

***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



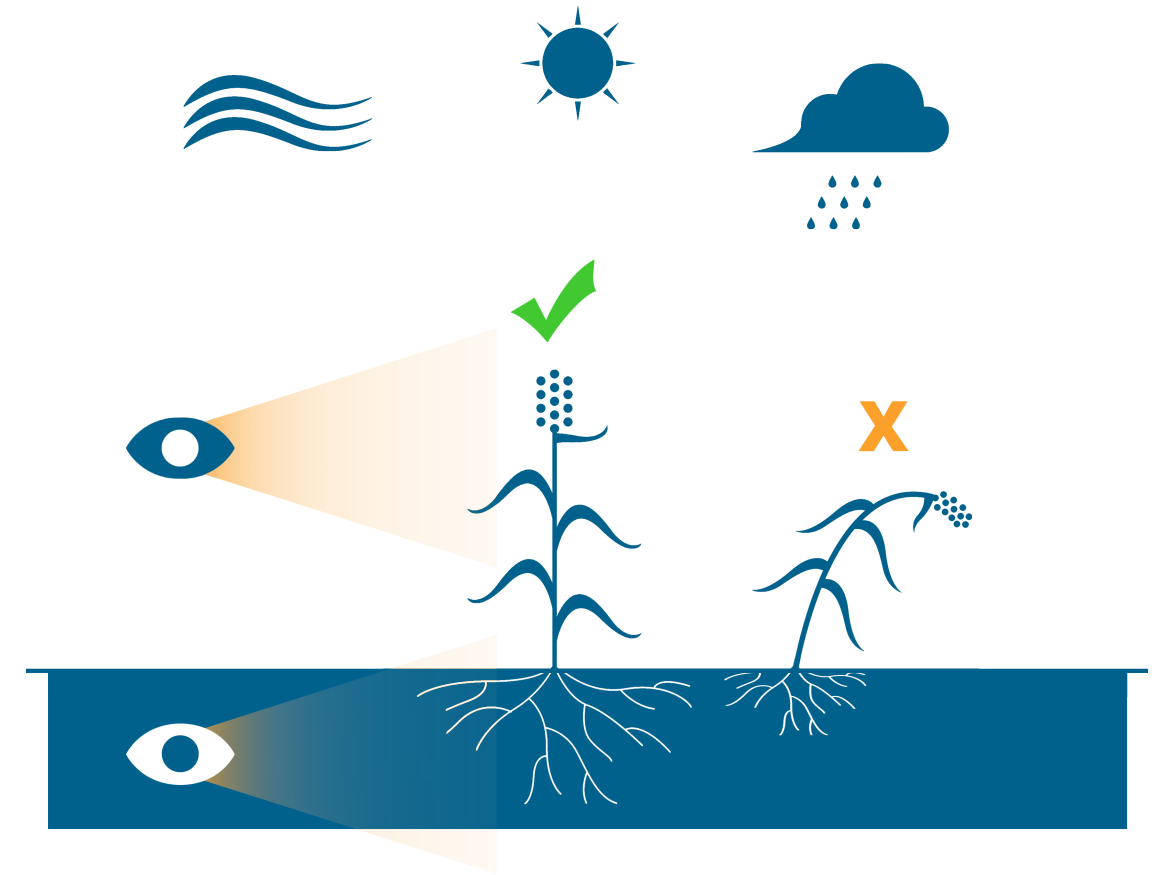
← Senior Research Scientist at the Danforth Plant Science Center



# Phenomics

**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.

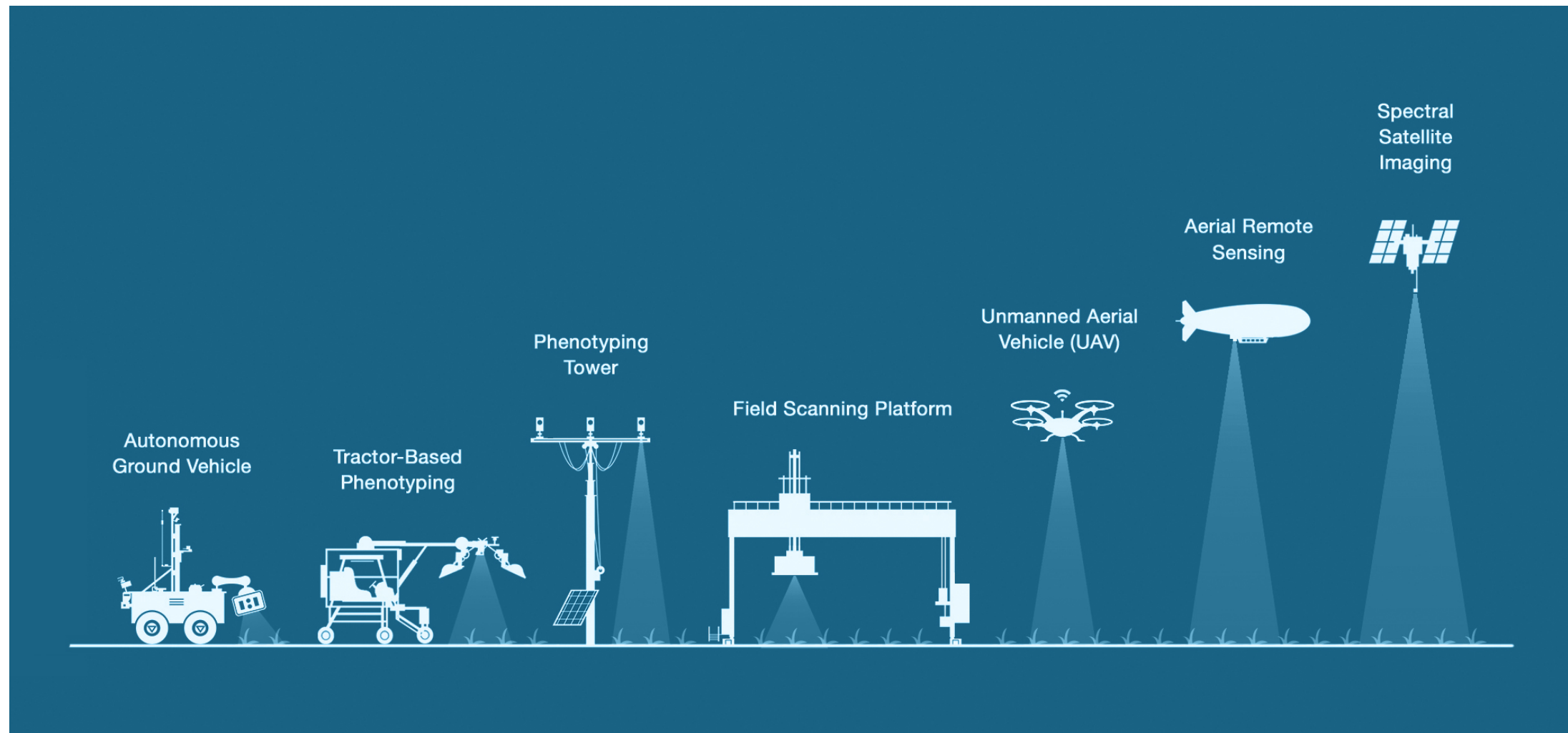
- Wikipedia



**Systematic measurement of any and all observable traits aka phenotypes**

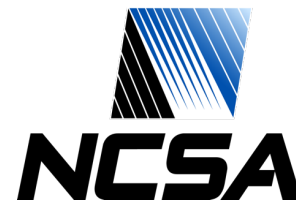
Genotype x Environment x Management = Crop Phenotype

# Current scales of field-level crop phenotyping



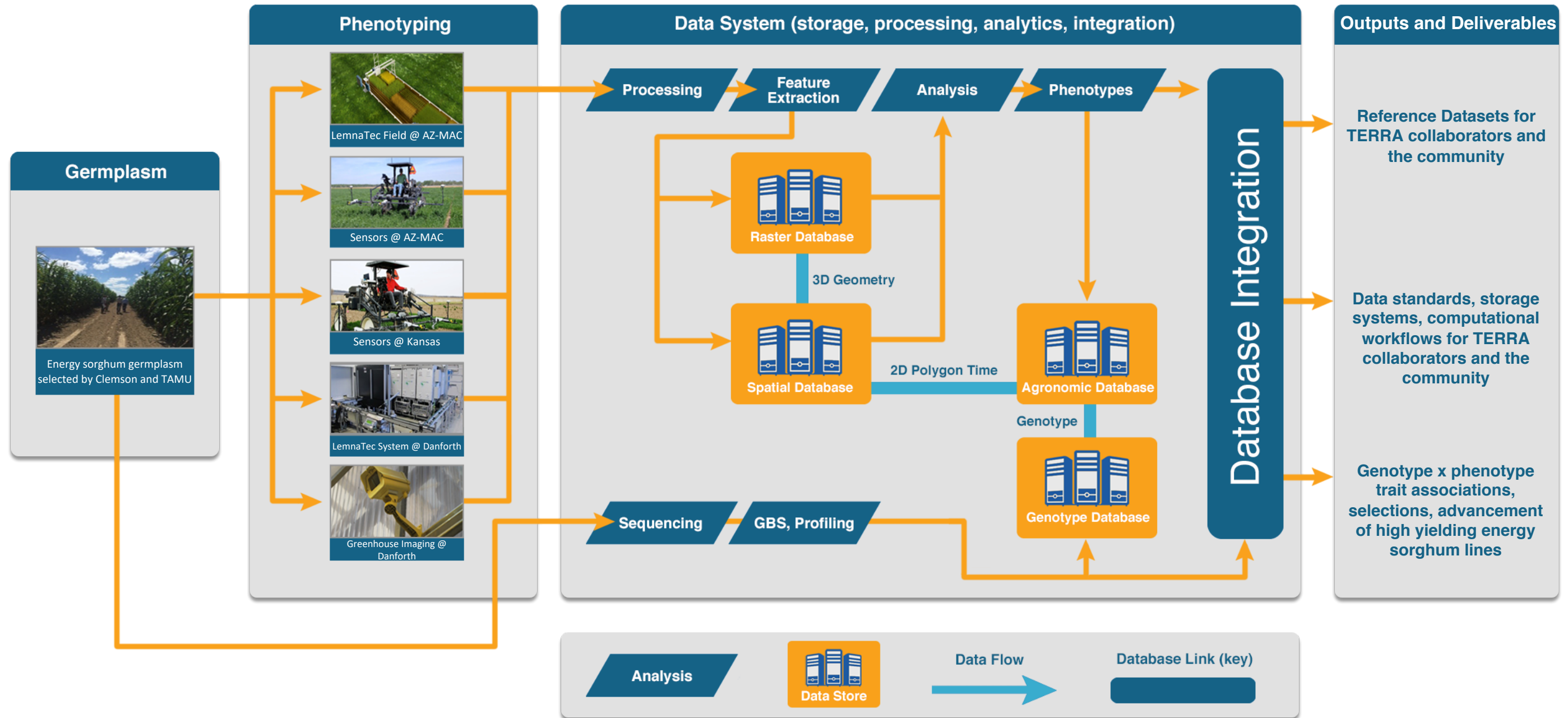


# TERRA-REF Team



[www.terraref.org](http://www.terraref.org)

# TERRA-REF: Roles and Capabilities





# TERRA-REF Field Scanner

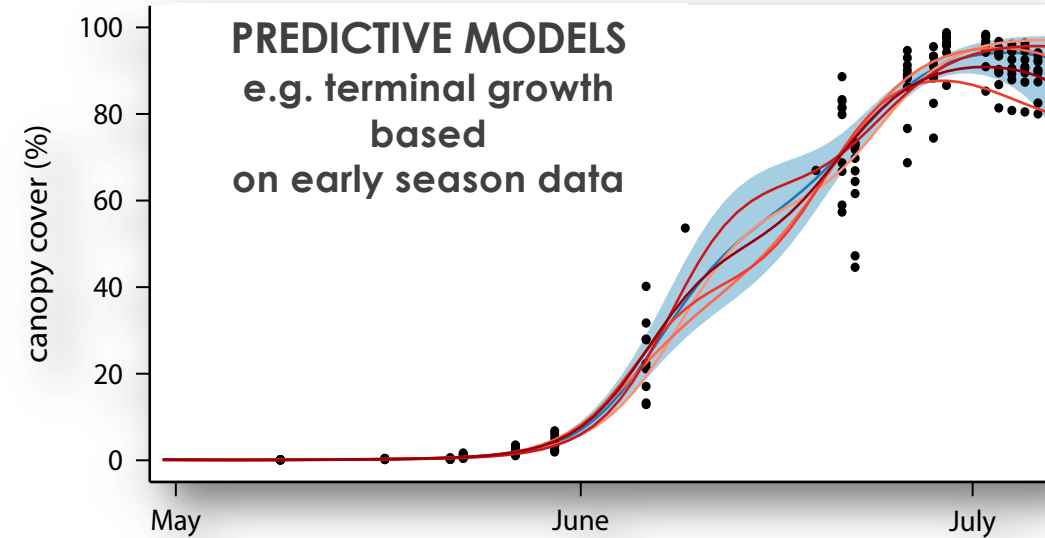
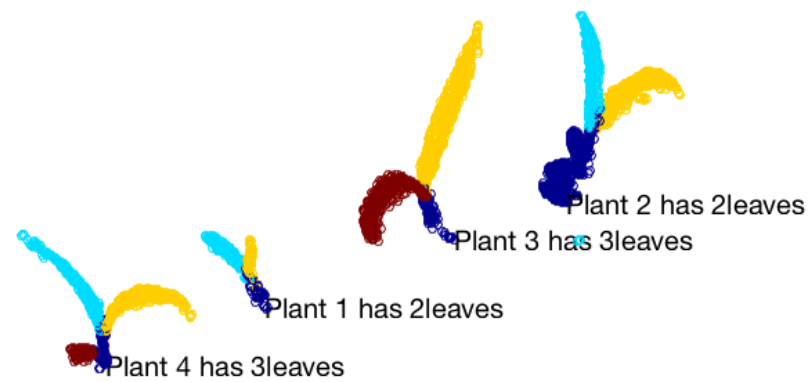


## Advanced sensor technologies on the TERRA-REF field scanner platform

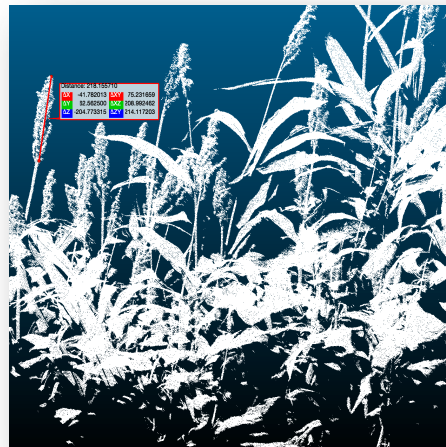
- hyperspectral (350nm-2500nm)
- thermal infrared
- NDVI / PRI
- 2D RGB
- stereo RGB
- PSII fluorescence
- 3D laser
- environmental sensors

# TERRA-REF Sensor Derived Data Products

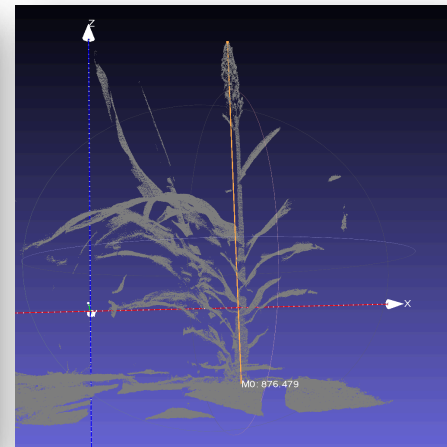
## AUTOMATED FEATURE DETECTION



## PLANT ARCHITECTURE TRAITS



Panicle Size



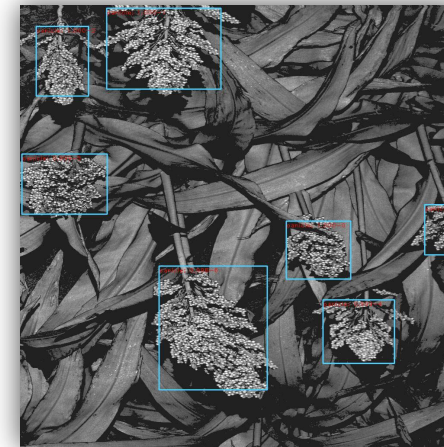
Height

## EMERGENCE

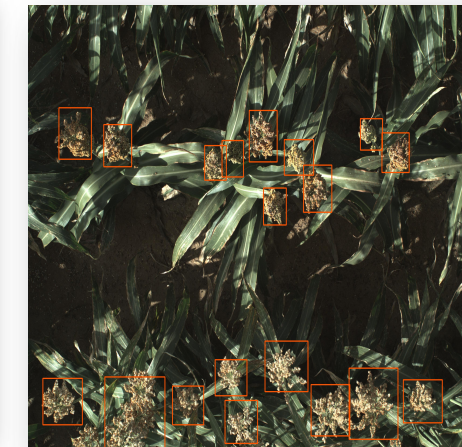


Stereo RGB

## PANICLE DETECTION AND QUANTIFICATION



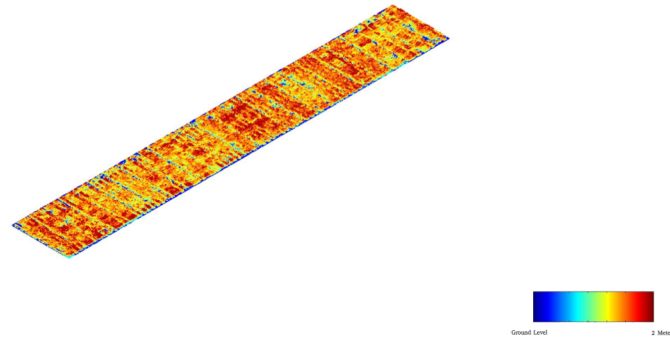
3D Laser Scanner



Stereo RGB



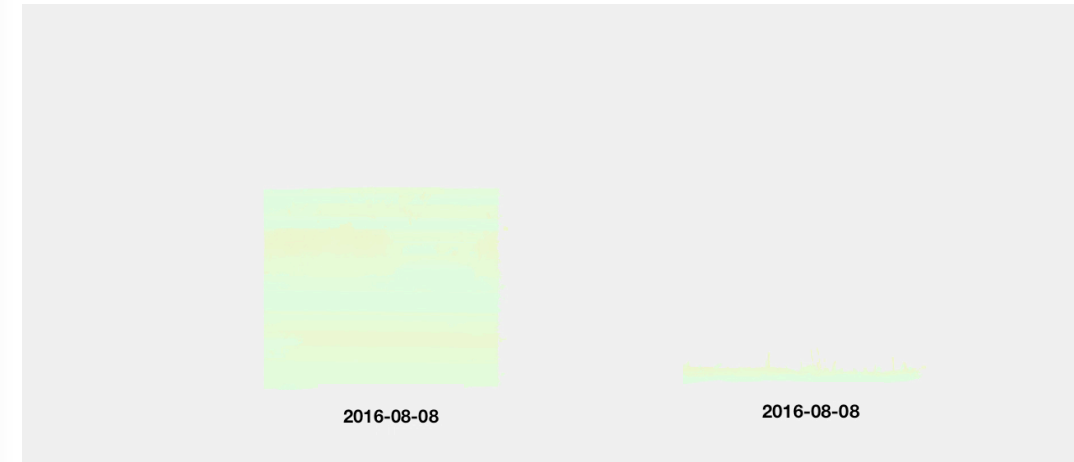
# TERRA-REF Data Products



## 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**

*Solmaz Hajmohammadi*



## 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

*Robert Pless*

# Grain Sorghum Genomics Toolbox: a TERRA Partnership

BILL & MELINDA  
GATES *foundation*

Phenotyping at DDPSC



App development at WUSTL



Sequencing at HudsonAlpha



Phenotyping at UA Maricopa



Phenotyping at Montpellier



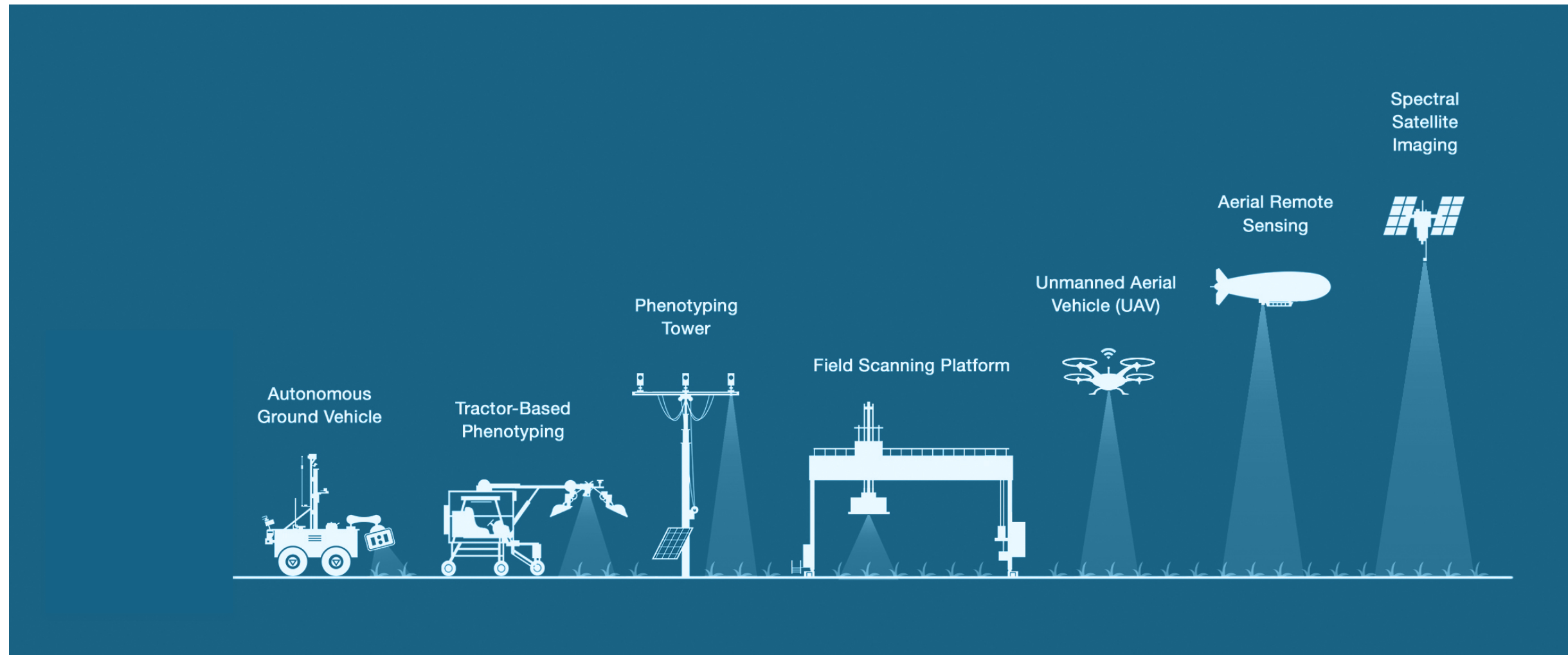
Phenotyping at ICRISAT-IN



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



# What's missing?



# 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](http://www.agrelaeco.com)



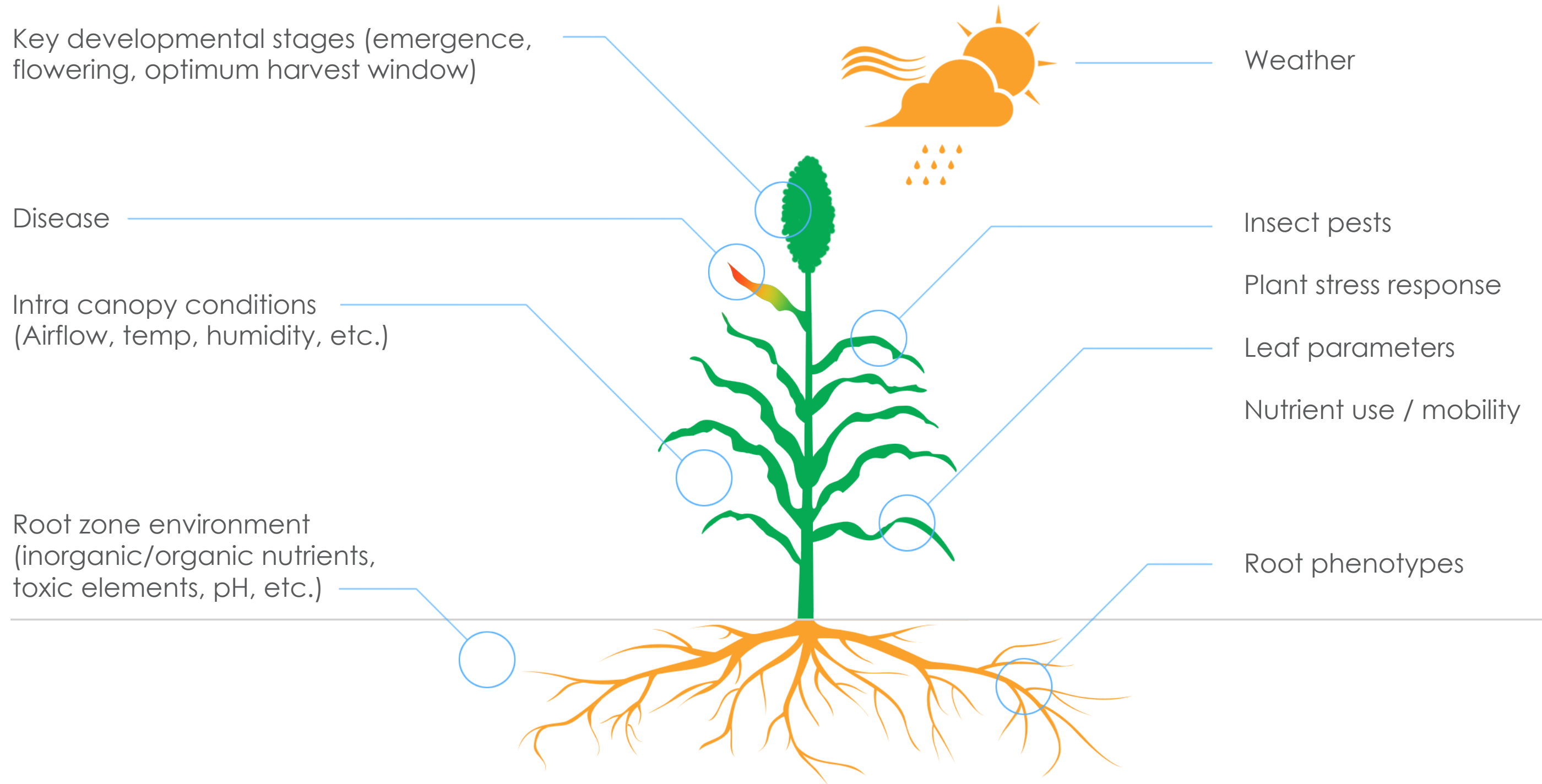
# AgTech Product Ecosystem

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





# Printed Sensors Needed For:



# 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





# Acknowledgments

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# Thank you

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