www.agrelaeco.com
AgTech Product Ecosystem

The AgTech ecosystem: Sensor Manufacturers, AgTech Hardware, Cloud/Analytics Services

Cloud Services / Analytics
- FieldView - Climate Corporation
- Microsoft FarmBeats
- Farmers Edge
- Crop X

AgTech Hardware
- Commercial Farming
  - Drones – DJI, John Deere
  - Satellite Imagery – Farmers Edge
  - Tractor-Based Tech – John Deere, FieldView
  - Sensor Hardware – Arable Mark, Libelium, Pynco
  - Greenhouse – Freight Farms, AeroFarms

Research
- Custom Solutions – Agrela Ecosystems, LemnaTec
- General – Phenospex, Photon Instruments

IoT Sensor Developers
- Bosch, Meter, Skye, Acclima, Headwall
Printed Sensors Needed For:

- Key developmental stages (emergence, flowering, optimum harvest window)
- Disease
- Intra canopy conditions (Airflow, temp, humidity, etc.)
- Root zone environment (inorganic/organic nutrients, toxic elements, pH, etc.)
- Weather
- Insect pests
- Plant stress response
- Leaf parameters
- Nutrient use / mobility
- Root phenotypes
What do we need from agricultural sensors?

- Scalable
- Biodegradable/Easily removed
- Low cost
- Durable (be able to withstand rain, heat and freezing temperatures)
- Low power
- Connected (WiFi, Cellular 4G/5G, LoRa WAN, etc.)
- Standard communication protocols
- Edge sensors and devices

The future of successful farming and breeding operations will heavily rely on sensor technology.
Looking Forward – Smart Farms

- Tractors, drones and rovers are deployed automatically
- UAV’s monitor field conditions, define and identify breeding blocks
- Drones and Rovers control for pests and manage pollination
- Remote soil probes detect water/fertilizer needs and alert the system
- Ground rovers take intra-canopy measurements
- Ground rovers spot spray for weeds and insect pests inside canopy
- All environmental data is correlated to satellite imagery
- Powered by sustainable energy
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Thank you

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