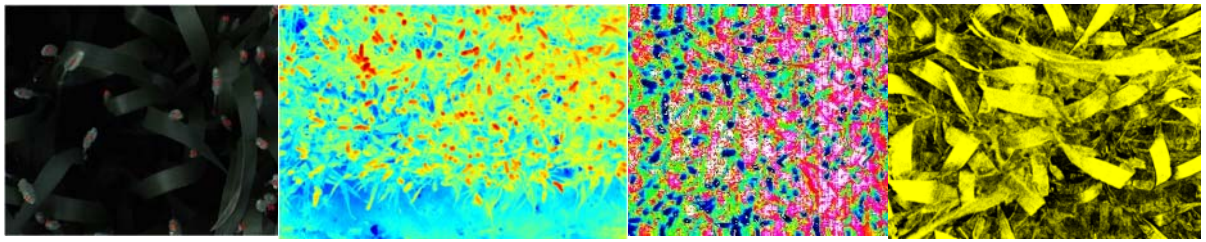
Rothamsted Research
where knowledge grows

What are the limits for crop phenotyping using drones and ground-based platforms?

Malcolm J Hawkesford



NPPN
November 2019

Biotechnology and Biological Sciences Research Council

Outline

ROTHAMSTED RESEARCH

- Background to project
- Some general considerations on phenotyping
- Platform types
- Examples from Rothamsted platforms and sensors
- Achievements and limitations
- Prospects

The Designing Future Wheat programme

ROTHAMSTED RESEARCH

Genotyping

Germplasm diversity → 26,000 lines → Breeders toolkit

Phenotyping



Traits

- Yield
- Sustainability
- Quality
- Pathogen and pest resistance

- 8 UK partners
- Open FAIR data
- https://designingfuturewheat.org.uk
- ckan.grassroots.tools

DFW

General considerations

ROTHAMSTED RESEARCH

- Which traits?
  - Canopy
  - Roots
- What throughput?
- How much resolution?
  - Spatial
  - Temporal
- Automation is desirable
- Costs a consideration

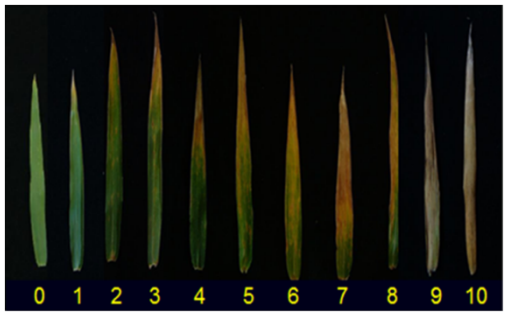
Platform types

- CE/indoor
- Ground
  - Vehicles
  - Autonomous robots
  - Swarms
  - Fixed field platforms
- Aerial
  - Fixed wing
  - Multi-rotor
  - Blimp
  - Swarms
  - Plane
  - Satellite

Traditional manual phenotyping

ROTHAMSTED RESEARCH

- Growth, health, biomass, **yield**, quality
- Manual methods including visual scoring
- Hand-held devices
- Labour intensive
- Time consuming
- Subject to error



Scope of the problem: in one season, one experiment:
5000 plots, 200km field walking, a few simple measurements

ROTHAMSTED RESEARCH

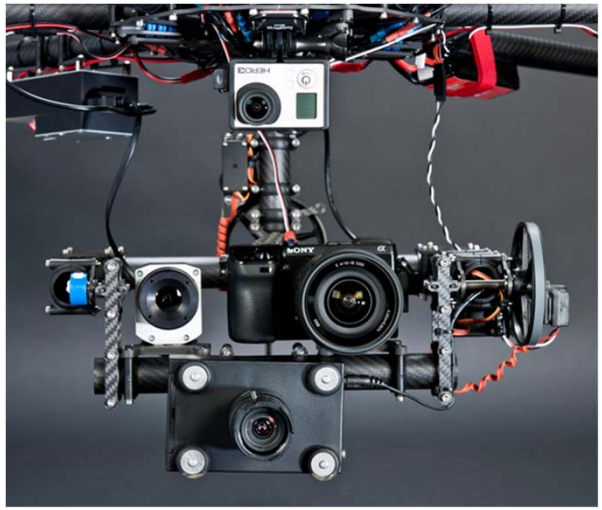
Meadow 2014

Rothamsted approaches

DJI S900 Hexacopter

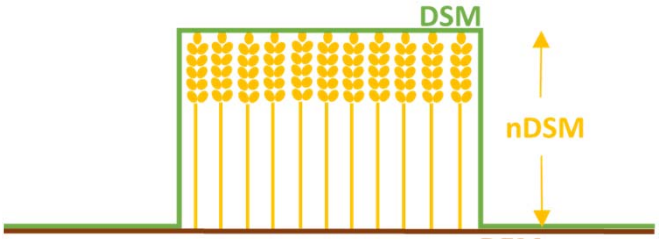
Lemnatec Scanalyzer

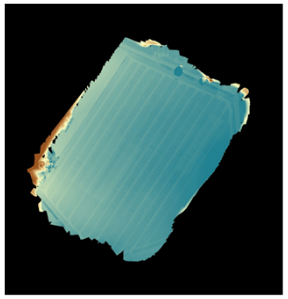
Rothamsted approaches



Drones also enable measurement of growth and biomass and more…..

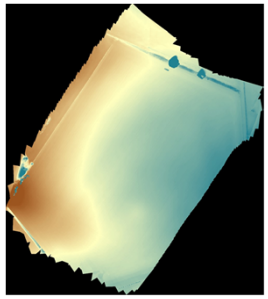
- 50cm border excluded from analysis (user defined)
- Crop height (above sea level) data extracted
- Soil level, from a bare ground orthomosaic, subtracted from crop height to give actual height above ground
- 99th percentile of point cloud used to estimate height





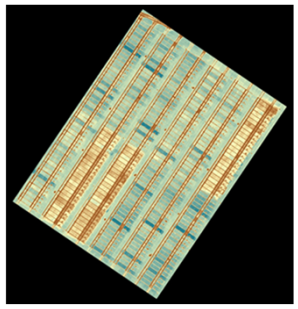
Crop height (above sea level) ortho

-

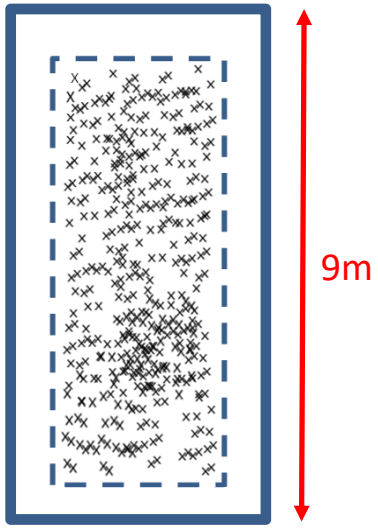


Bare earth ortho

=



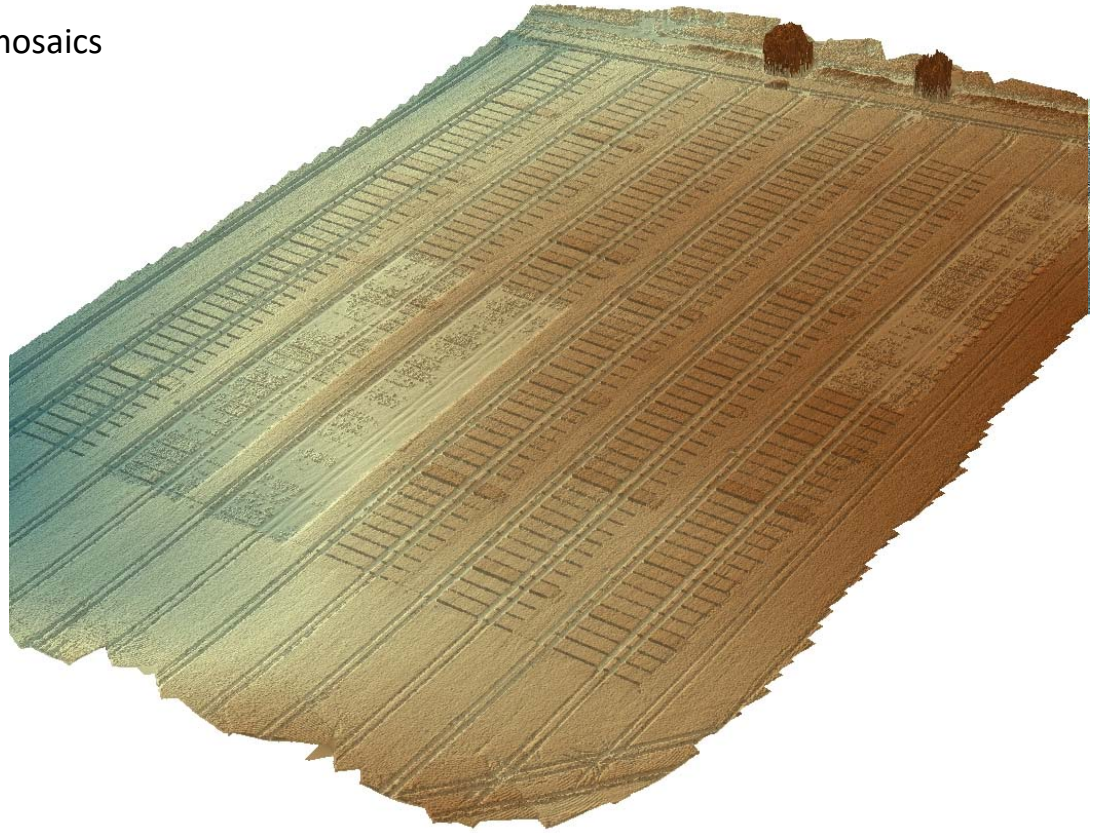
True crop height

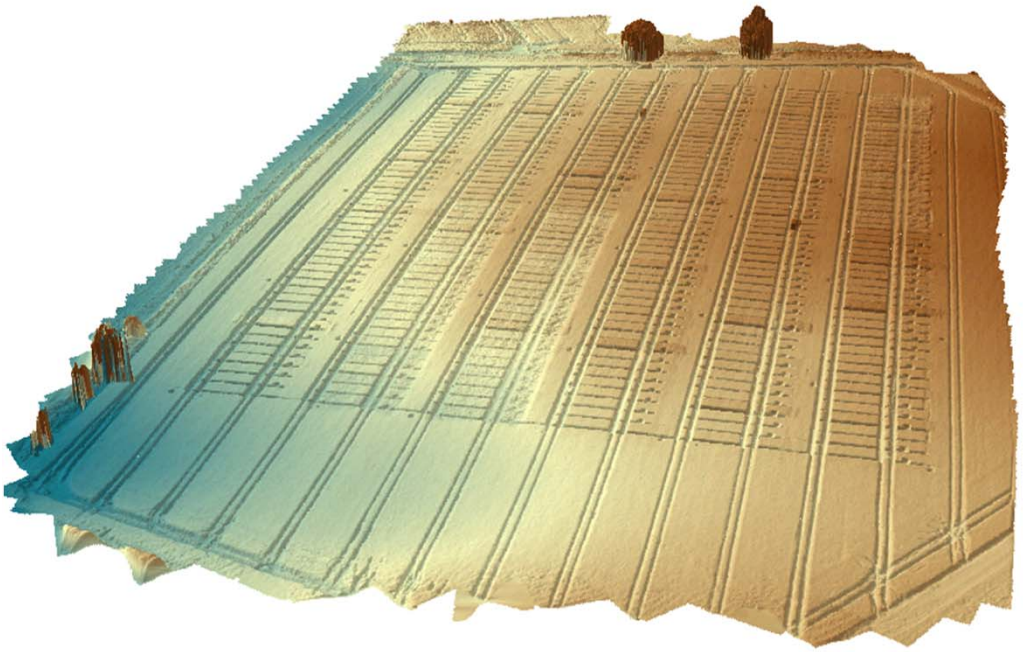


Digital evaluation models of field trials (DEMs)

ROTHAMSTED RESEARCH

Height: models from mosaics of 800 photos (AgiSoft Photoscan; ArcGIS)





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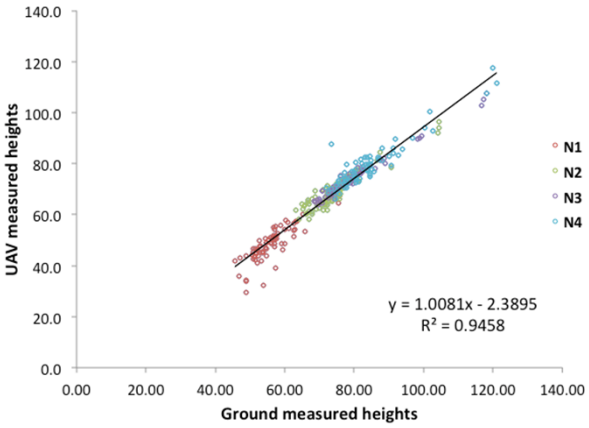
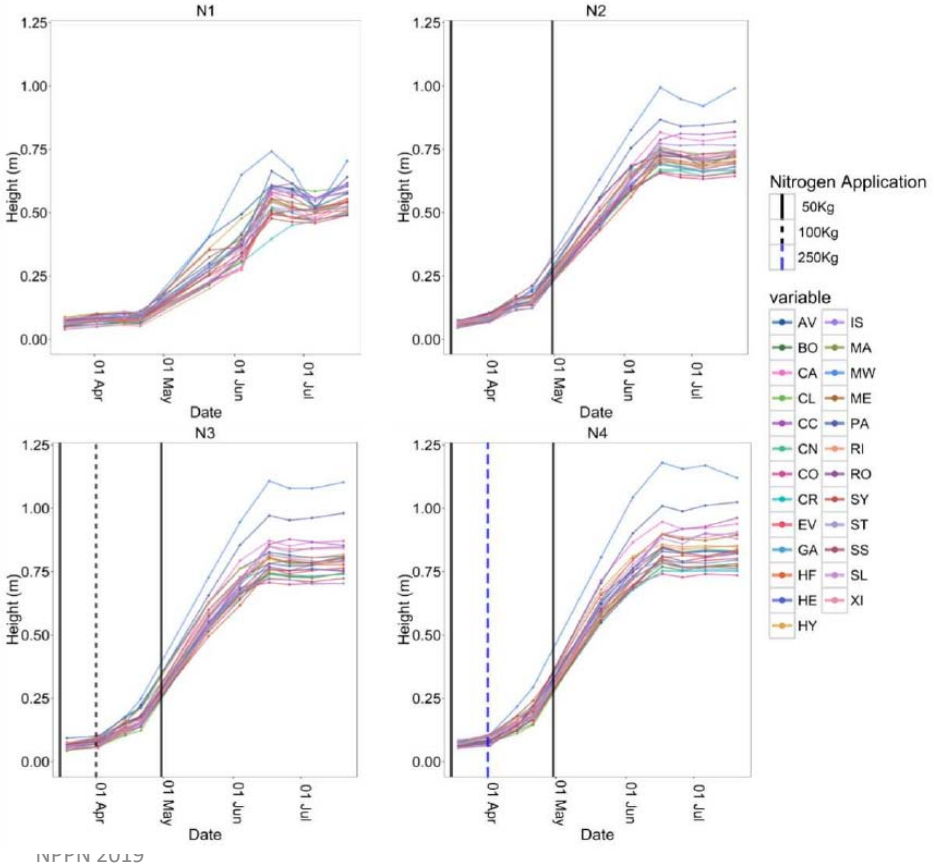
Drone-based height data (RGB camera photogrammetry)



Calibration



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Nitrogen/variety interactions

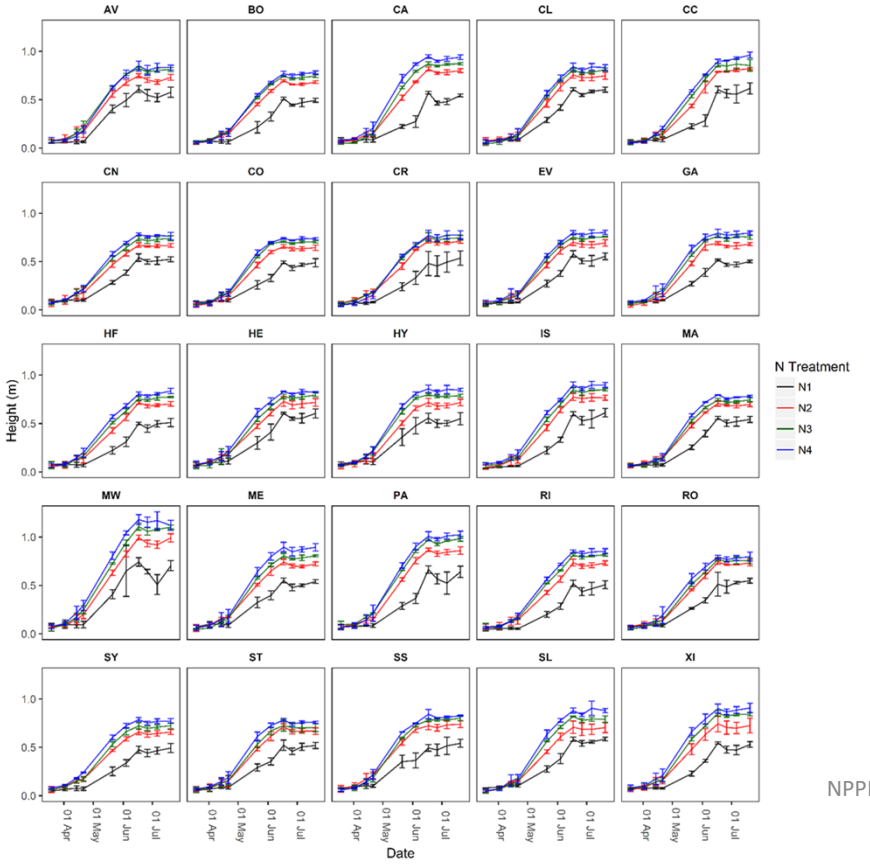
remote sensing **2016: 8** (12), 1031

MDPI

Article

High Throughput Field Phenotyping of Wheat Plant Height and Growth Rate in Field Plot Trials Using UAV Based Remote Sensing

Fenner H. Holman [1,*], Andrew B. Riche [2], Adam Michalski [2], March Castle [2], Martin J. Wooster [1,3] and Malcolm J. Hawkesford [2,*]



Further application: lodging from DEMs

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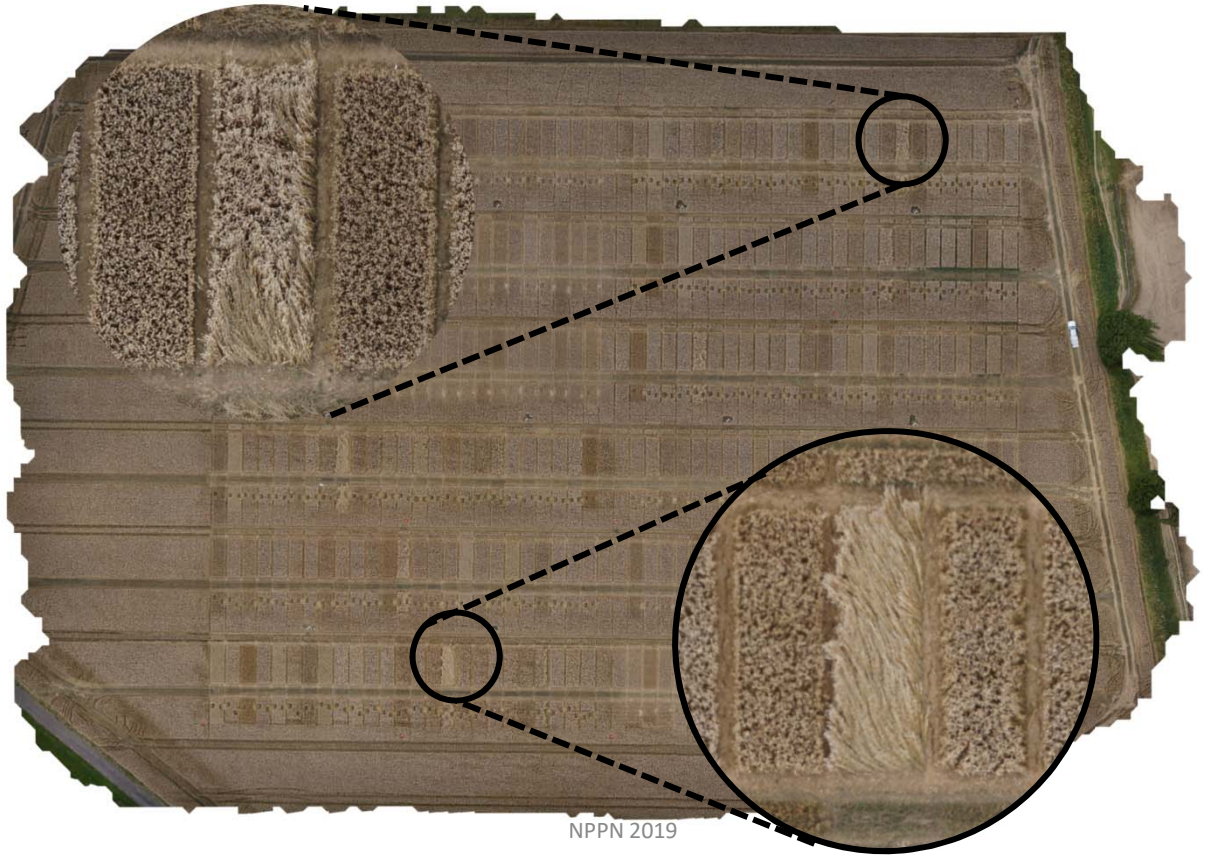
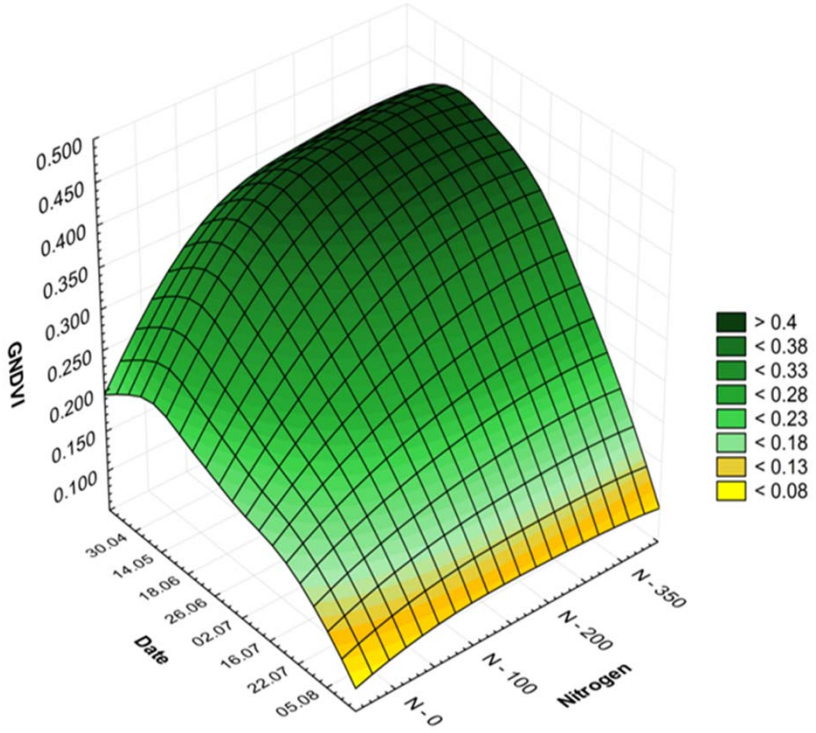


NDVI, senescence and crop maturation



Adam Michalski and Grzegorz Kulczycki

NDVI for canopy evaluation from drones

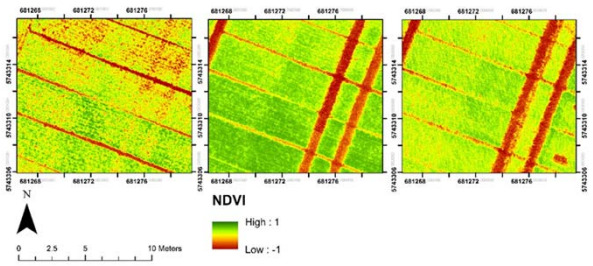
remote sensing

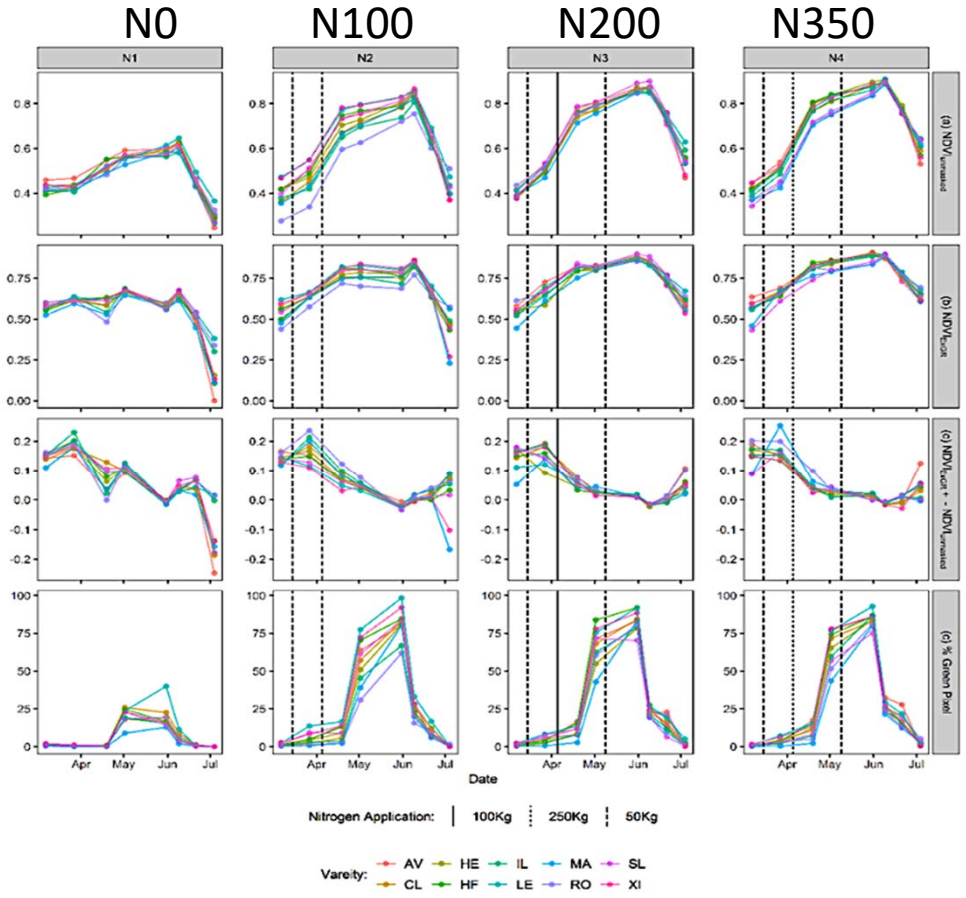
(2019) Vol 11, 1657

Article

Radiometric Calibration of 'Commercial off the Shelf' Cameras for UAV-Based High-Resolution Temporal Crop Phenotyping of Reflectance and NDVI

Fenner H. Holman [1,*], Andrew B. Riche [2], March Castle [2], Martin J. Wooster [1,3] and Malcolm J. Hawkesford [2]





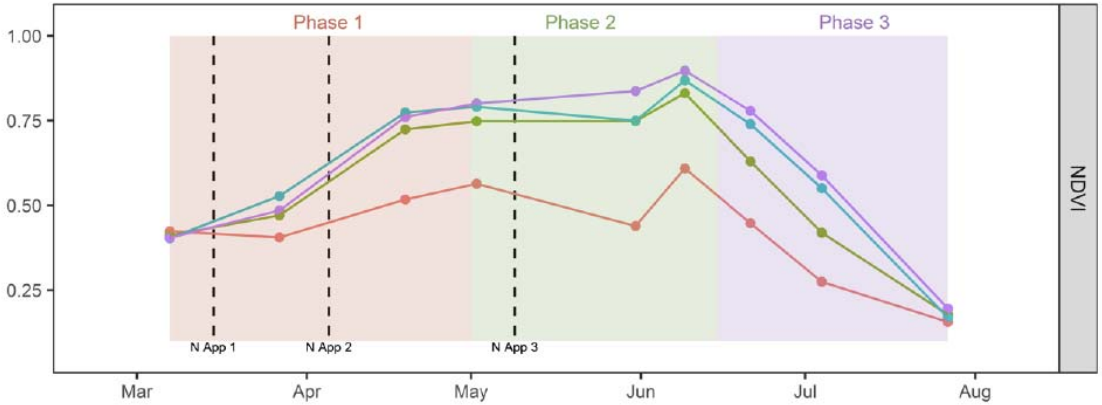
NDVI

NDVI ExGR

diff.

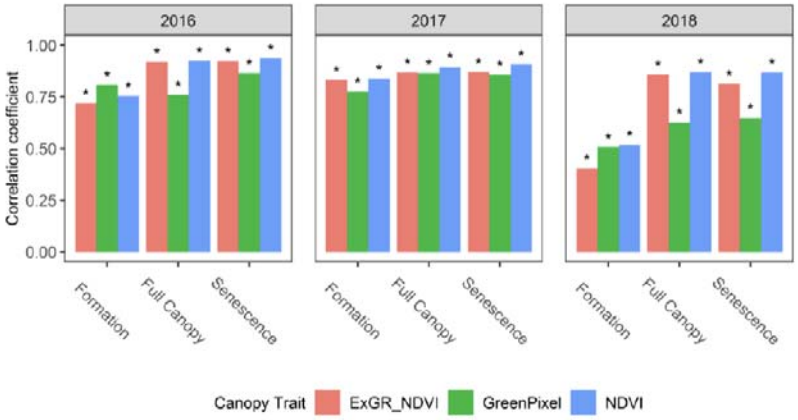
Green pixel

Measuring canopy kinetics



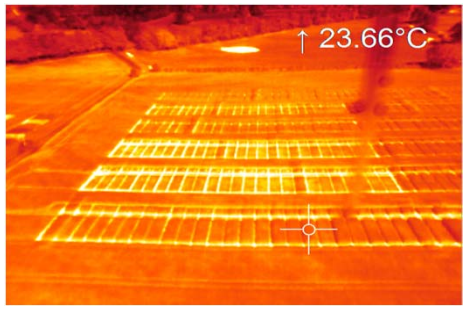
Canopy phases

Yield correlations

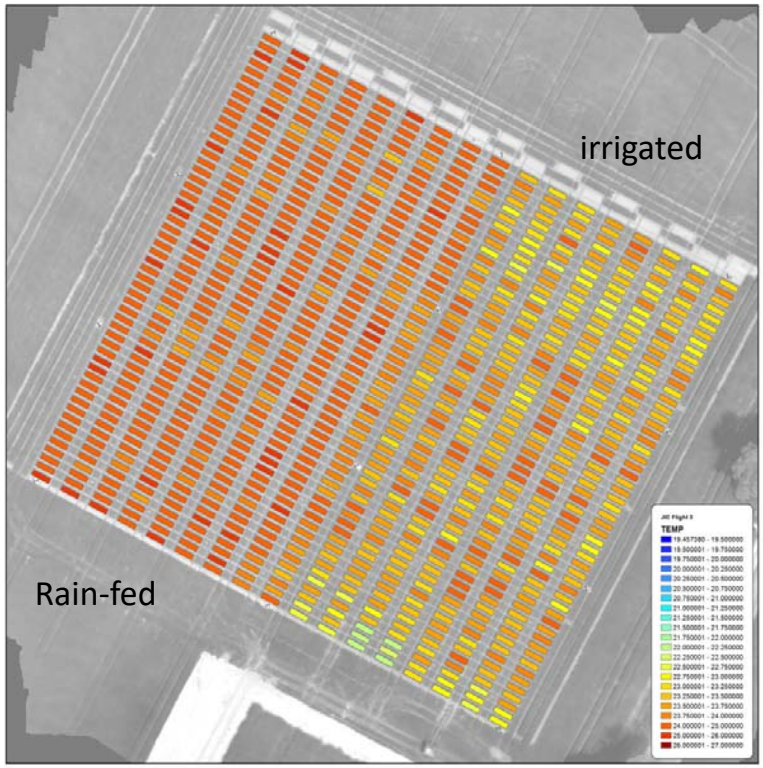


Fenner Holman, unpublished

Thermal infrared camera: canopy temperatures from drones for water use efficiency

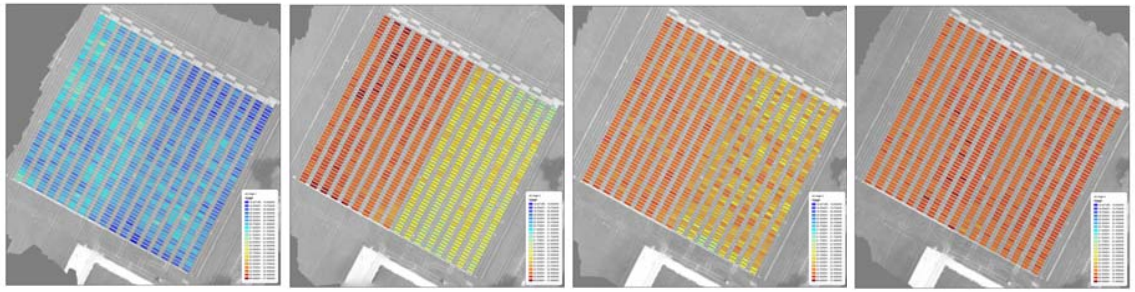


Optris thermal camera

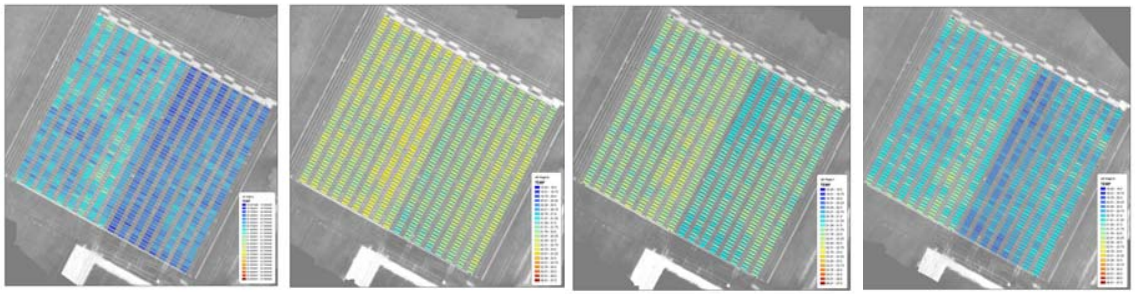


TEMP
- 19.45 - 19.5
- 19.51 - 19.75
- 19.76 - 20.0
- 20.01 - 20.25
- 20.26 - 20.5
- 20.51 - 20.75
- 20.76 - 21.0
- 21.01 - 21.25
- 21.26 - 21.5
- 21.51 - 21.75
- 21.76 - 22.0
- 22.01 - 22.25
- 22.26 - 22.5
- 22.51 - 22.75
- 22.76 - 23.0
- 23.01 - 23.25
- 23.26 - 23.5
- 23.51 - 23.75
- 23.76 - 24.0
- 24.01 - 25.0
- 25.01 - 26.0
- 26.01 - 27.0

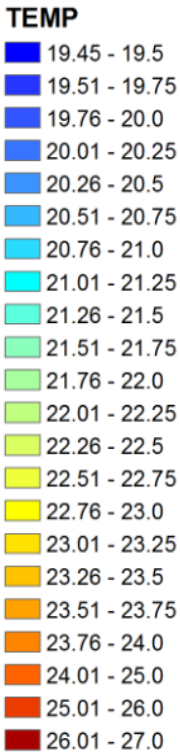
Changing temperatures through the day



8:47, 24.7^{0}C (air temp) 9:38, 27.5^{0}C 10:40, 28.2^{0}C 11:14, 29.7^{0}C



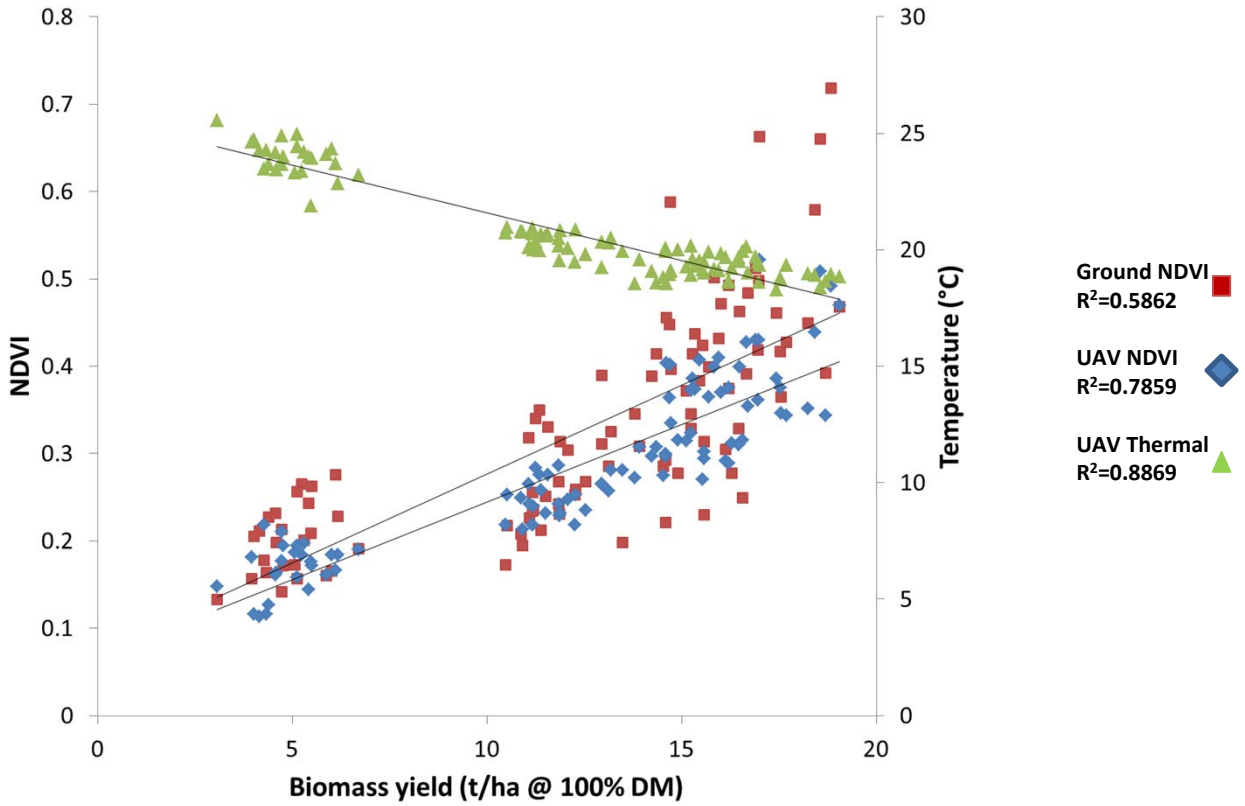
11:58, 24.5^{0}C 13:16, 27.9^{0}C 14:03, 28.9^{0}C 15:33, 26.5^{0}C



Irrigated heats up more slowly, then cools quicker than the rain-fed

Canopy temperatures are useful estimators of biomass

ROTHAMSTED RESEARCH



Rothamsted platform description

- **Programmable,** 24/7 operation, **fully automated**
- High throughput
- High spatial and dense temporal information capture
- Accurate X, Y Z positioning
- **Range of sensors** to measure crop/individual plant growth, development and health
- **Non-invasive**
- **Virlet et al 2017** *Functional Plant Biology* **44**, 143-153

Field Scanalyzer – 1000 lines capacity

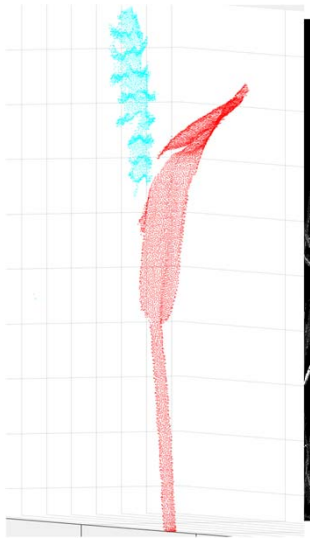
ROTHAMSTED RESEARCH

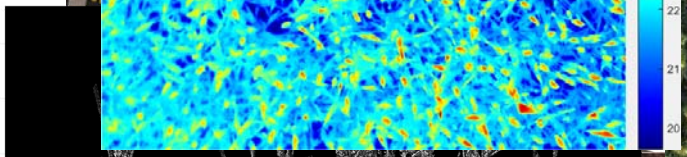
Camera bay (500kg payload)

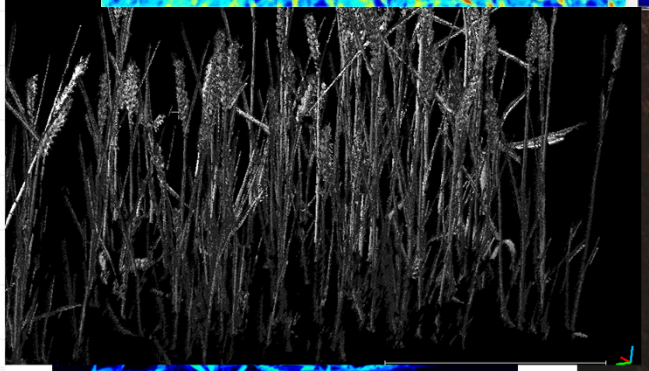
ROTHAMSTED RESEARCH

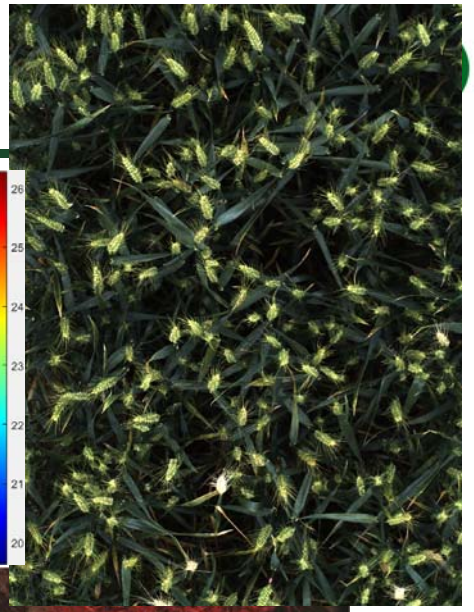
5. Thermal Infrared

- ✓ 7.5 - 13 µm
- ✓ **330 plots/hour**
- ✓ **Canopy temperature (water**









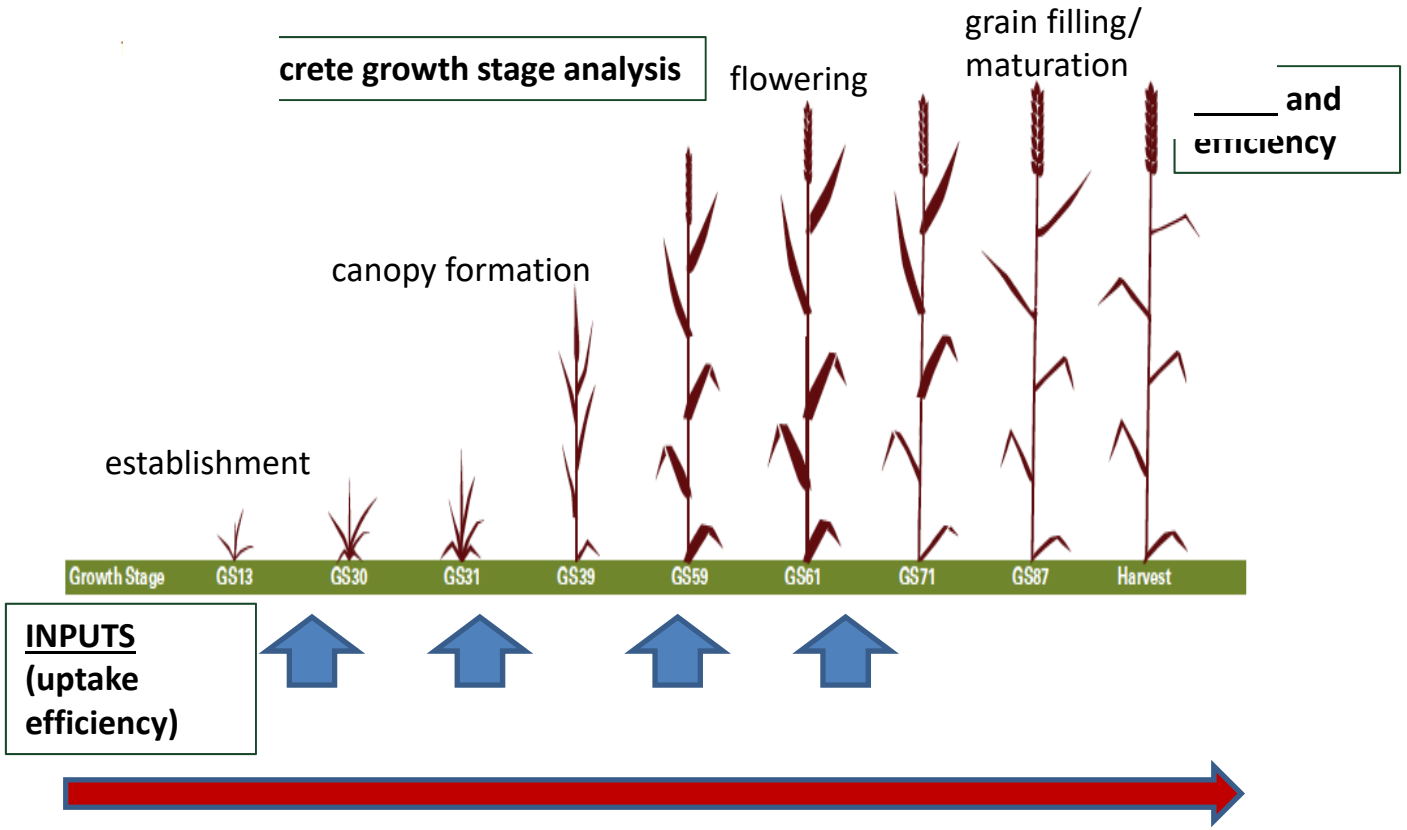
hape and size

1750nm) – **50 to 80 plots/hour**

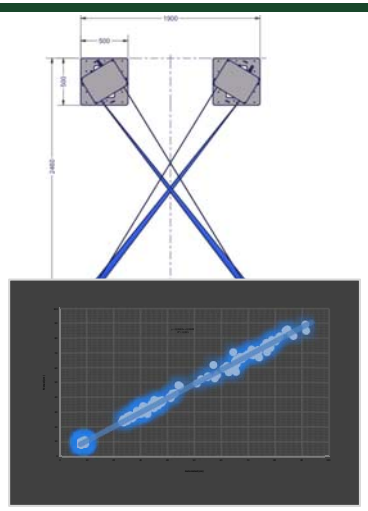
ment, water, heat dissipation

+ on-board weather station

Unprecedented precision

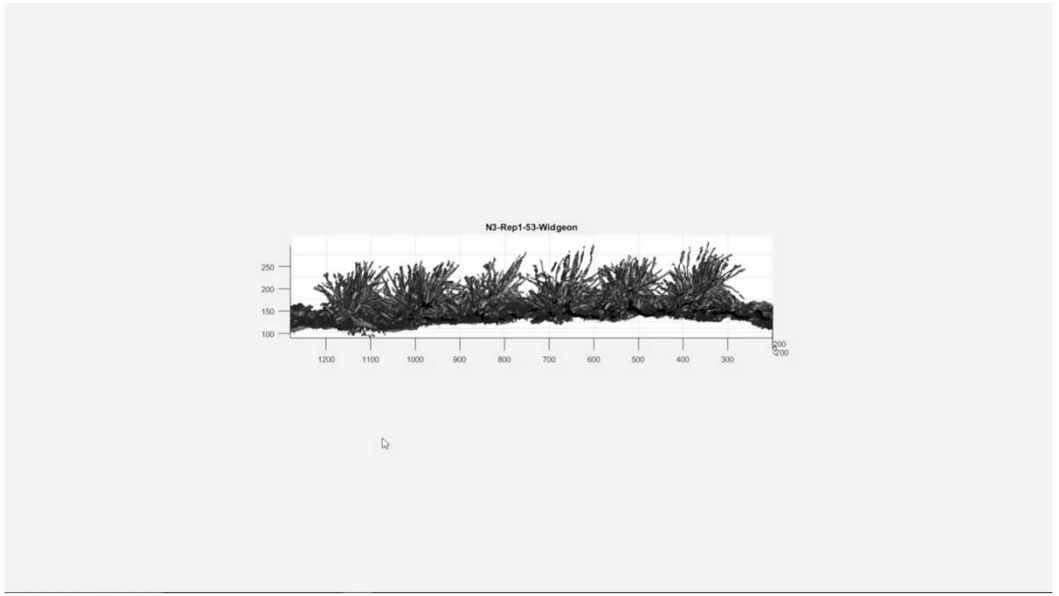


3D imaging



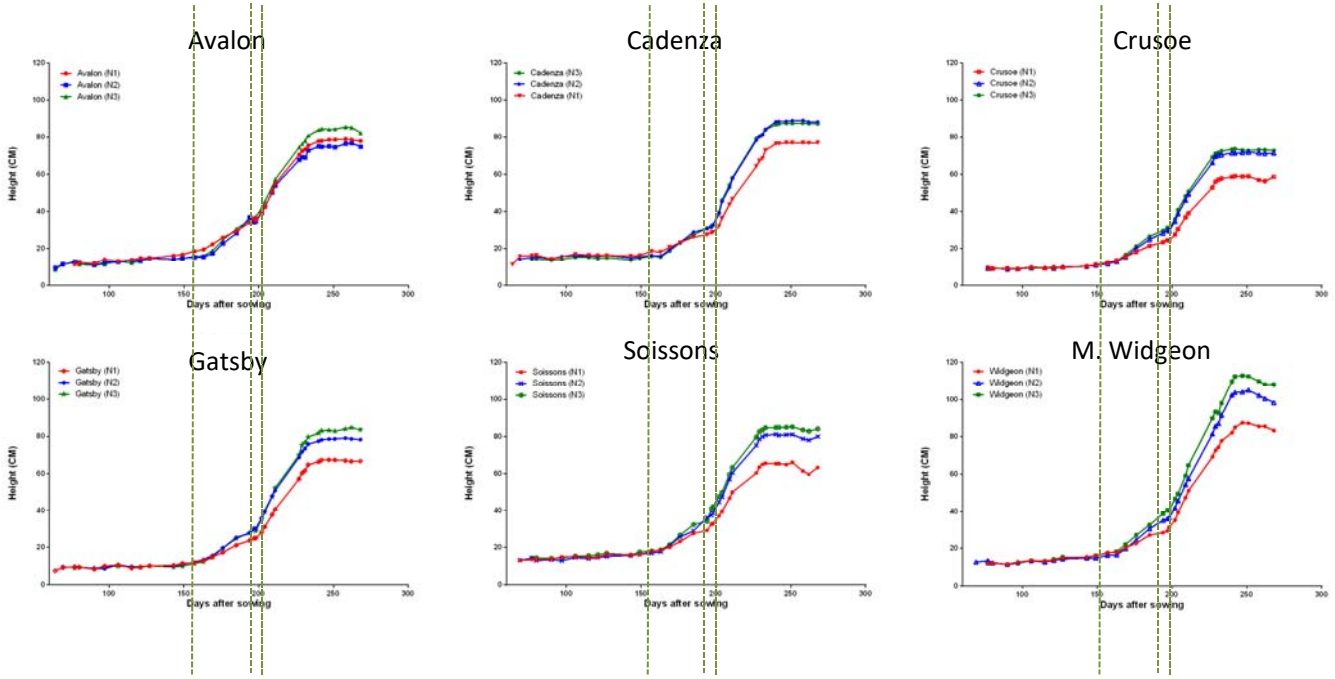
Evaluating canopy height and architecture

1. Twin lasers designed by Fraunhofer
2. Canopy height
3. Leaf size, angle, shape
4. Spike development
5. 0.25mm resolution at 2 m



Crop height determination from laser imagery: nitrogen and variety

ROTHAMSTED RESEARCH



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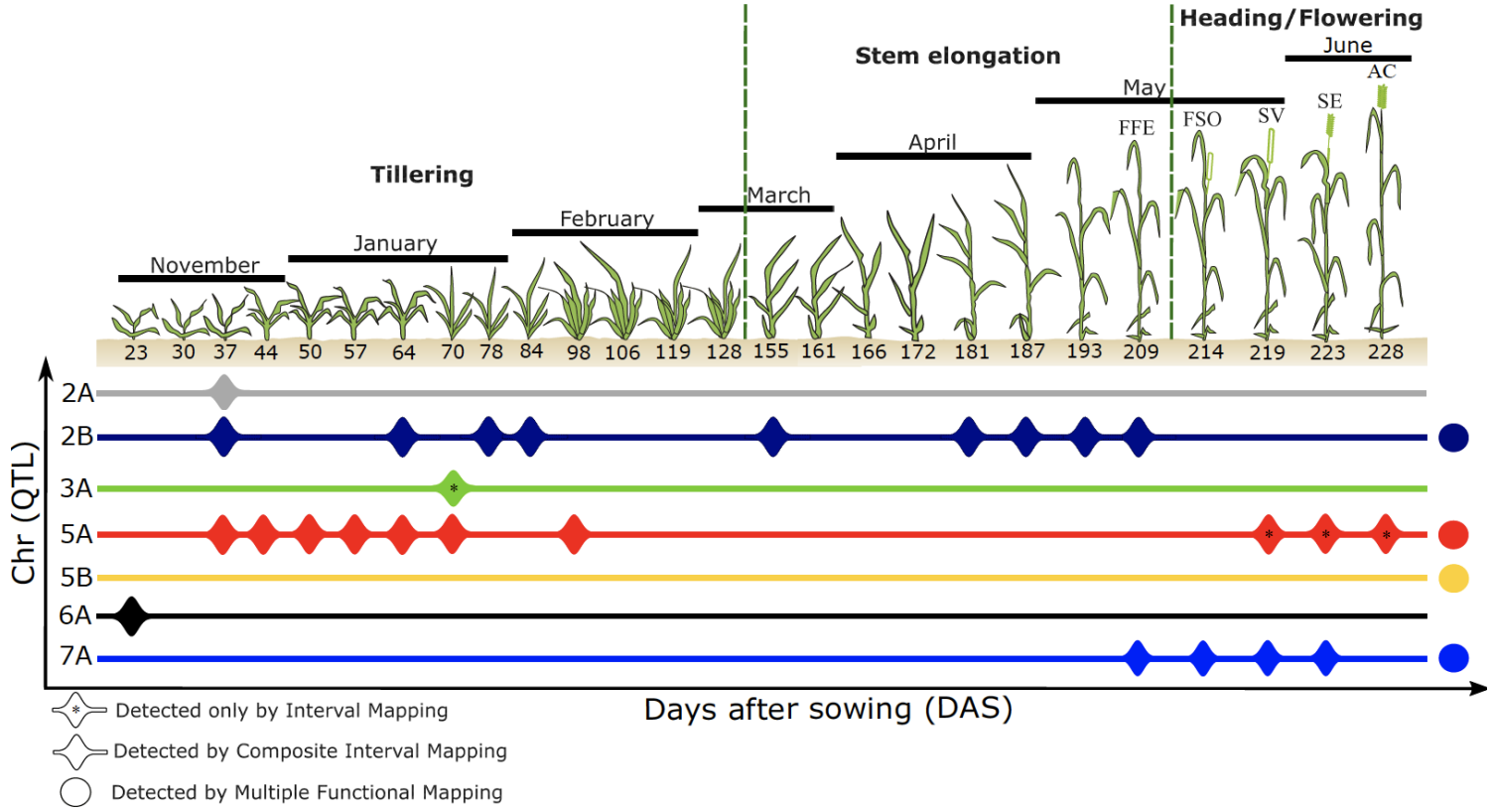
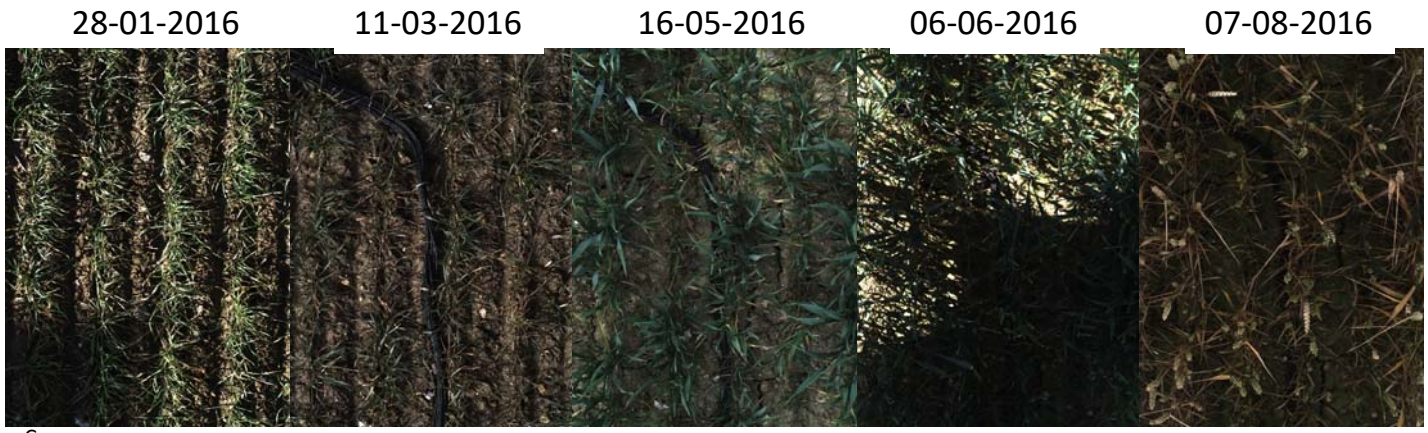
New development stage growth determinants for breeders

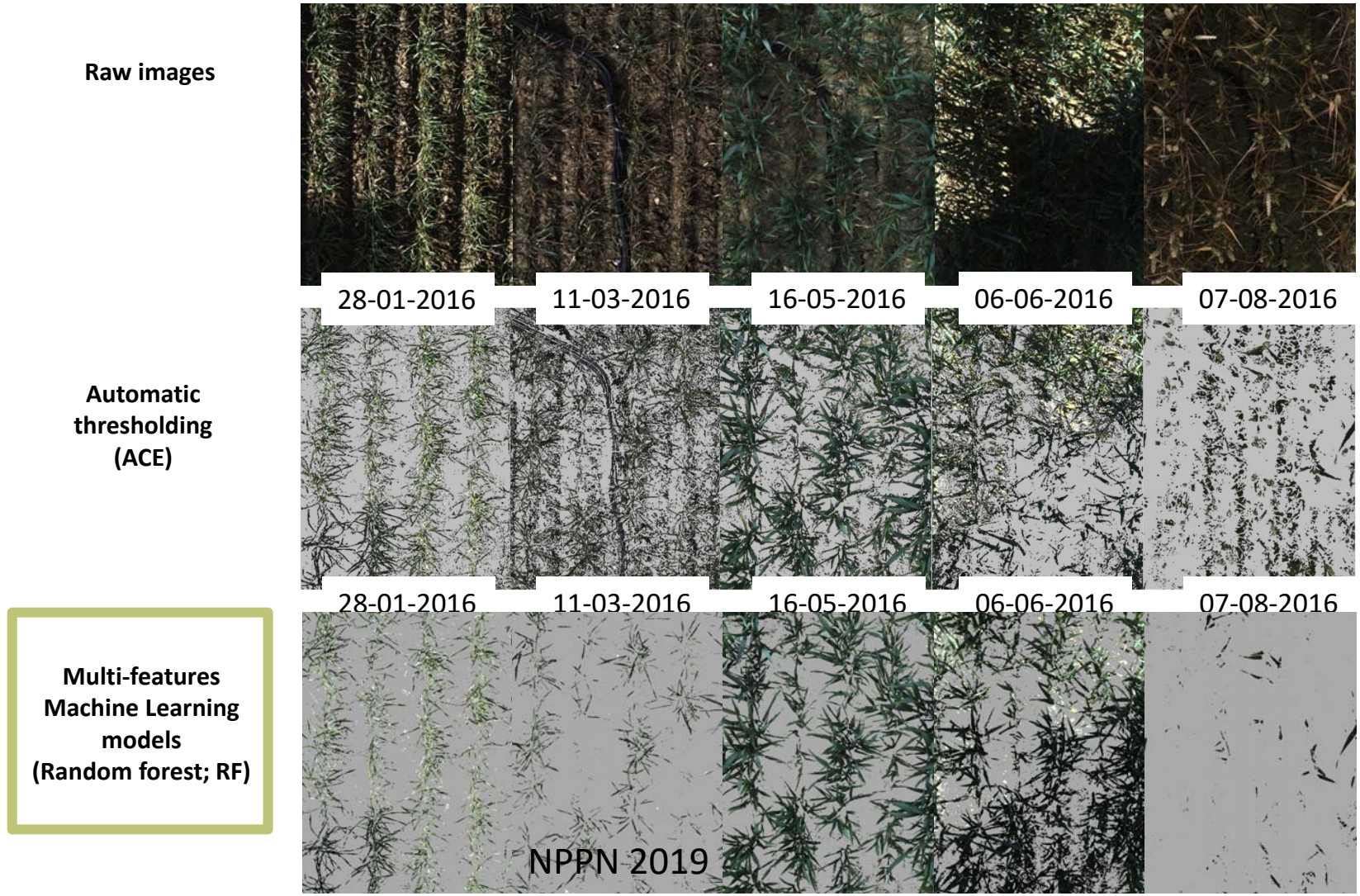


RGB cameras: challenges of outdoor conditions



Crusoe

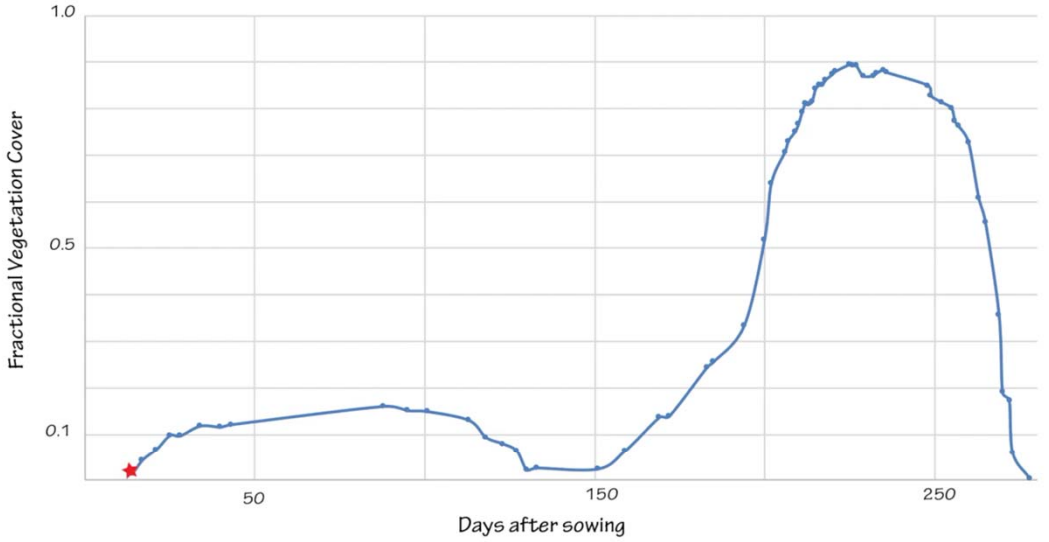
- ✓ **Ambient illumination**
  - o Sun position
  - o Sunny vs cloudy day
  - o Shadows
- ✓ **Background**
  - o Algae
  - o Weeds
  - o Stones….


Raw images
28-01-2016
11-03-2016
16-05-2016
06-06-2016
07-08-2016
Automatic thresholding (ACE)
28-01-2016
11-03-2016
16-05-2016
06-06-2016
07-08-2016
Multi-features Machine Learning models (Random forest; RF)
NPPN 2019

Fractional vegetation cover

ROTHAMSTED RESEARCH

- Monitored throughout season
- Information on establishment
- Canopy formation
- Canopy senescence



Sadeghi-Tehran et al. Plant Methods (2017) 13:103
DOI 10.1186/s13007-017-0253-8

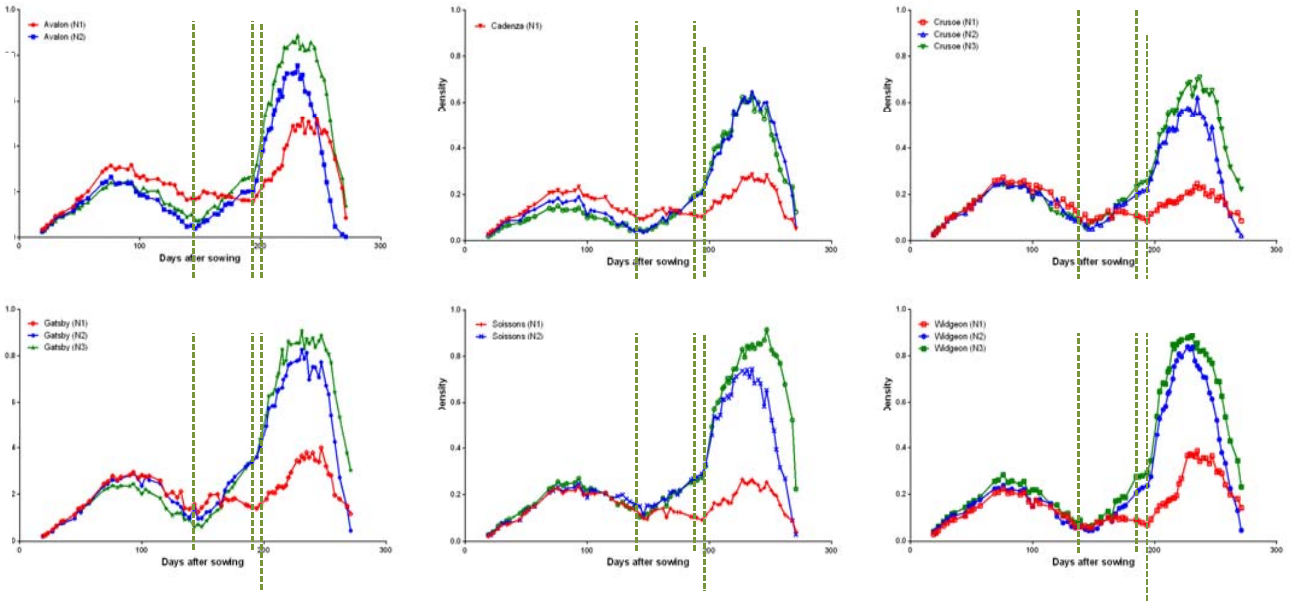
Plant Methods

RESEARCH Open Access

Multi-feature machine learning model for automatic segmentation of green fractional vegetation cover for high-throughput field phenotyping

Pouria Sadeghi-Tehran*, Nicolas Virlet, Kasra Sabermanesh and Malcolm J. Hawkesford

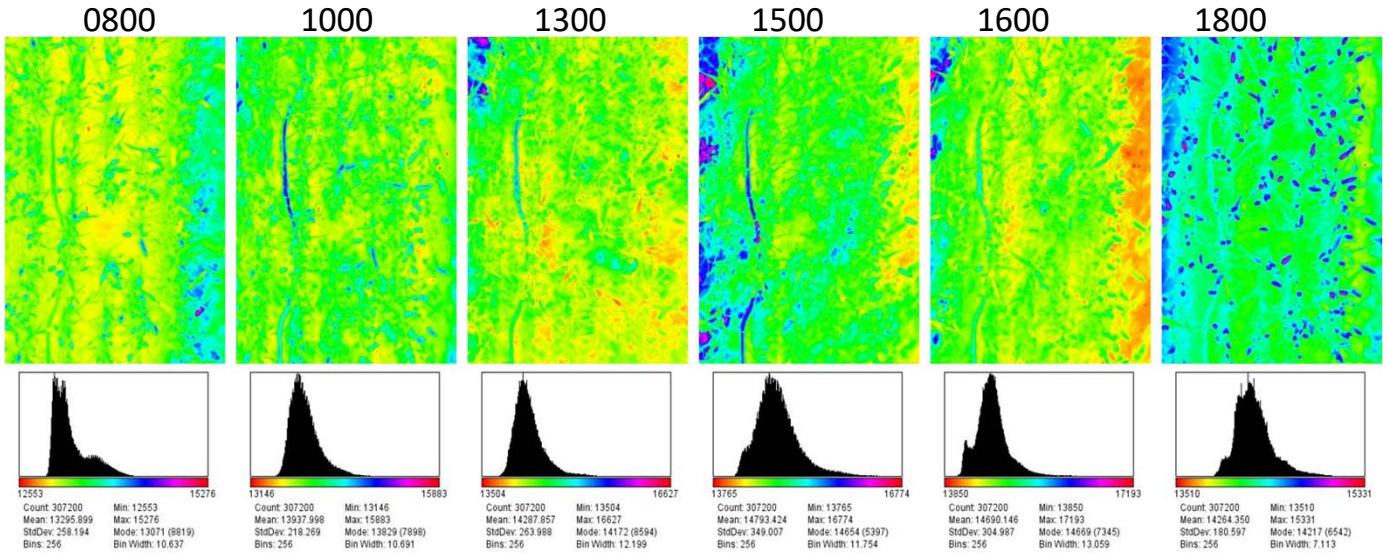
Monitor canopy development -> maturation



Thermal Infrared imaging – poor contrast an issue

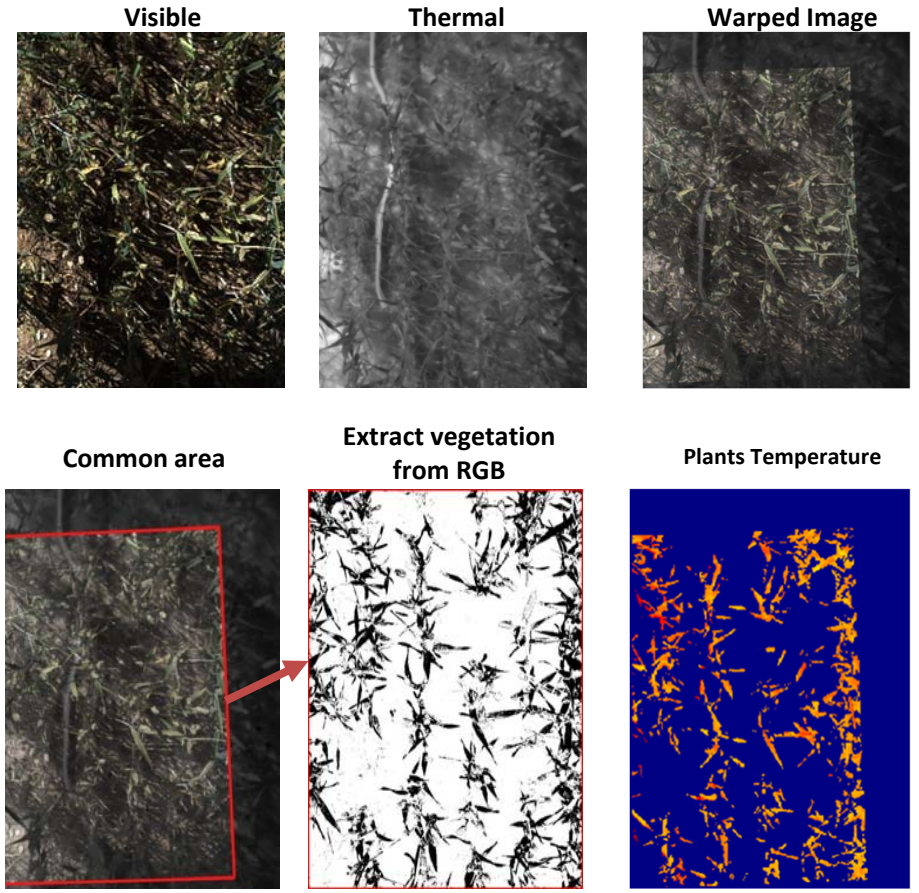
ROTHAMSTED RESEARCH

- Contrast between plant and soil not always enough for image segmentation
  - Histogram do not present clear separation soil/plant
  - Required data fusion with RGB images



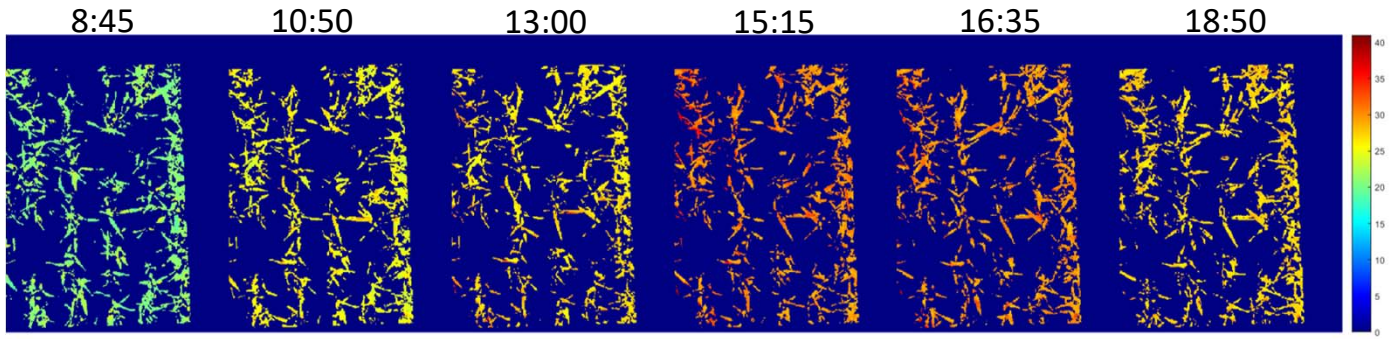
Fusion RGB and TIR images

ROTHAMSTED RESEARCH



Fusion of RGB and TIR images – daily kinetics

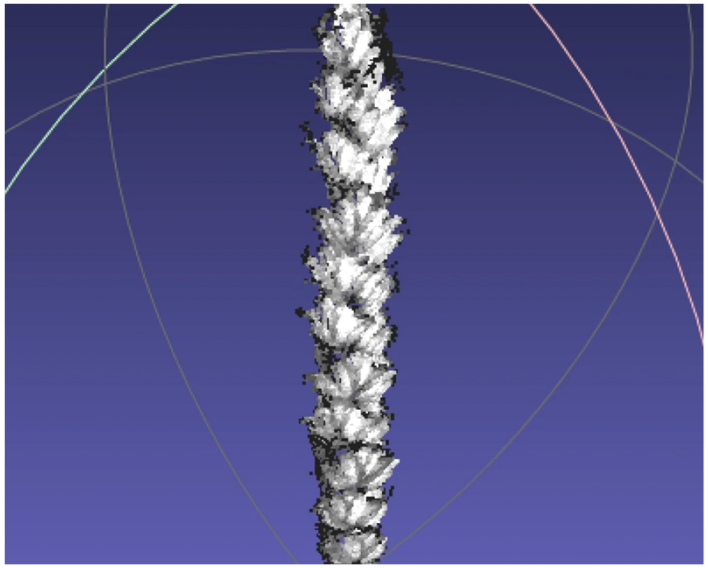
ROTHAMSTED RESEARCH



Imaging technology and application to breeders

ROTHAMSTED RESEARCH

- Germplasm screening
- Yield components
- Key stages of development



Wheat Key Growth Stages: Heading & Flowering

ROTHAMSTED RESEARCH

Heading

Flowering

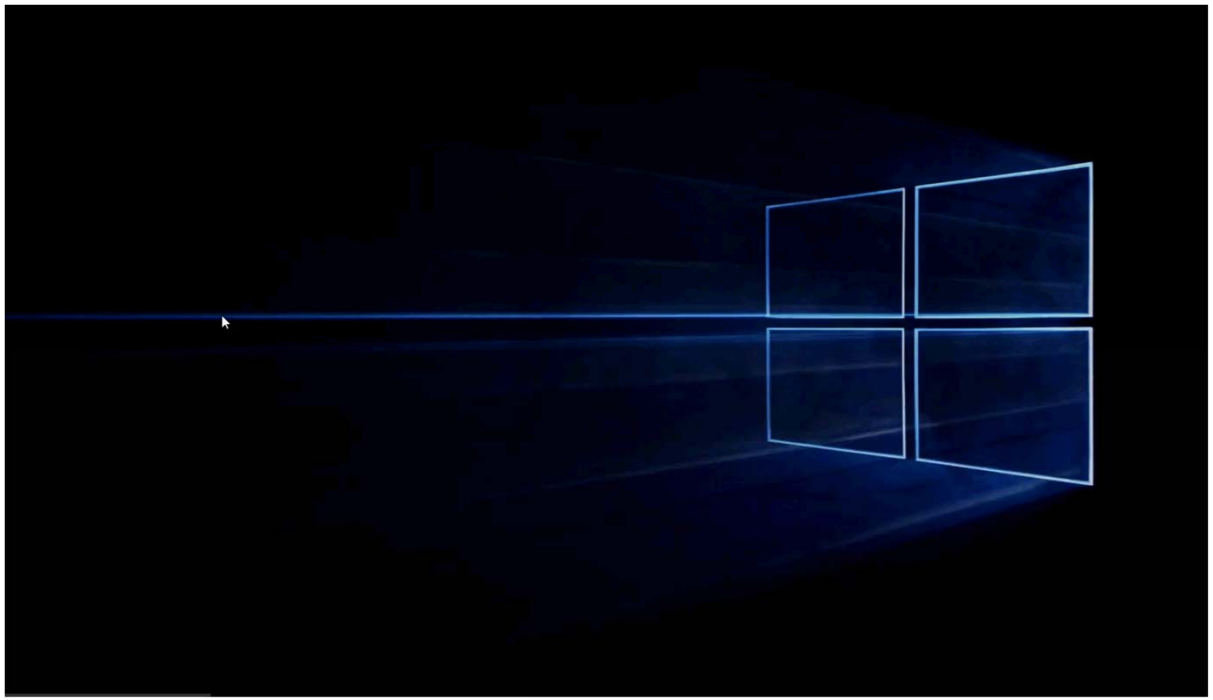
Side View Cameras

ROTHAMSTED RESEARCH

Heading

Flowering

Technology transfer to breeders: ear counting



- Popular target trait
- **Collaboration with breeders and currently under testing**
- Any photograph
- Including from drones

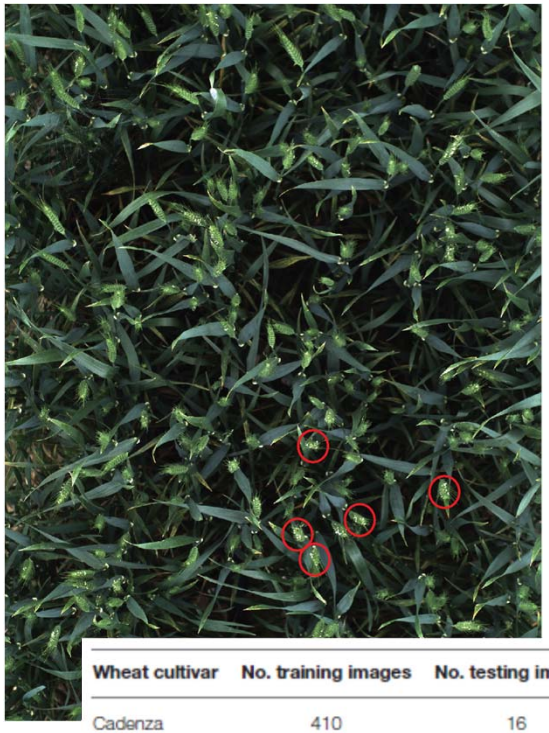
- Sadeghi-Tehran, P., Virlet, N., Ampe, E. M., Reyns, P., & Hawkesford, M. J. (2019). DeepCount: In-Field Automatic Quantification of Wheat Spikes Using Simple Linear Iterative Clustering and Deep Convolutional Neural Networks. Frontiers in Plant Science, 10, 1176. doi.org/10.3389/fpls.2019.01176

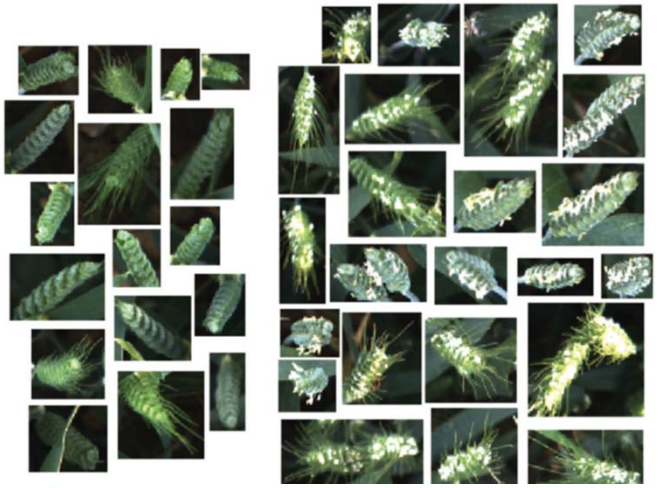
Ear counting from drones

ROTHAMSTED RESEARCH

Automated Flowering Stage Detection (ML; Matlab)

ROTHAMSTED RESEARCH





frontiers in Plant Science

METHODS
published: 27 February 2017
doi: 10.3389/fpls.2017.00252

Check for updates

Wheat cultivar	No. training images	No. testing images	Accuracy (%)
Cadenza	410	16	92.91
Soissons	410	23	76.72
Maris widgeon	410	15	80.33
All three	410	54	82.54

Automated Method to Determine Two Critical Growth Stages of Wheat: Heading and Flowering

Pouria Sadeghi-Tehran, Kasra Sabermanesh, Nicolas Virlet and Malcolm J. Hawkesford**

Department of Plant Biology and Crop Sciences, Rothamsted Research, Harpenden, UK

Quantify Flowering (individual ears; colour segmentation)

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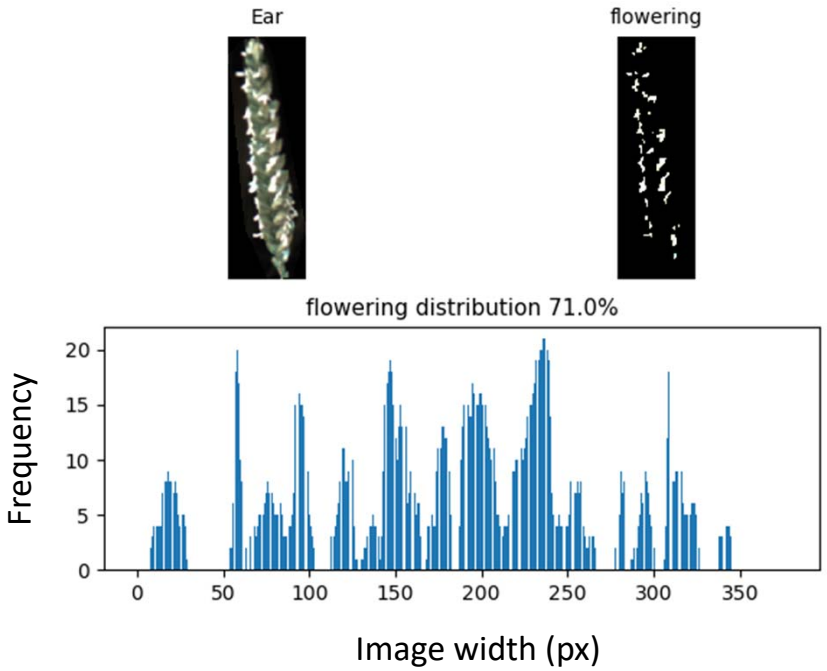

Multi-spectral analysis with dual hyper-spectral cameras

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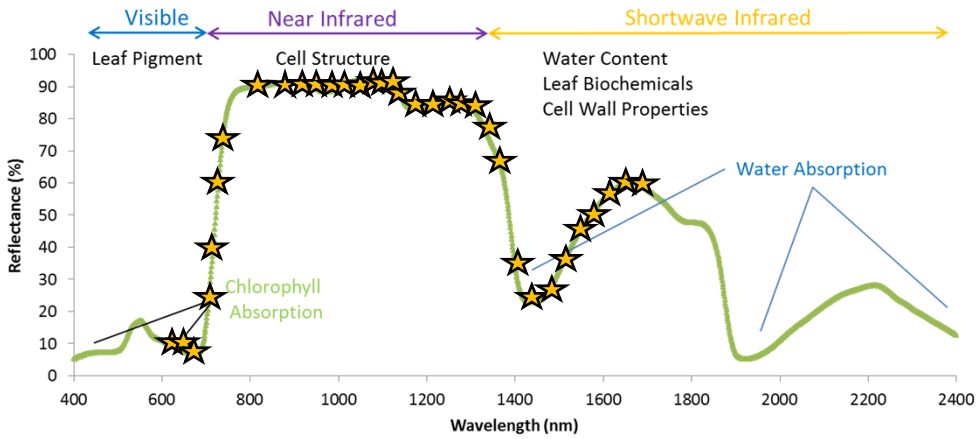
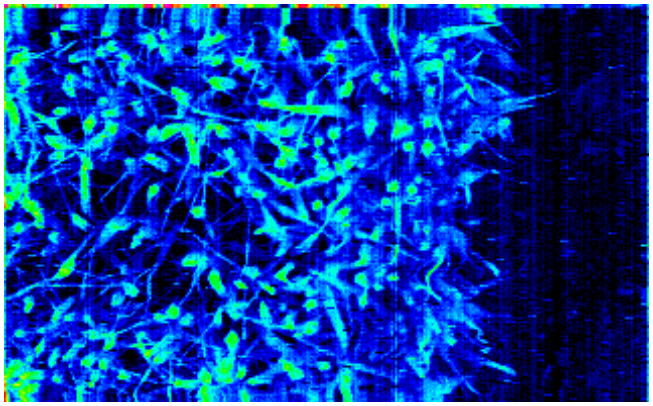


False colour

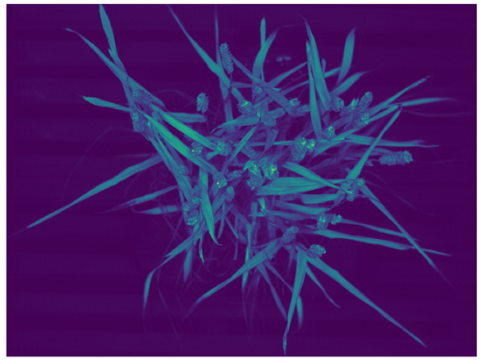


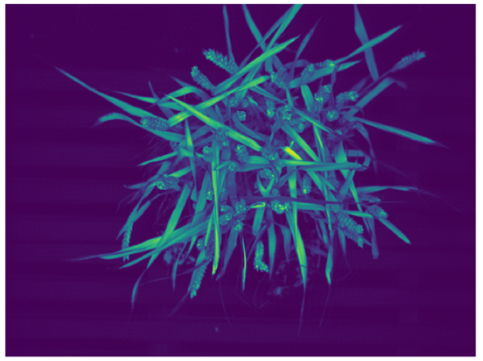
Chlorophyll fluorescence (Fv/Fm)

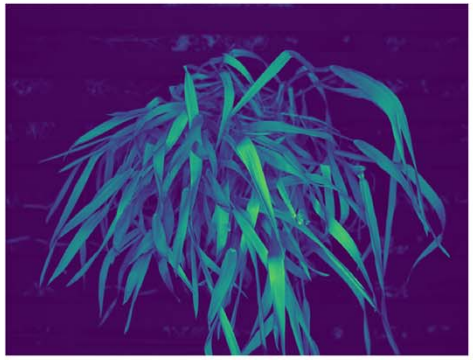
ROTHAMSTED RESEARCH

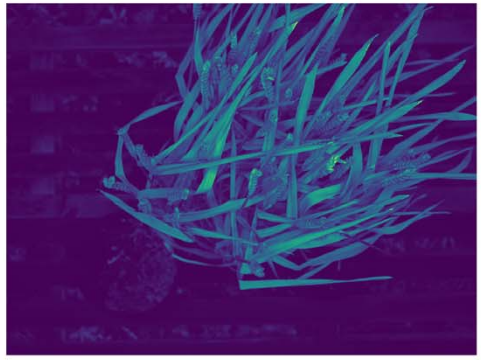
CropReporter:
Excitation source: LED
LED emission: 620nm (red)
Intensity: 0-7000 µmol m^{-2} s^{-1} @ 70 cm
Resolution: 1388*1038 =1.4Mp
Frame Rate: 25 images s^{-1}
Detection Filter: 710nm ± 20nm

PhenoVation Life Sciences









Working in 3D

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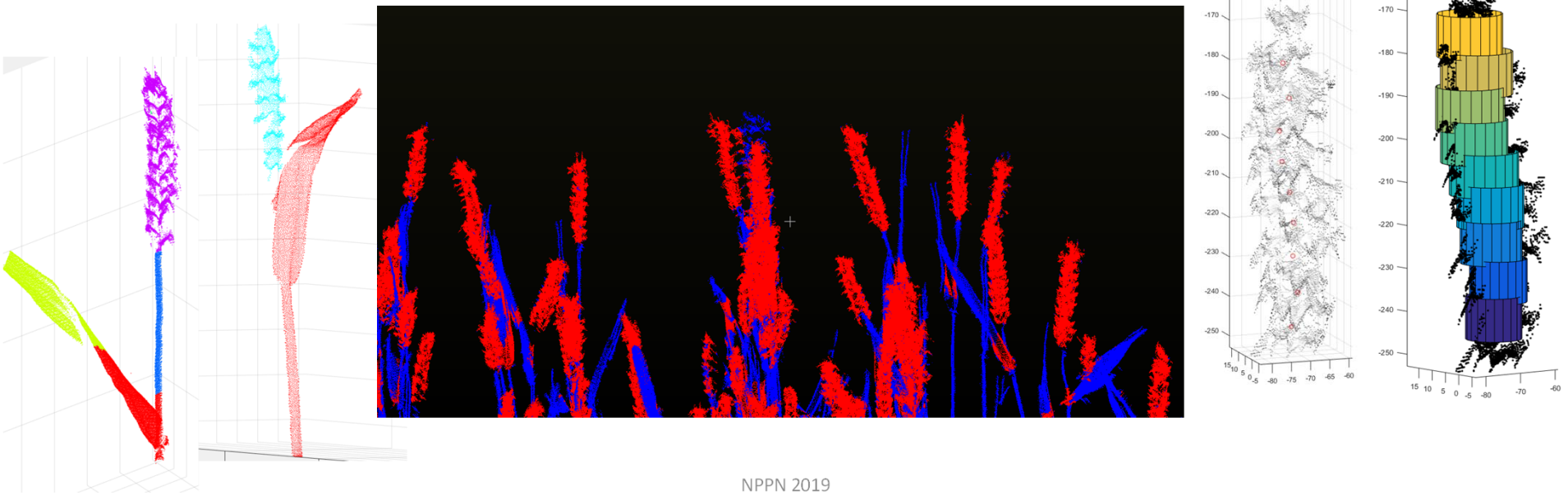
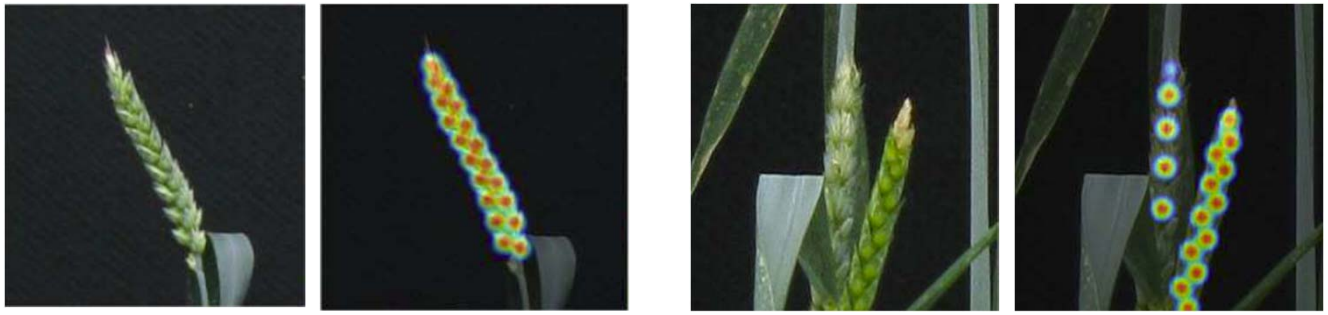
- In situ non-destructive measurements
- Segmentation of 3D images



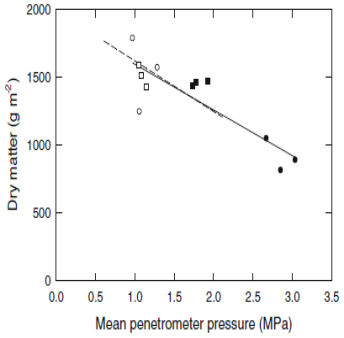
Wheat Spikelets Quantification

ROTHAMSTED RESEARCH



source: Michael P. Pound et. al.
Nottingham University

What about roots? Some approaches:



ERT to measure soil drying as proxy for root activity

Electrical Resistance Tomography in place below gantry

Root monitoring in the field: ratio inversion ERT

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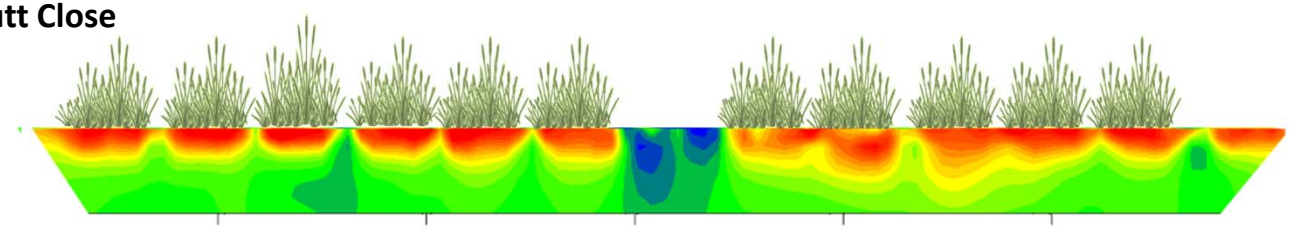
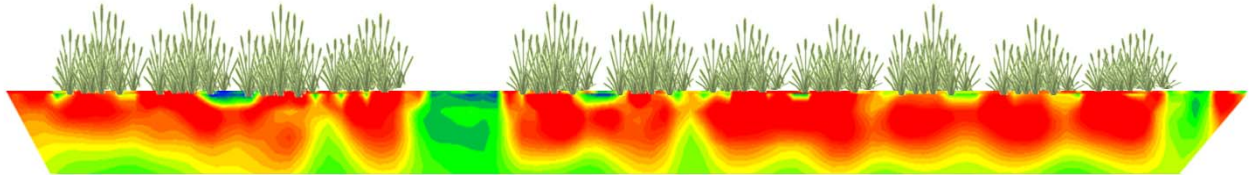
Butt Close



Warren Field

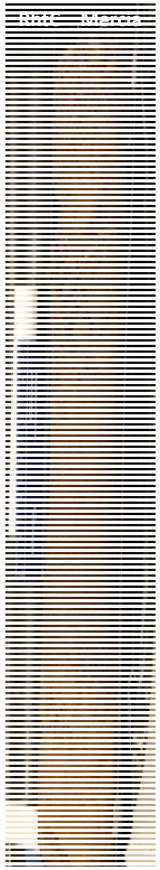


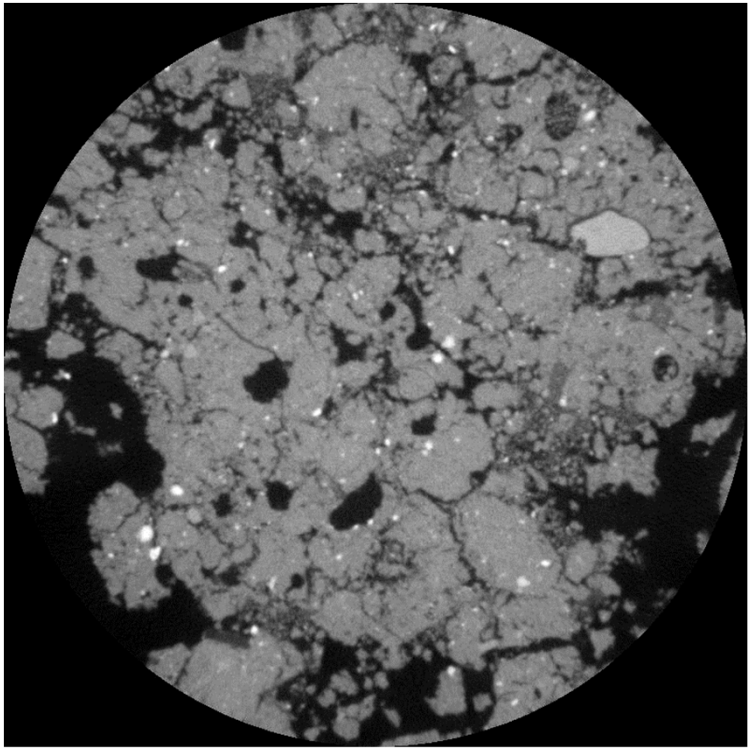
Whalley et al (2017)
Plant Soil, online
Courtesy R. Whalley (RES) and A. Binley

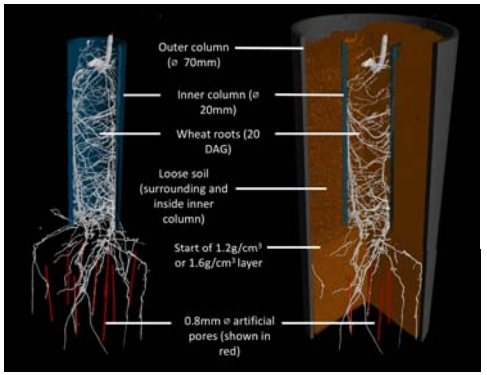
More conductive — More resistive

LANCASTER UNIVERSITY

X-ray CT scanning of field cores







S Mooney, University of Nottingham

Prospects: phenotyping developments

- Drones and robot technology
- Use of consumer products
- Greater sophistication of data extraction tools
- Coordinated information systems
- <u>Wider deployment of technology</u>
  - Balancing costs/benefits
  - Time demands for user
  - Avoiding rapid obsolescence

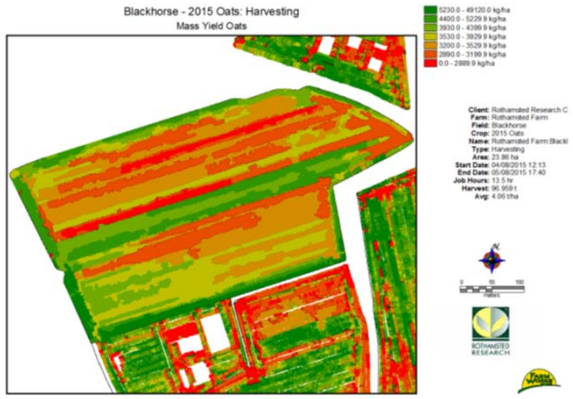
Swarms for higher throughput



- http://echord.eu/mars/index.php.html
- https://americansecuritytoday.com/defending-drone-swarms-dronetracker-3-5-multi-video/drone-swarm/
- http://uasmagazine.com/articles/2028/drone-swarm-operations-gaining-traction

Prospects: impact in agriculture?

- **Plant breeding and prebreeding**
  - Trait dissection
  - High spatial and temporal data
- **Agronomy**
  - Precision farming – controlling nutrient and water inputs
  - Yield prediction
  - Pest and weed detection and control
  - Monitoring in horticulture/plant factories
  - Harvesting



Acknowledgements

Andrew Riche, March Castle, Nicolas Virlet, Pouria Sadeghi, Fenner Holman

Gancho Slavov, Danilo Hottis-Lyra

Adam Michalski, Grzegorz Kulczycki (Wroclaw University)

Martin Wooster (KCL)

DFW and WGIN colleagues

Rothamsted farm staff

From Lemnatec

https://www.rothamsted.ac.uk/field-scanalyzer
https://www.phenomuk.net