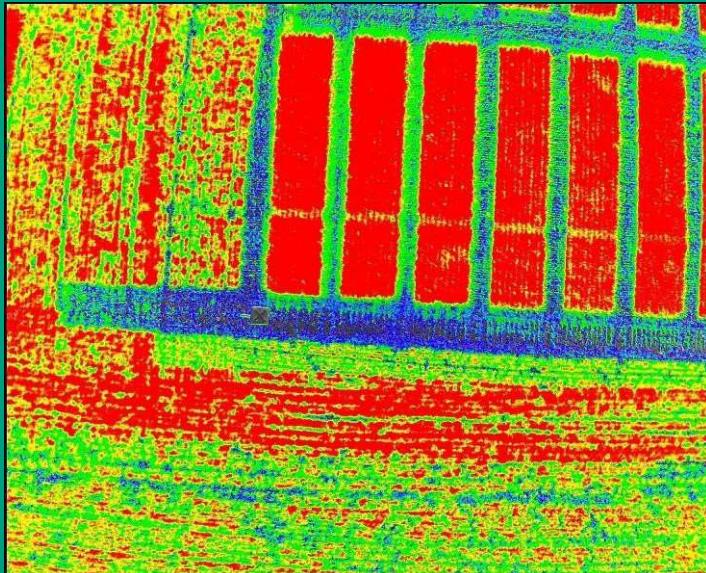


Imaging in Field Phenotyping



Sahameh Shafiee
September 2022



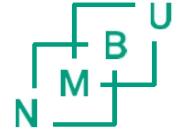
Outline

- Part I – Theory and general overview
 - Sensors and cameras
 - Phenotyping platforms
- Part II – Examples of phenotyping activities at NMBU



Why phenotyping?

How to produce more food with limited resources?



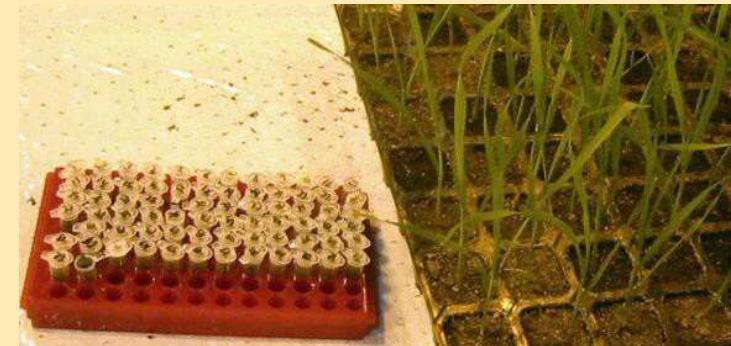
- Improved agronomy



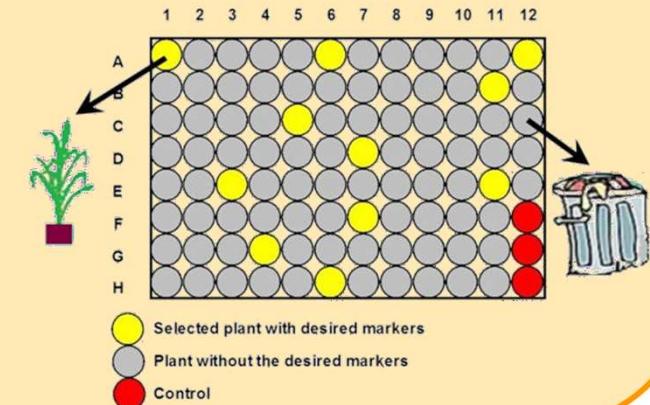
Precision agriculture



- Improved varieties – plant breeding



Precision genetics

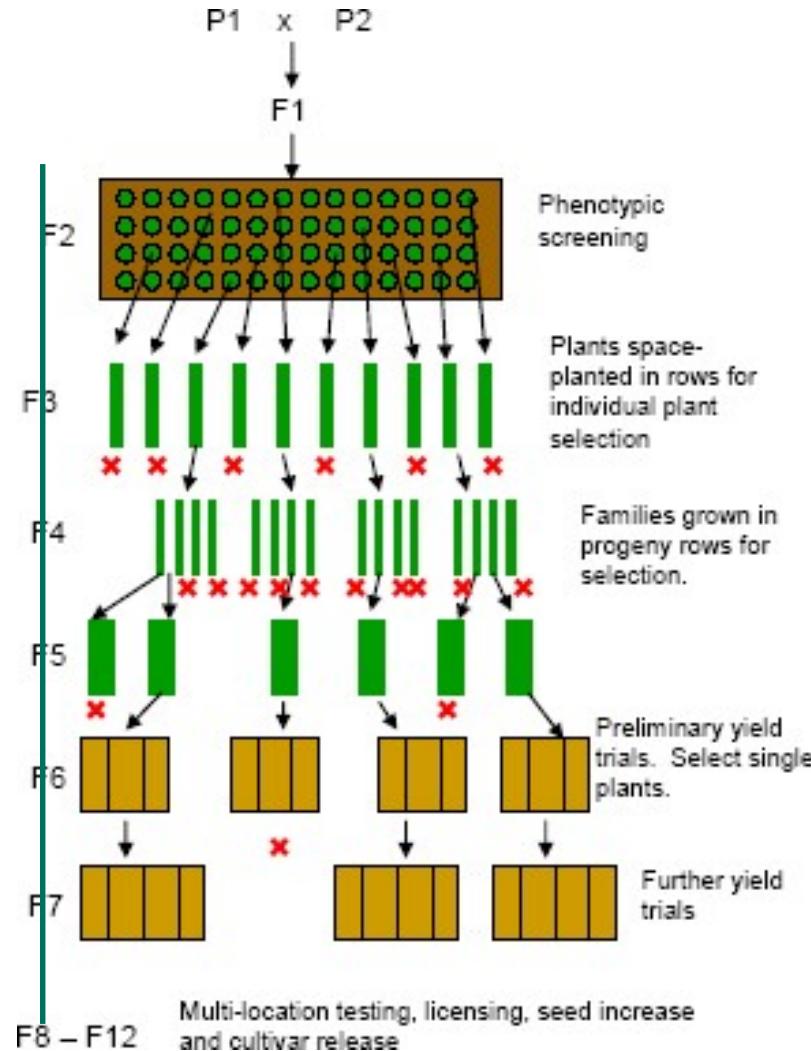


Plant breeding in a «nutshell»

Example: Pedigree selection, self-pollinated crop

Visual selection

Quantitative data

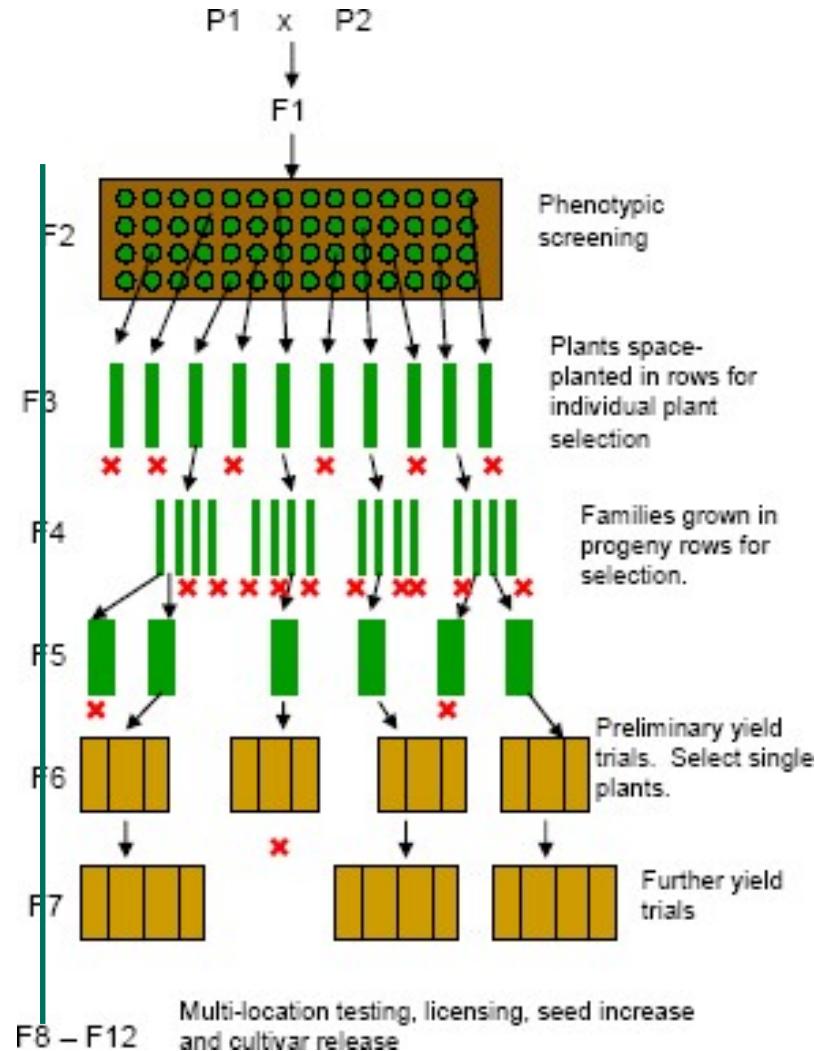


Plant breeding in a «nutshell»

Example: Pedigree selection, self-pollinated crop

Visual selection

Quantitative data



How can we help the breeder to do more effective selection?



Plant selection tools



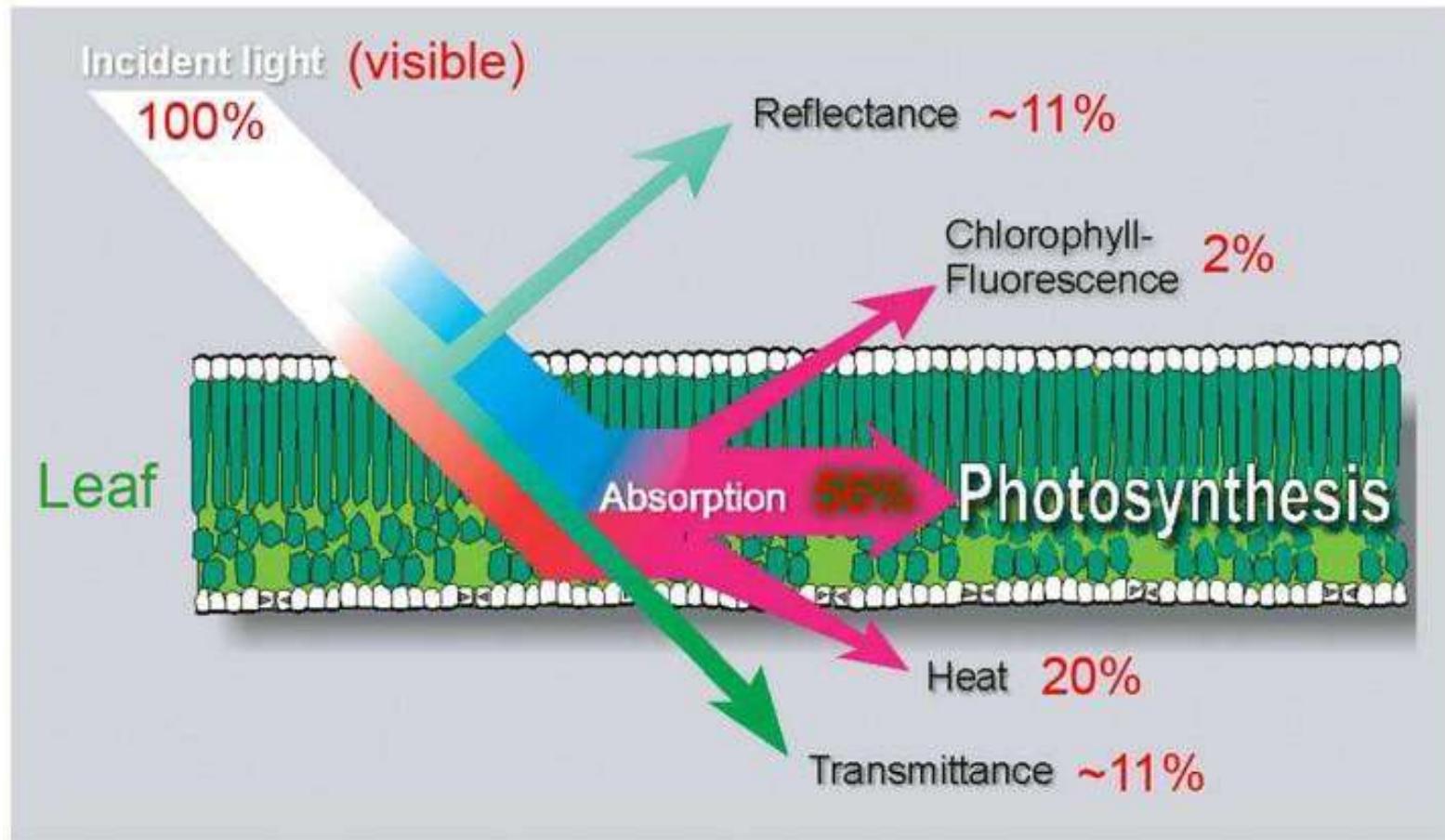
Visual selection





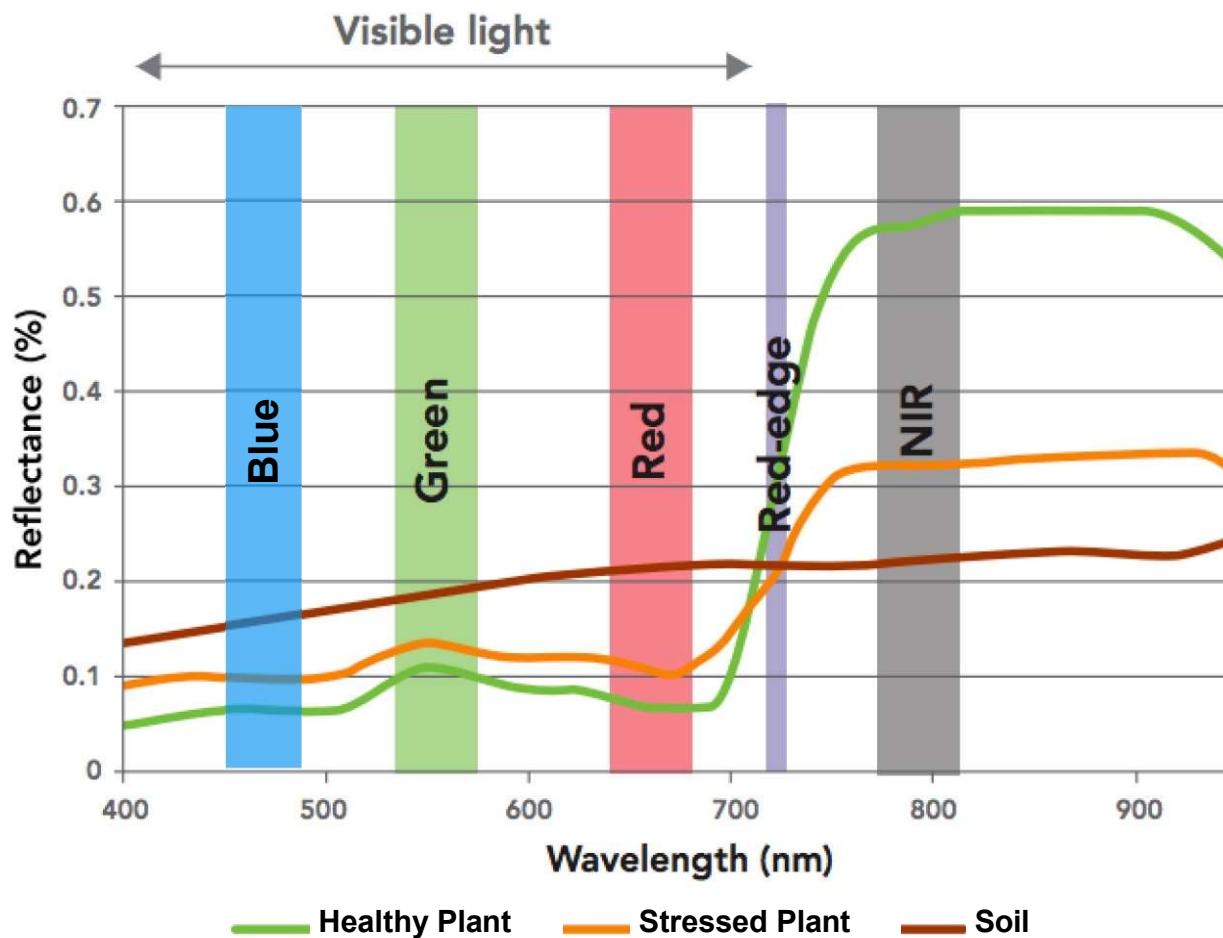
Sensors and cameras

Spectral reflectance



Mapping Photosynthesis from Space - a new vegetation-fluorescence technique
ESA bulletin. Bulletin ASE. European Space Agency. 11/2003; 116:34-37.

Spectral reflectance



- Vegetation indices:

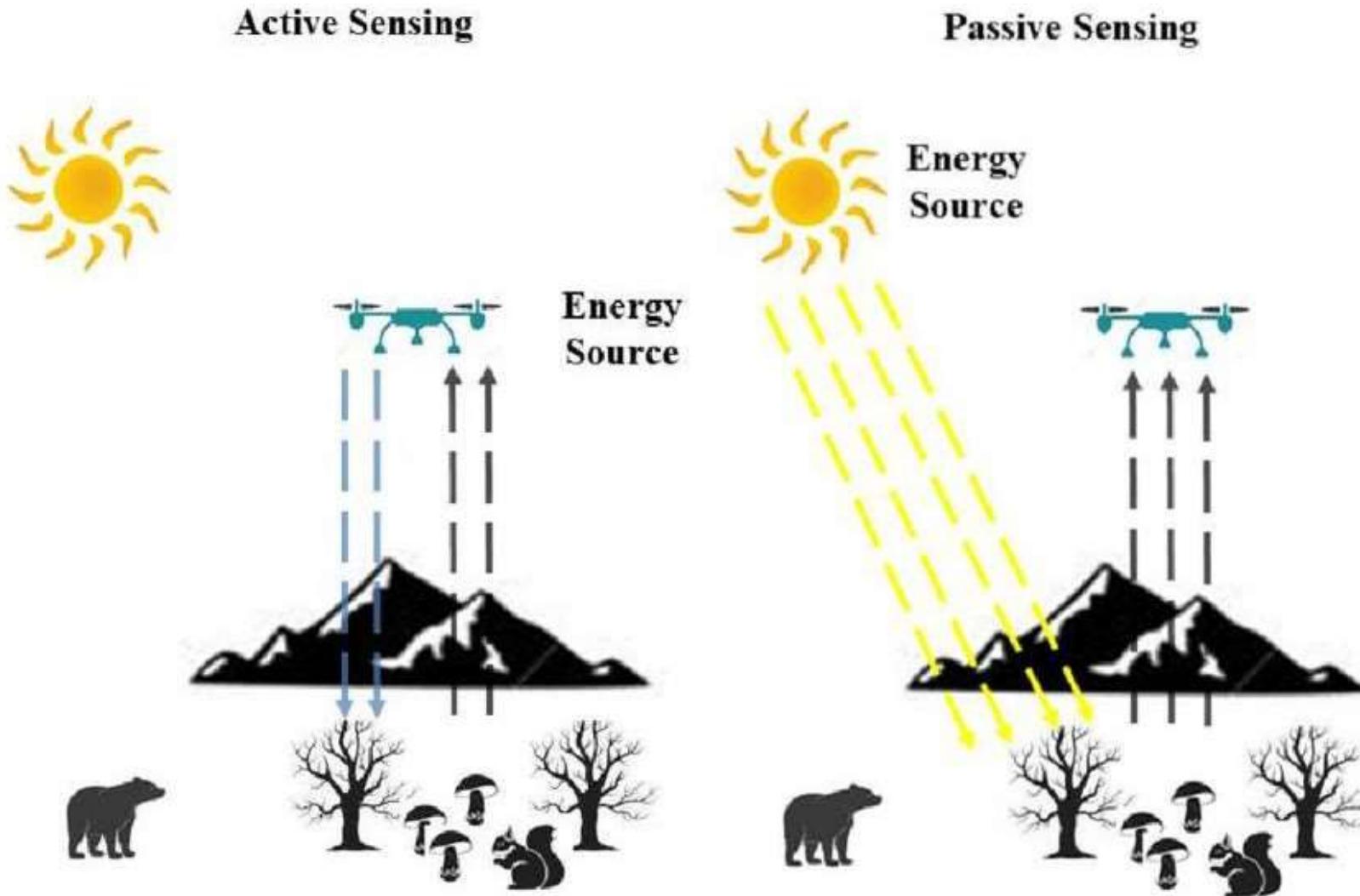
Normalized Difference Vegetation Index (NDVI):

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

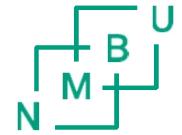
MERIS Terrestrial Chlorophyll Index (MTCI):

$$MTCI = \frac{NIR - Red_{edge}}{Red_{edge} - Red}$$

Active vs passive sensors



Spectroradiometers – active sensors



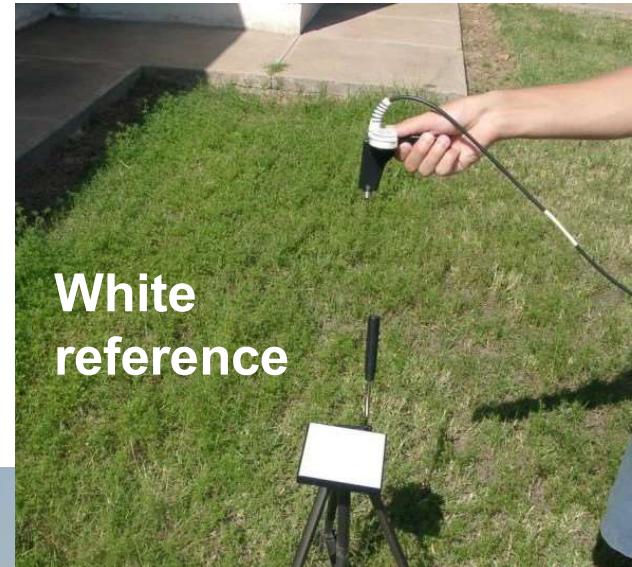
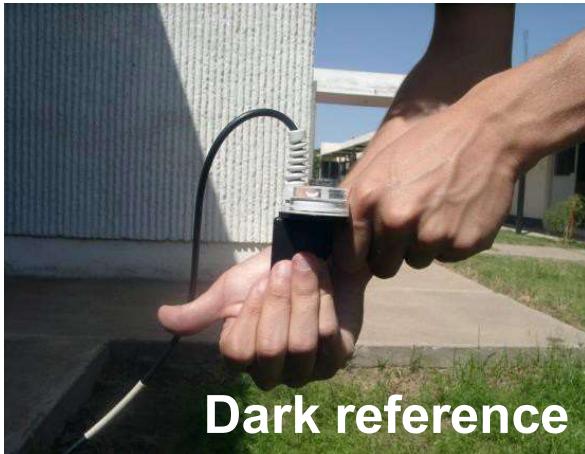
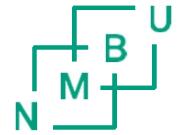
- GreenSeeker

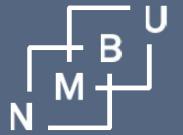


- SPAD



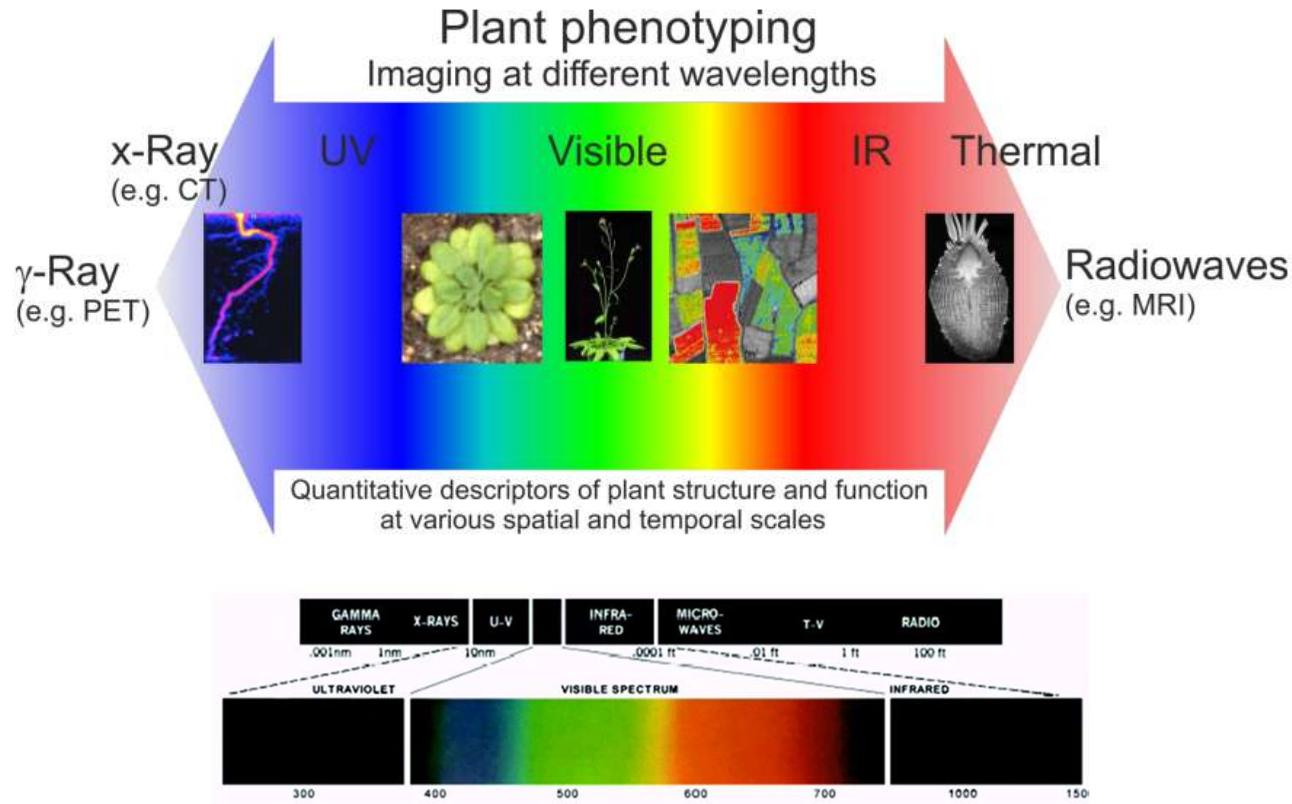
Spectroradiometers – passive sensors



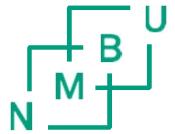


Cameras

Light and the Electromagnetic Spectrum



Fiorani et al. 2012, Current Opinion Biotechnology



Sensors for imaging in Phenotyping

Currently, the most used image sensor devices are standard digital cameras and/or surveillance cameras that capture electromagnetic waves within the visible light spectra to generate digital images (color or grayscale).

However, there are also other technologies that have been used for more specific applications, such as devices that are based on infra-red, ultrasound, and ionizing radiation. Moreover, some technologies can generate more complex arrays of images such as three-dimensional (3D) and hyperspectral images. They are, however, in general, more expensive than standard digital cameras. Nonetheless, each different imaging technology can be used for specific applications.



Images on the Visible Light Spectrum- Conventional camera



Red \approx 645 nm



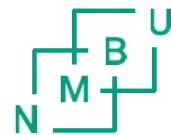
Green \approx 510 nm



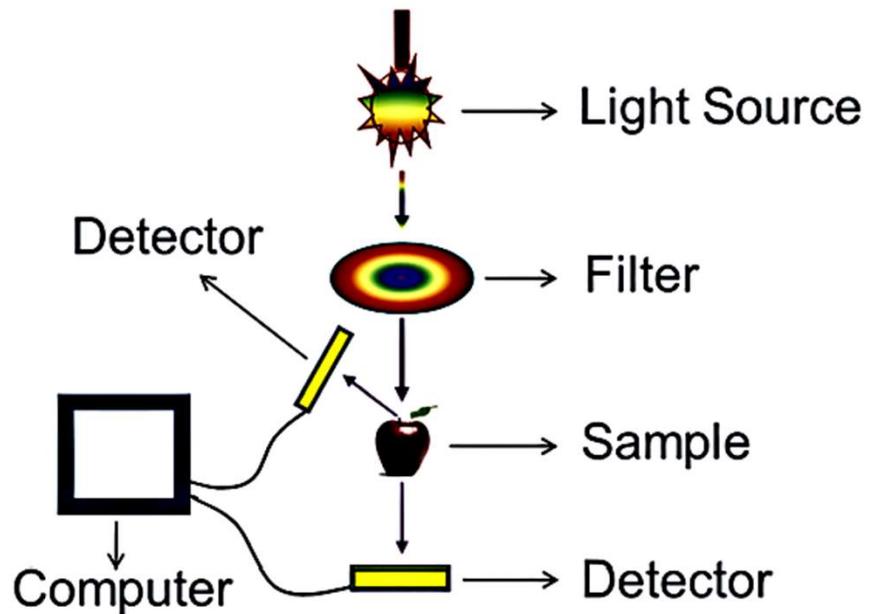
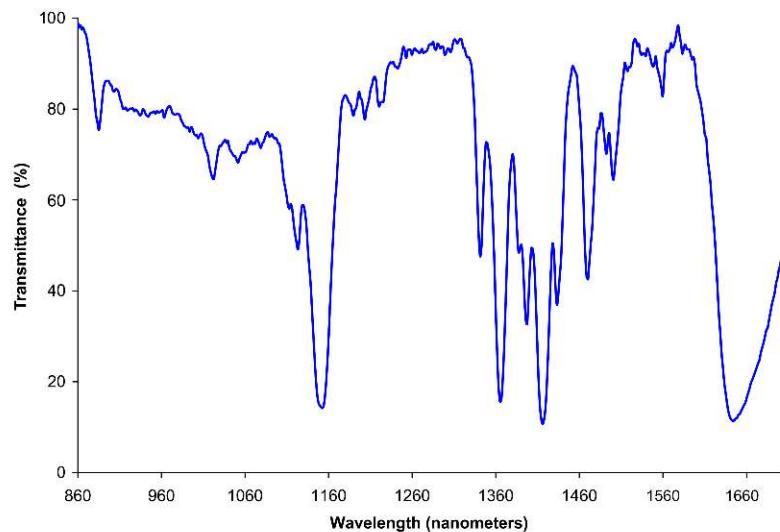
Blue \approx 400 nm



Spectroscopy



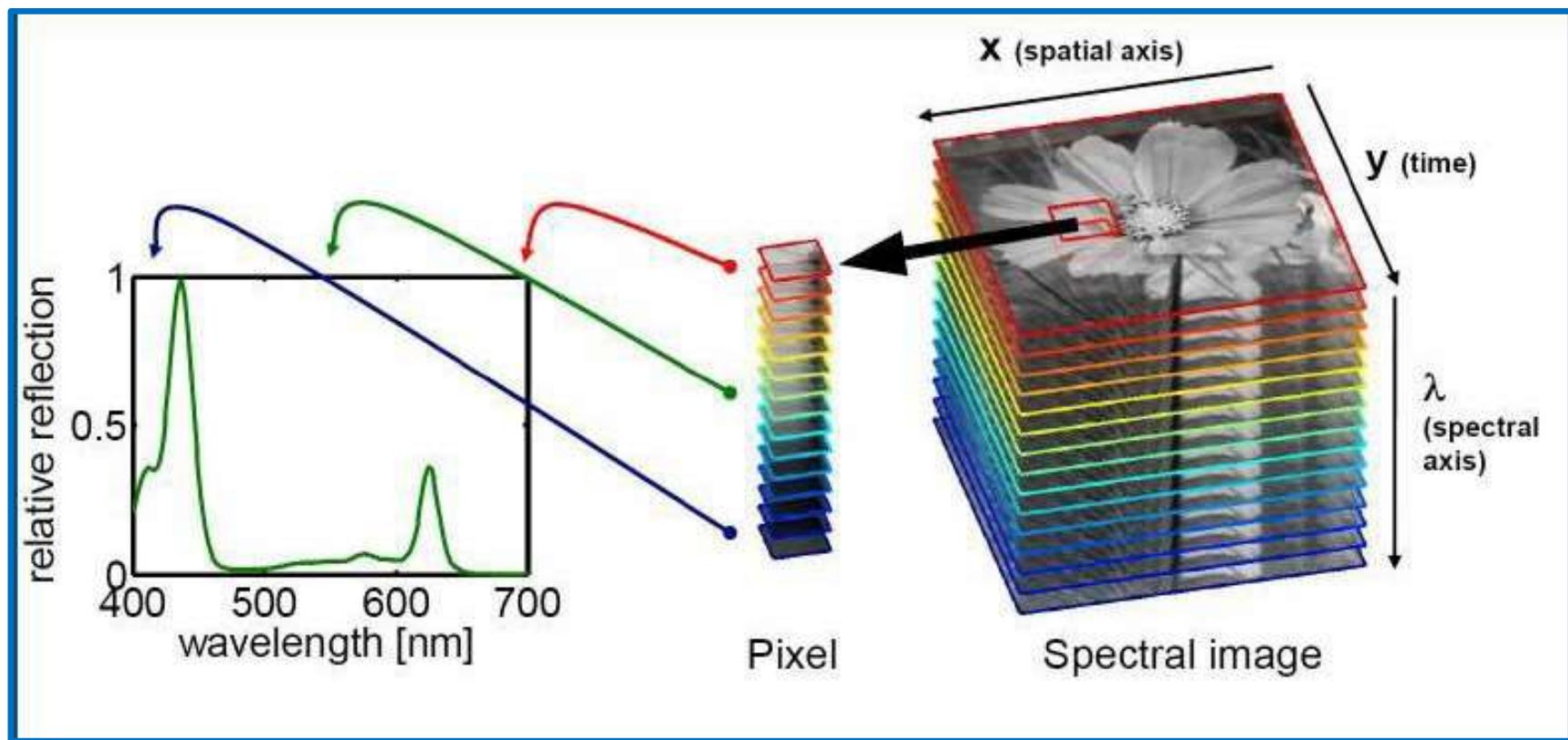
- These technologies are mostly composed of sensors equipped with a NIR emitter
- Principle: different compounds will absorb the radiation differently in each wavelength, thus generating a “signature”.
- In Spectroscopy, for each wavelength measured inside the range, a punctual value of absorbance is generated.



Food Anal. Methods (2019) 12:2438–2458

Hyperspectral camera

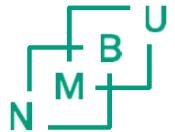
- Each pixel contains spectral information of many wavelengths



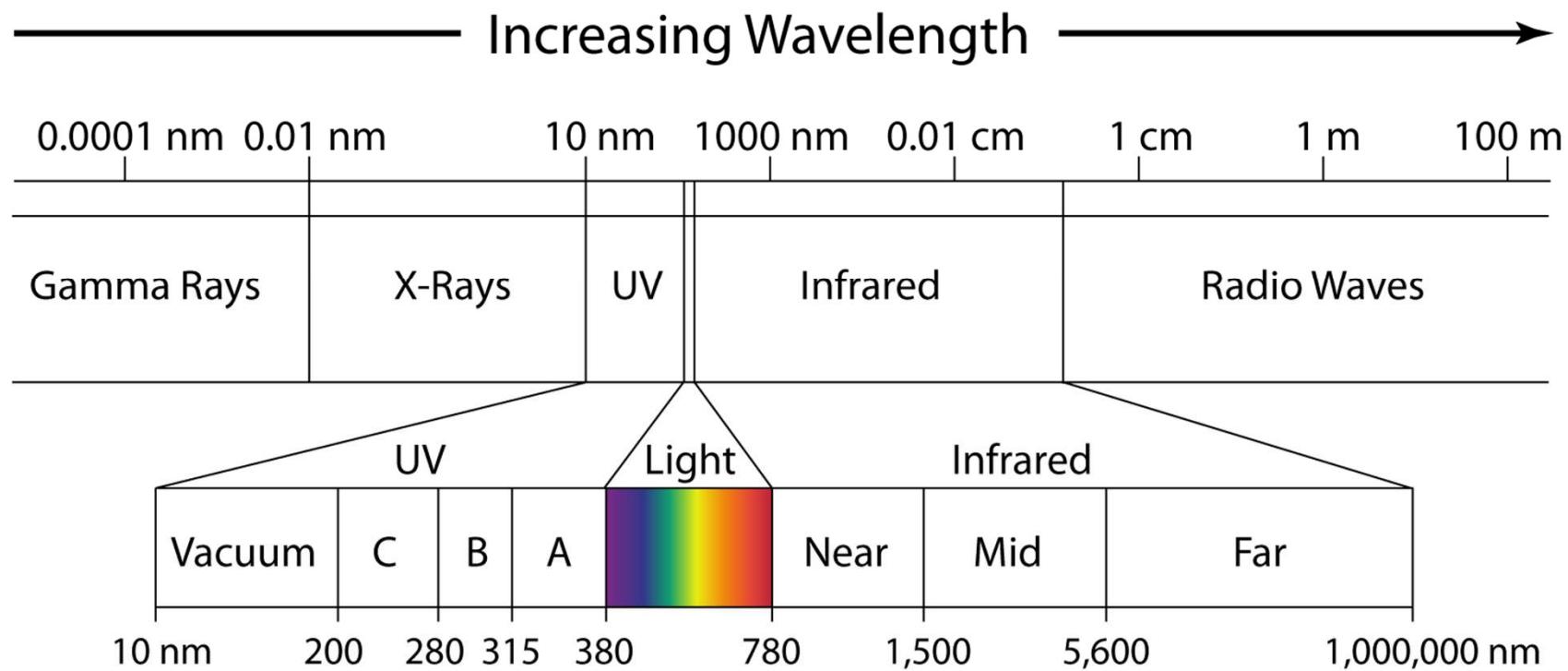


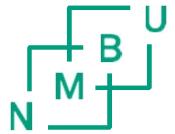
Multispectral camera





Infrared radiation (IR)





Infrared radiation (IR)

There are many different applications of IR in imaging, the most significant ones are in 3D imaging, spectroscopy, night vision, and thermal imaging (also known as Thermography). For all these applications, there are different IR sensors specific to capture radiation within NIR, MIR, or FIR ranges.

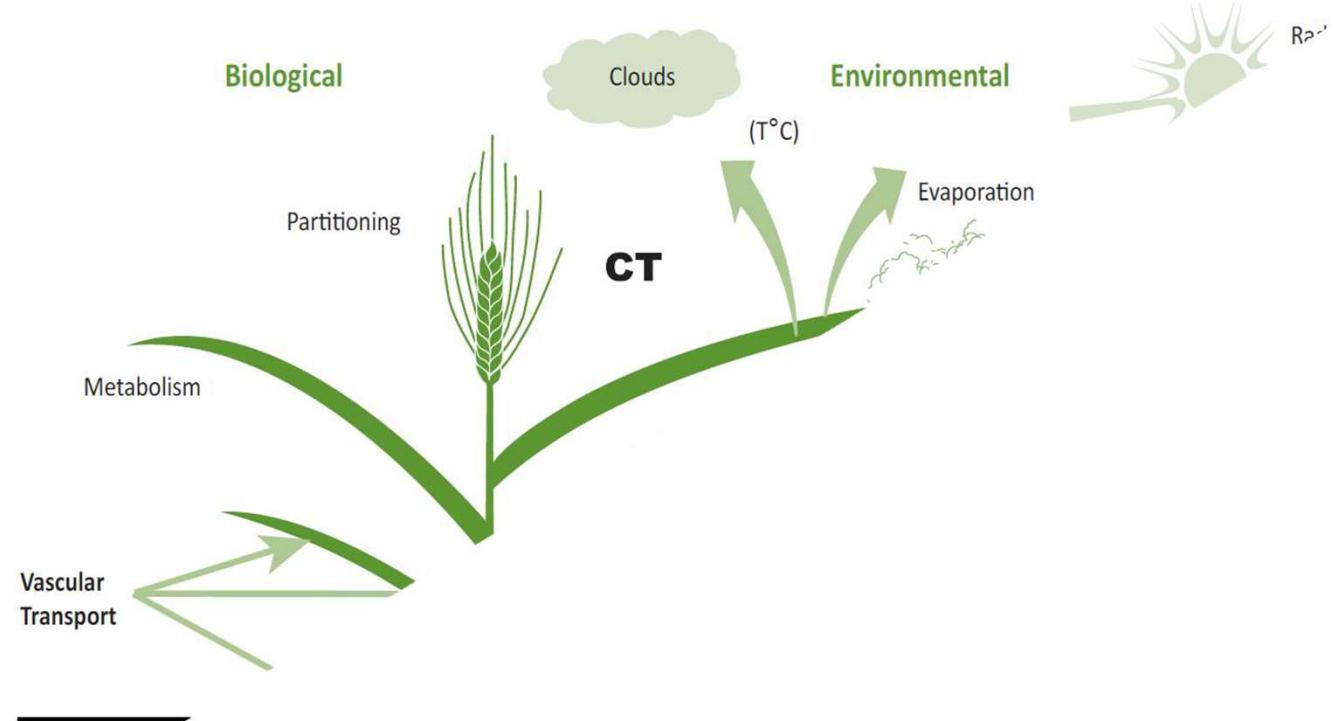
In most night vision cameras, the sensors rely on an emitter, which emits IR on the NIR wavelength to actively illuminate the scene.

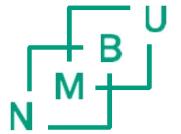


Thermal cameras

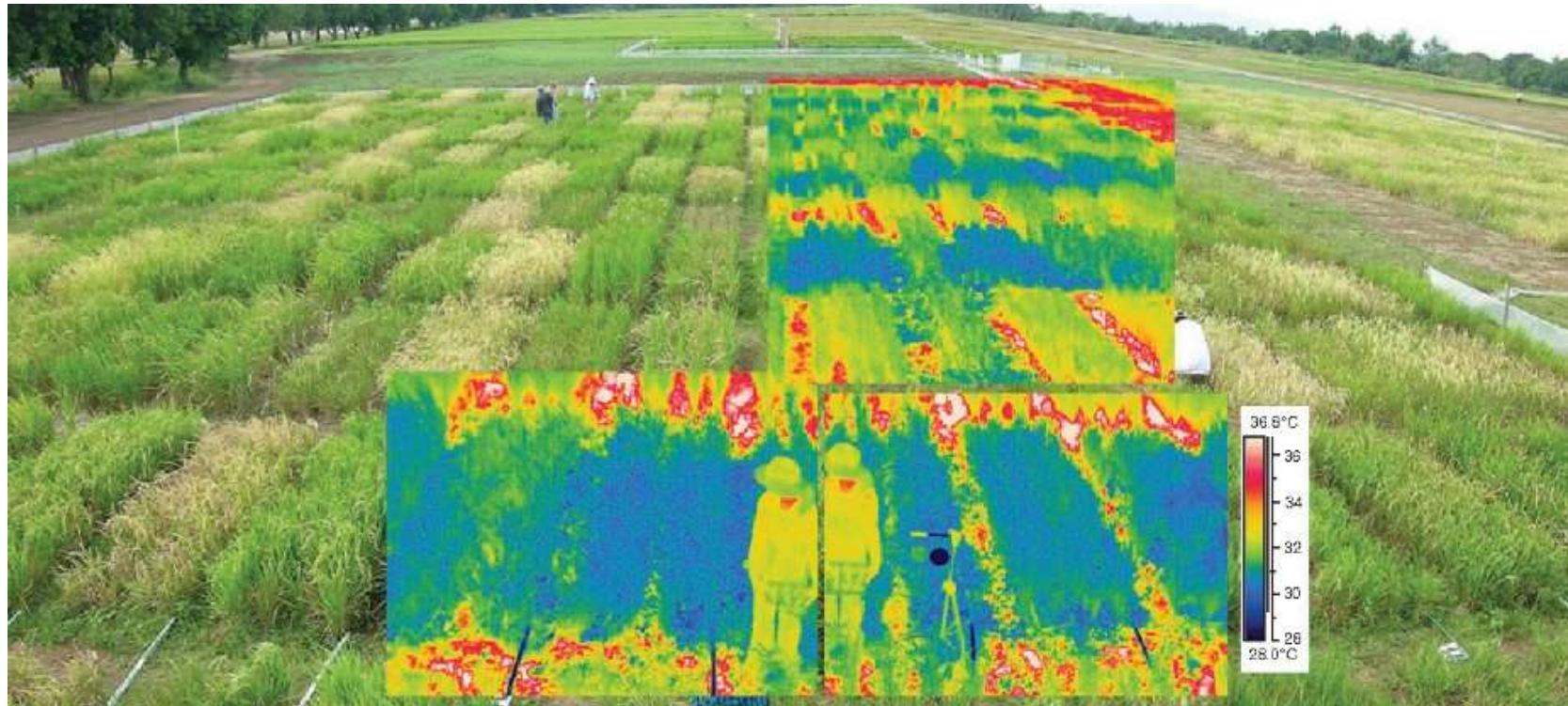


- Transpiration as a cooling system





Thermal Imaging

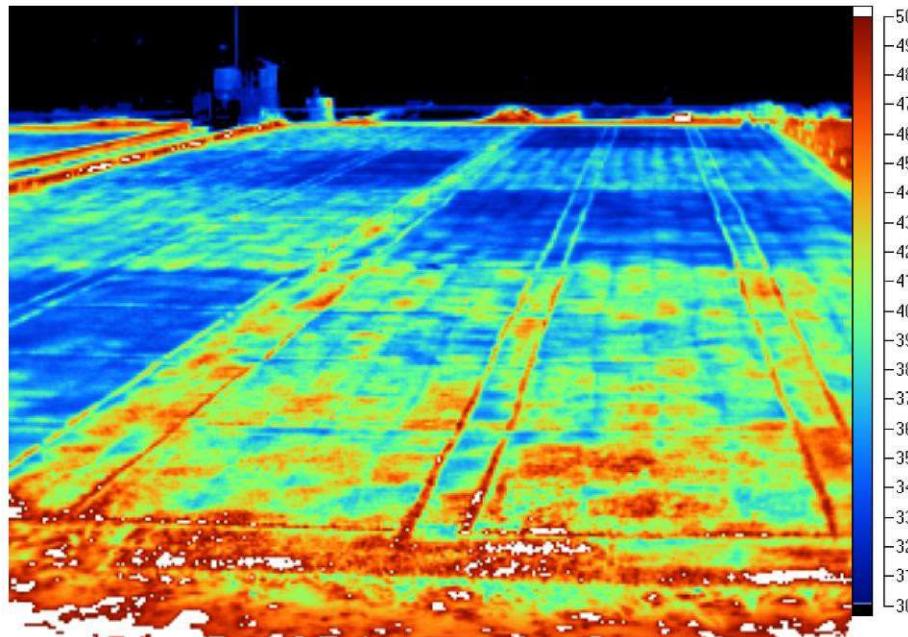


[Thermal infrared imaging of crop canopies for the remote diagnosis and quantification of plant responses to water stress in the field - PubMed \(nih.gov\)](#)

Thermal Imaging

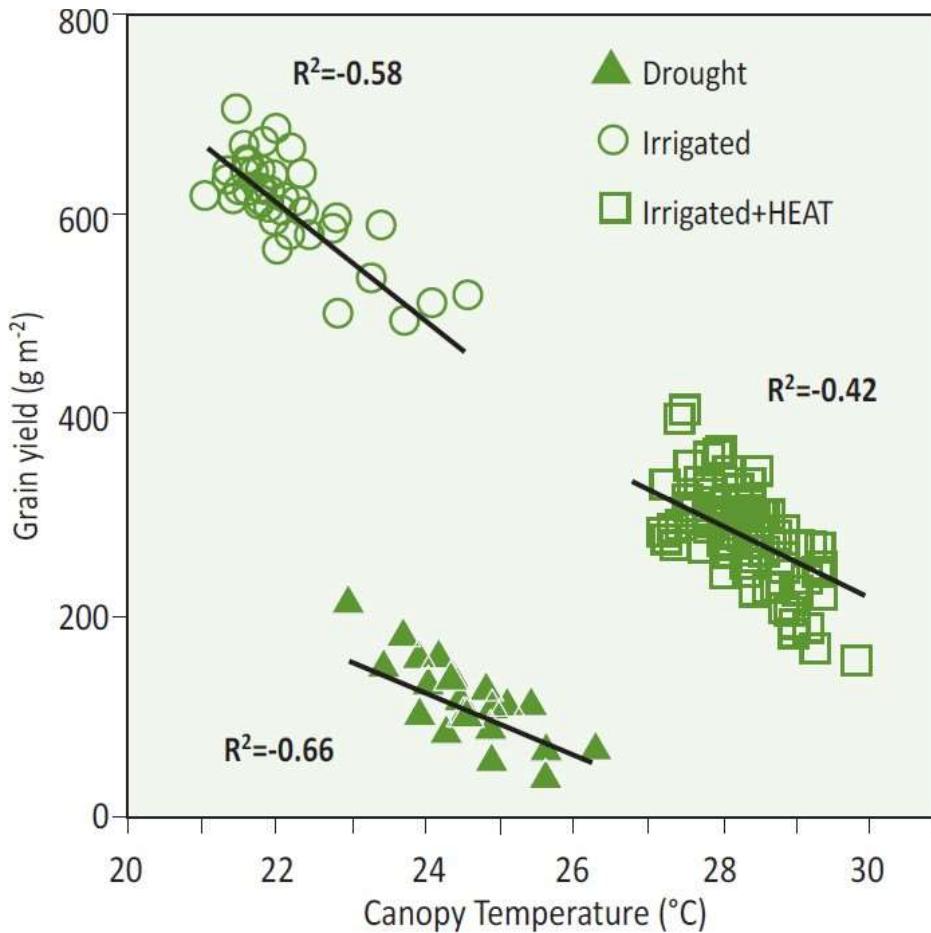


- Turfgrass experiment well-watered vs drought



Prashar & Jones (2014), Agronomy 4: 397-417

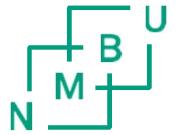
Canopy temperature vs Grain Yield



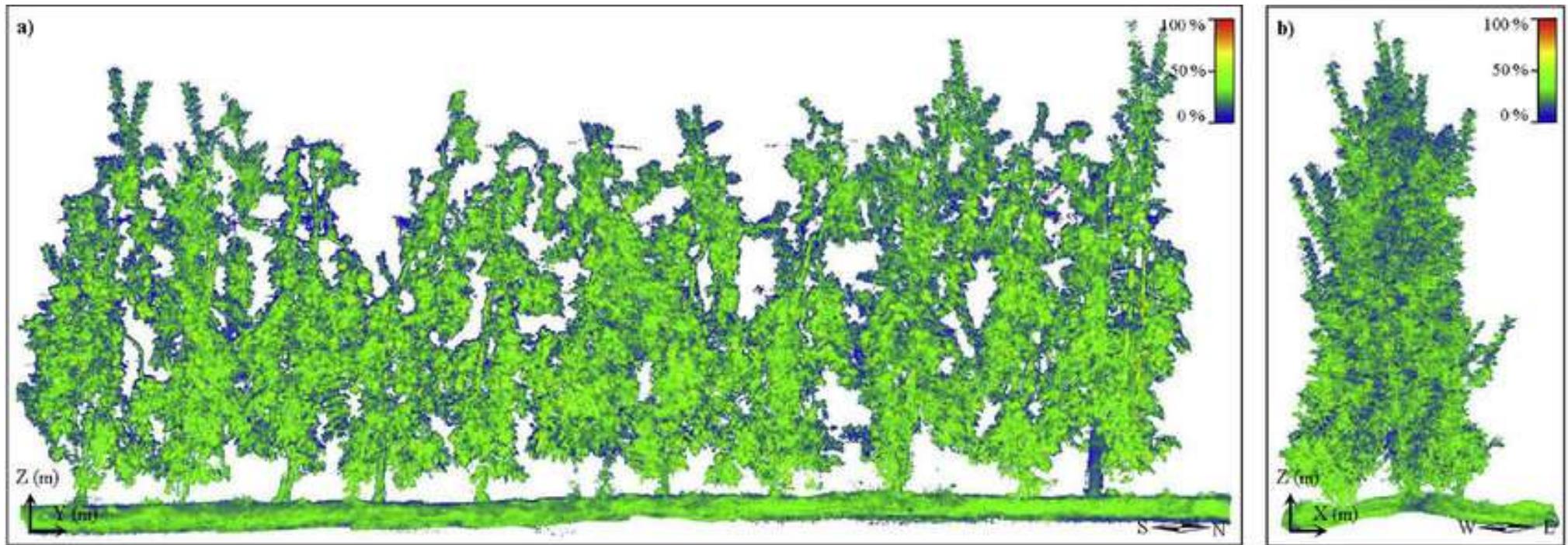
- Wheat yield trials in Yaqui Valley, Mexico

Source:

Physiological Breeding:
Interdisciplinary Approaches
to Improve Crop Adaptation,
CIMMYT.



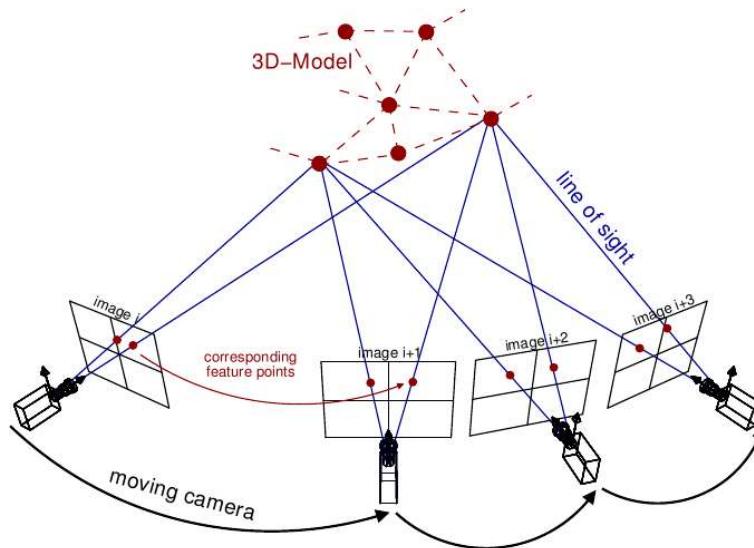
3D Imaging



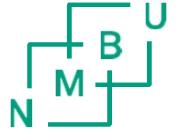
Annotated 3D LiDAR point clouds of Fuji apple trees for fruit detection scanned under different forced air flow conditions
[\(researchgate.net\)](https://www.researchgate.net)

Structure from Motion (SfM)

- Creating a disparity map between the images from a single moving camera.
- The distance between the points where each image was captured by the camera can be used as the distance between “cameras.”
- The main challenge of such a strategy: is for the object of interest to be practically motionless.

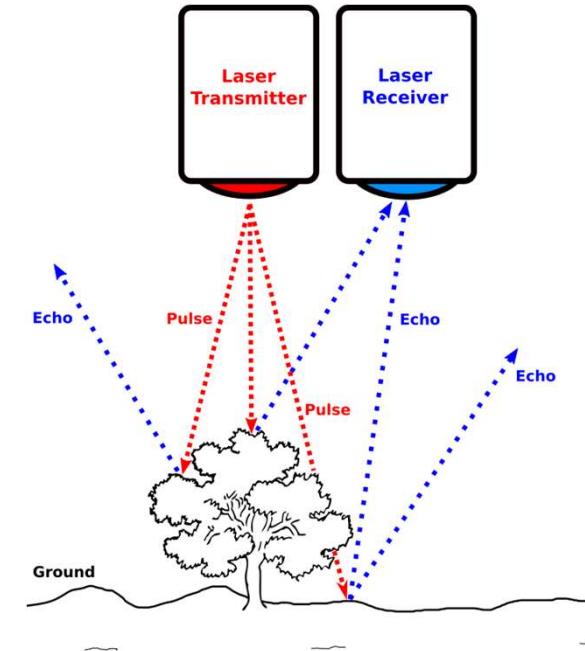


Structure from Motion (SfM) photogrammetric principle. Source: Theia-sfm.org (2016)

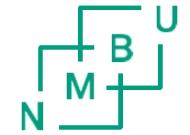


Time of flight (ToF) and Light Detection and Ranging (LiDAR)

- ToF and LiDAR cameras are based on signal modulation and ranging.
- Measuring the distance between the sensor and a target object by detecting the time difference from the signal emitted by a transmitter, reflected on a target object, and captured back by a receiver.



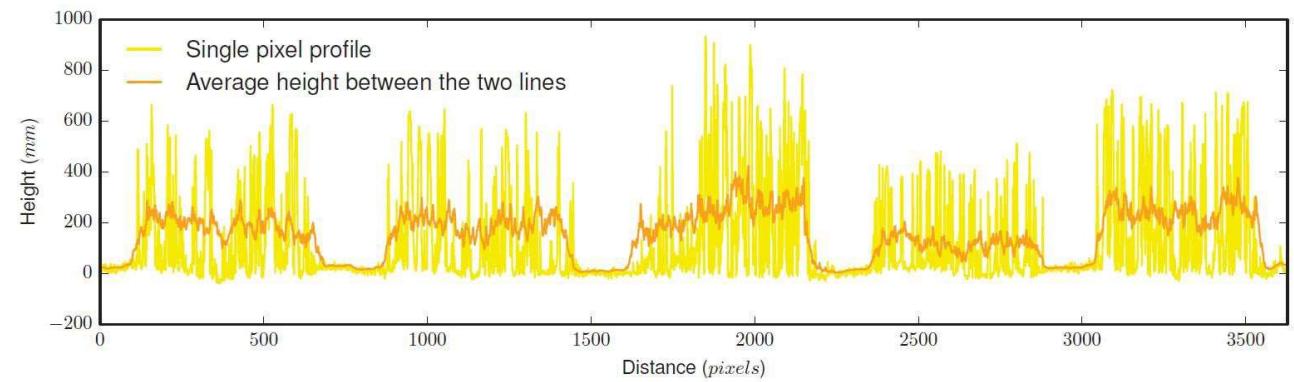
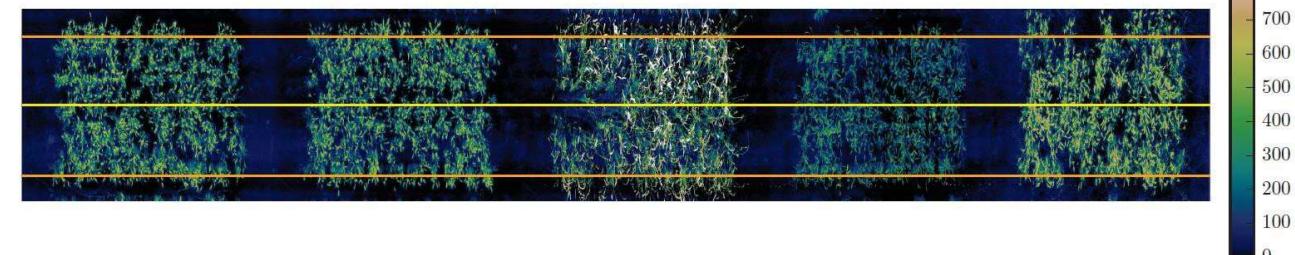
The drone LiDAR operation principle - LiDAR drone OnyxScan, UAV 3D laser scanner (onyxscan-lidar.com)



LiDAR – Light Detection and Ranging



- Generation of 3D point clouds
- Example: Estimating plant height:

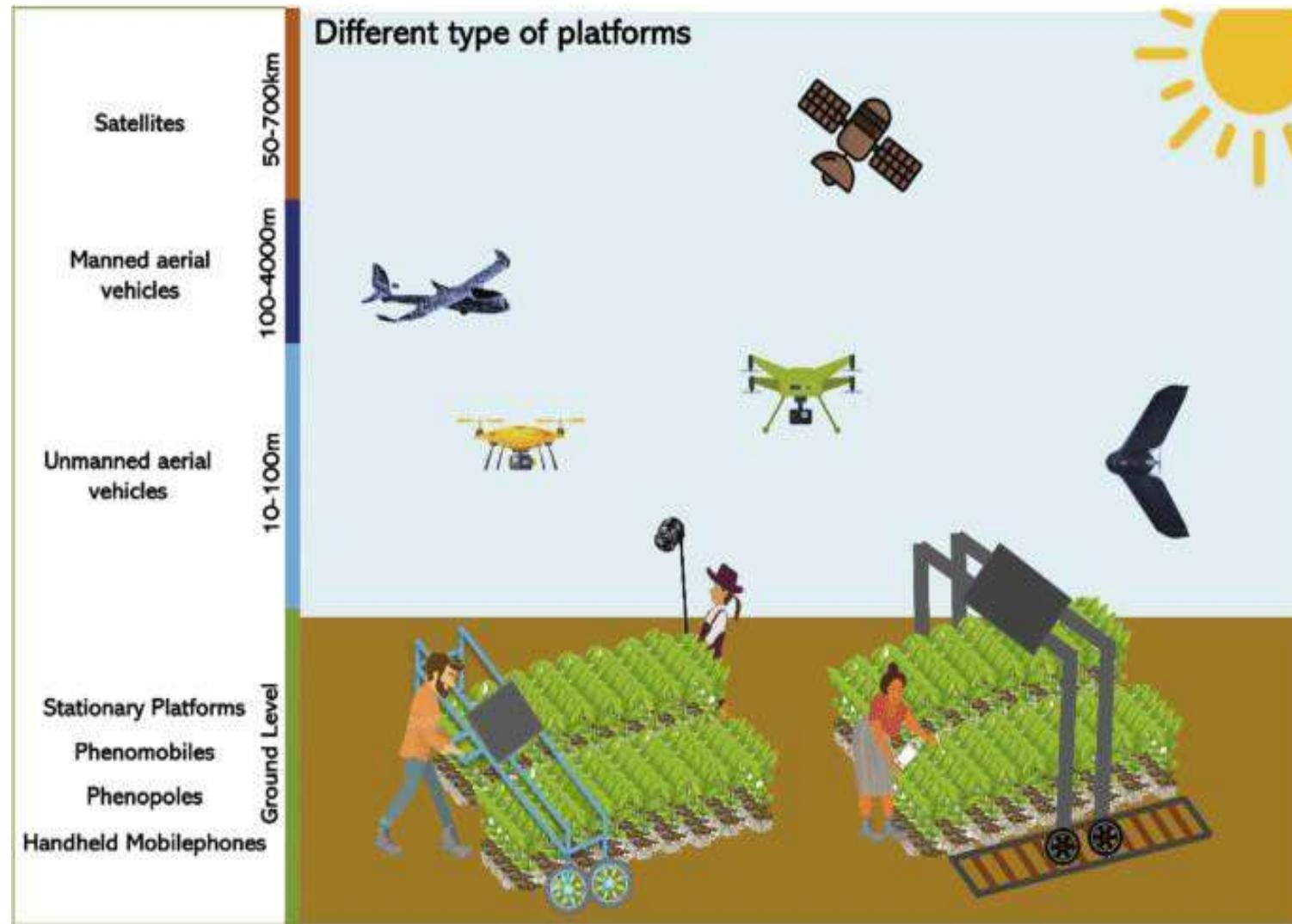


Deery et al. (2014)
Agronomy



UAV Imagery

Phenotyping platforms

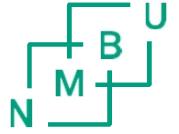


[Field Based High Throughput Phenotyping Rapidly Identifies Genomic - gn.racesociety.com](http://gn.racesociety.com)

UAV Applications in Agricultural

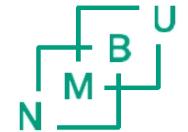
- Plant Phenotyping
- Planting seeds
- Field Monitoring
- Disease Control
- Pest and herbs control
- Crop damage assessment (lodging)
- Livestock management
- And lastly pollination drones



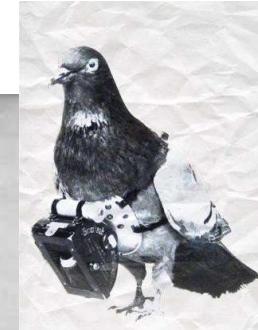
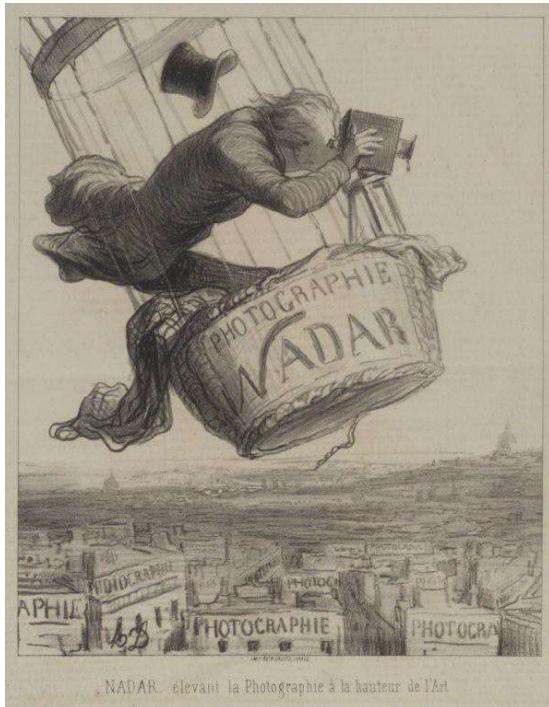


Why Using UAVs?

- Independent data acquisition
- Flexible agile deployment
- Customised sensors
- Increased spatial detail

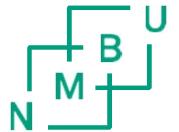


First Drone in 1905 The Drones that You have to Feed — Pigeons



Before there were Drones, there were ... Pigeons with Cameras? | by Nathan Allen | Frame of Reference | Medium

UAV Different Types



pros and cons

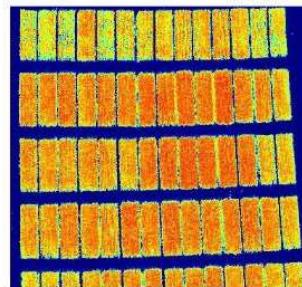
	Pros	Cons	
Multi-Rotor	Accessibility Ease of use VTOL and hover flight Good camera control Can operate in a confined area	Short flight times Small payload capacity	
Fixed-Wing	Long endurance Large area coverage Fast flight speed	Launch and recovery needs a lot of space no VTOL/hover Harder to fly, more training needed Expensive	
Single-Rotor	VTOL and hover flight Long endurance (with gas power) Heavier payload capability	More dangerous Harder to fly, more training needed Expensive	
Fixed-Wing Hybrid	VTOL and long-endurance flight	Not perfect at either hovering or forward flight Still in development	



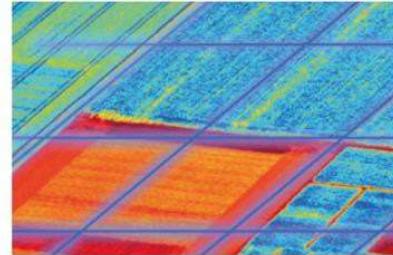
What we can do with a UAV?



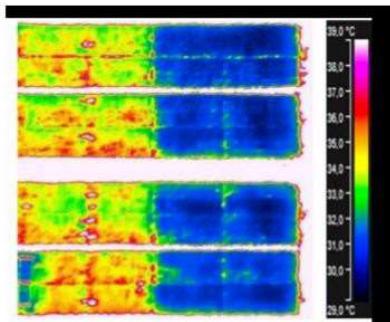
RGB images



Multispectral
images



Hyperspectral images

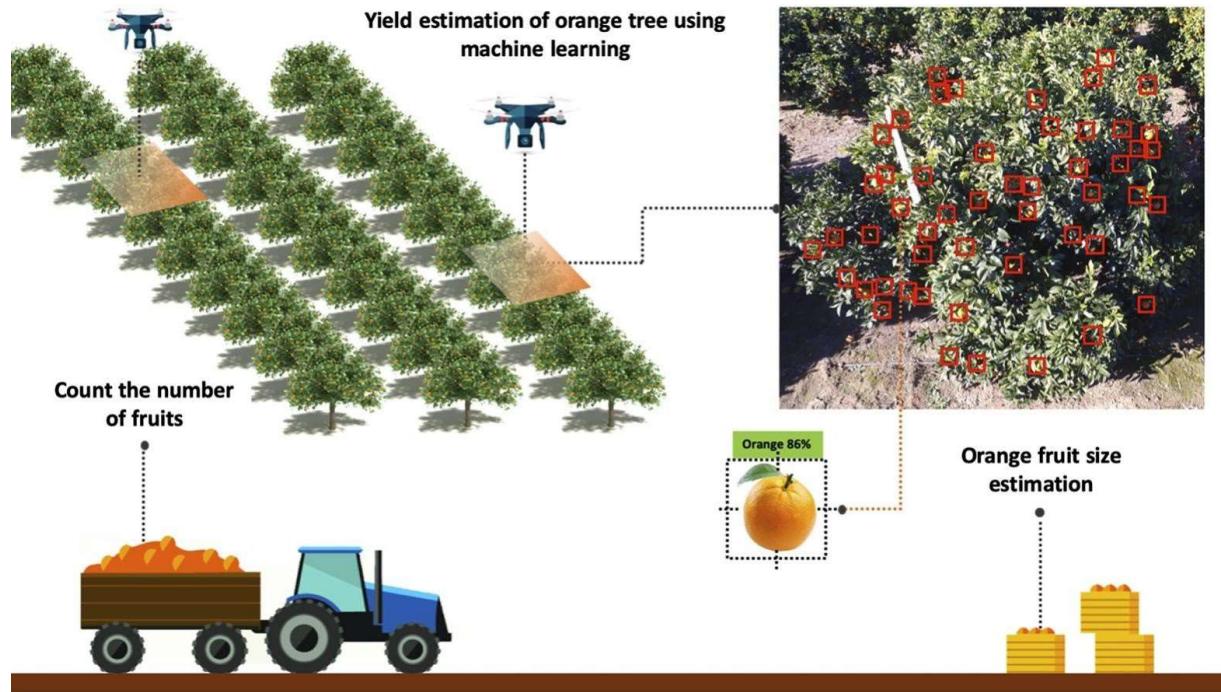


Thermography (IR)

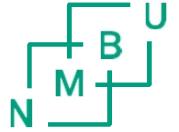


3D models

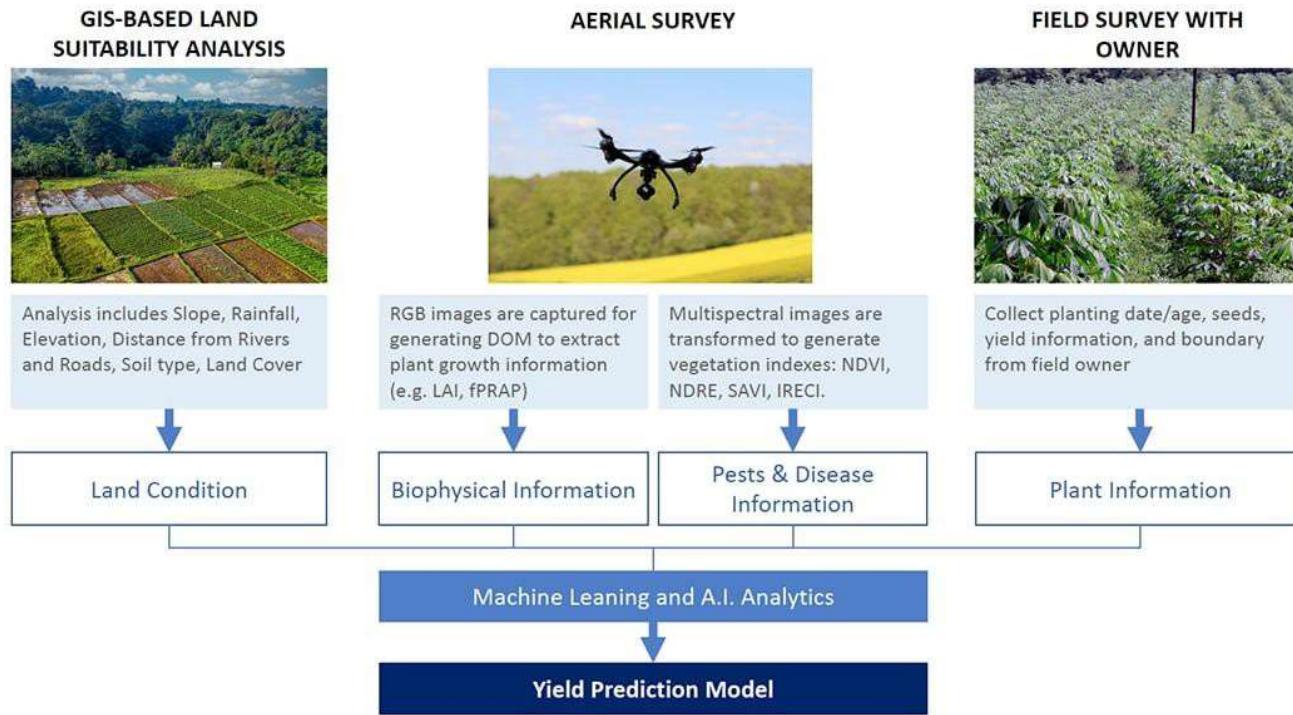
Yield Estimation



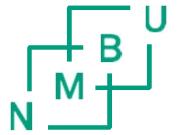
<https://www.sciencedirect.com/science/article/pii/S1161030120300381#fig0055>



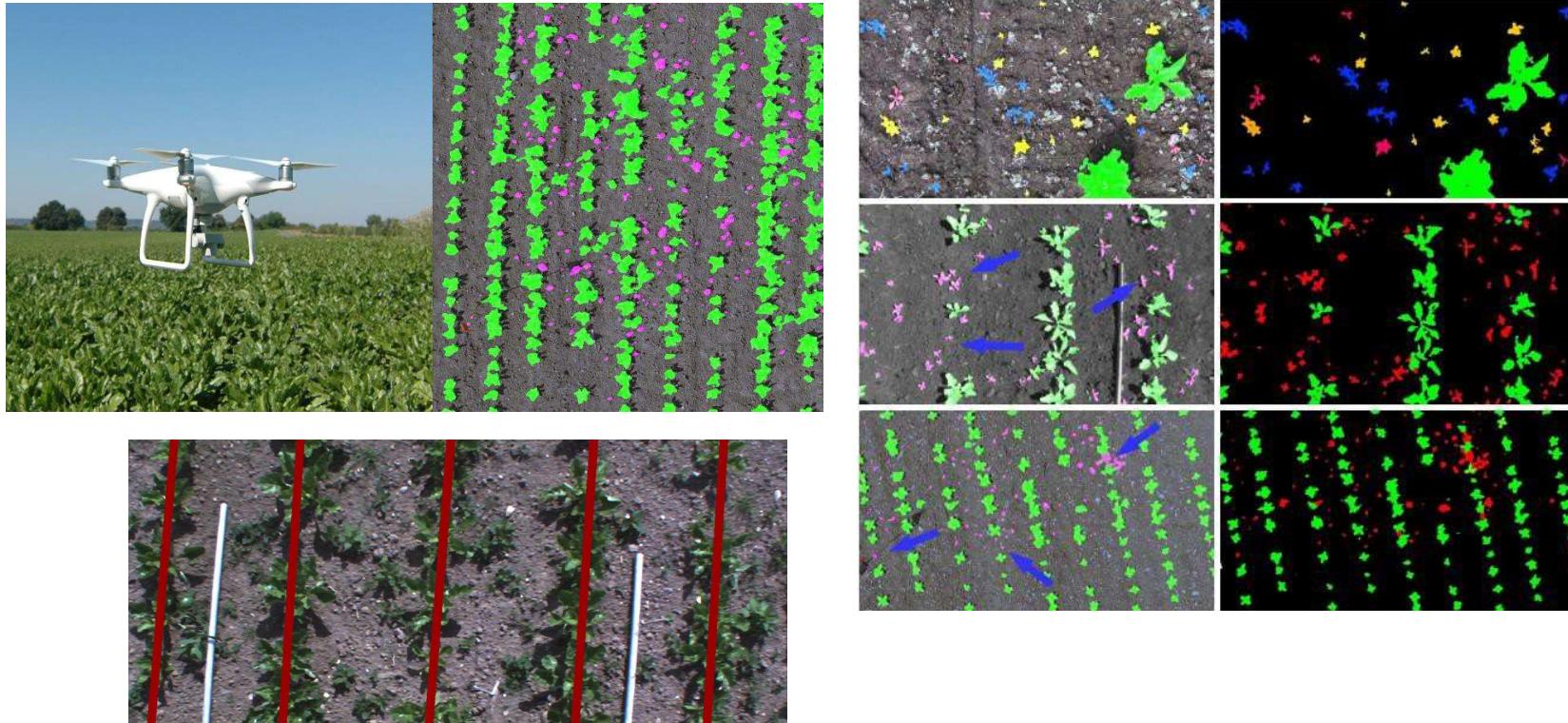
Development of Cassava Yield Prediction Model



<https://anavision.com/blog/cassava-yield-prediction/>

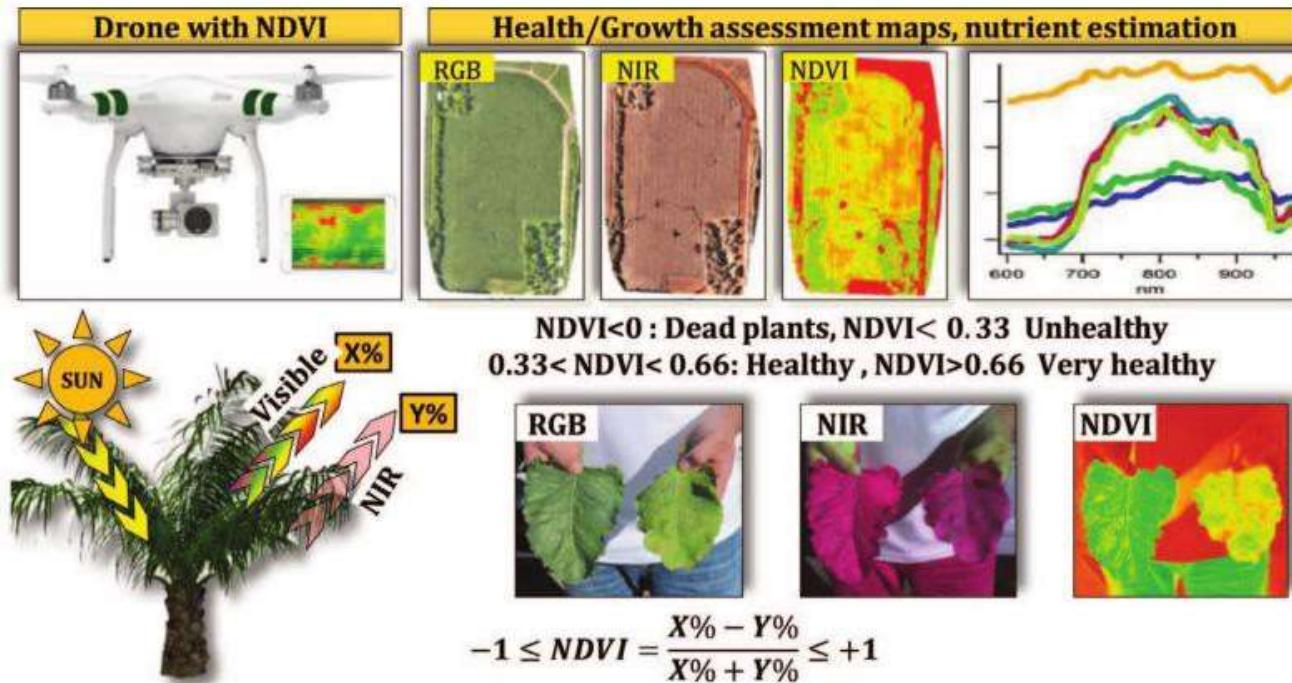


Weed Detection



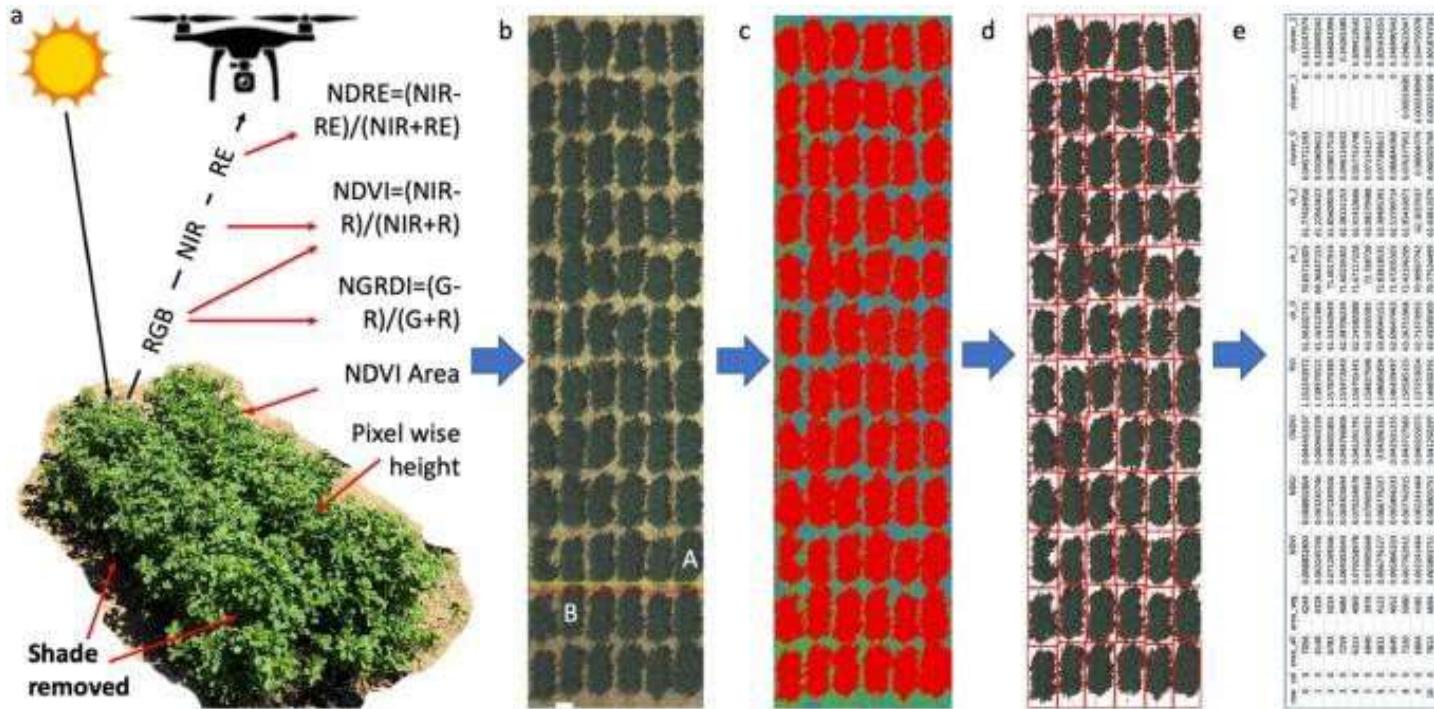
<https://robohub.org/uav-based-crop-and-weed-classification-for-future-farming/>

Disease detection



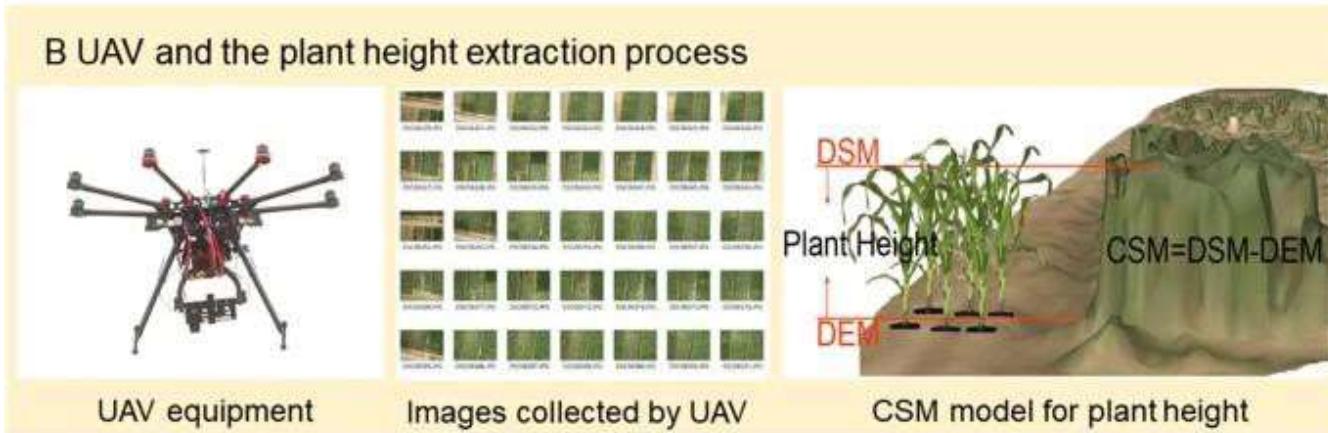
UAV sample NDVI mapping for health assessment and disease detection (Shamshiri et al., 2018).

Biomass Estimation



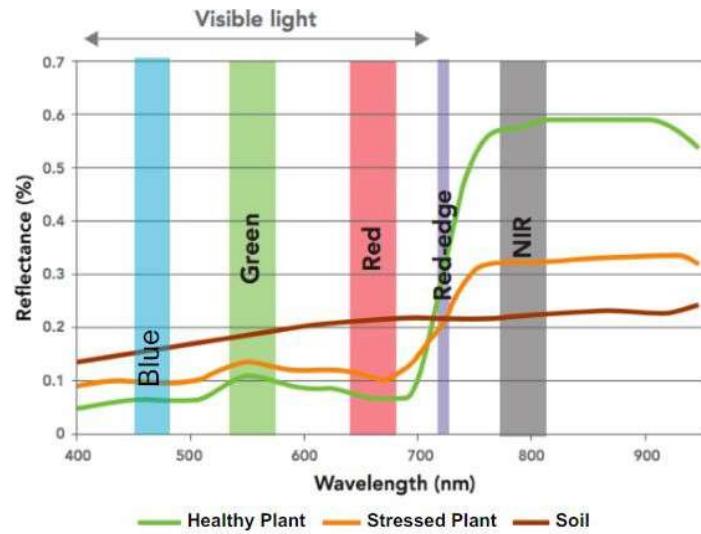
[Validation of UAV-based alfalfa biomass predictability using photogrammetry with fully automatic plot segmentation | Scientific Reports \(nature.com\)](#)

Plant Height Measurement



Dynamic plant height QTL revealed in maize through remote sensing phenotyping using a high-throughput unmanned aerial vehicle (UAV)
| Scientific Reports (nature.com)

Multispectral imaging



$$NDVI = \frac{NIR - Red}{NIR + Red}$$

$$MTCI = \frac{NIR - Rededge}{Rededge - Red}$$

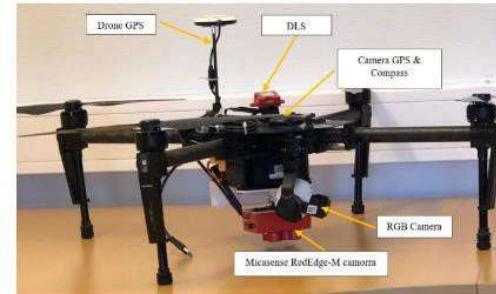
$$EVI = 2.5 * \frac{(NIR - Rededge)}{(NIR + 6 * Red - 7.5 * Blue + 1)}$$

UAV Based Sensors at NMBU

- Multispectral
 - I. Micasense RedEdge-M
 - II. Phantom 4 Multispectral

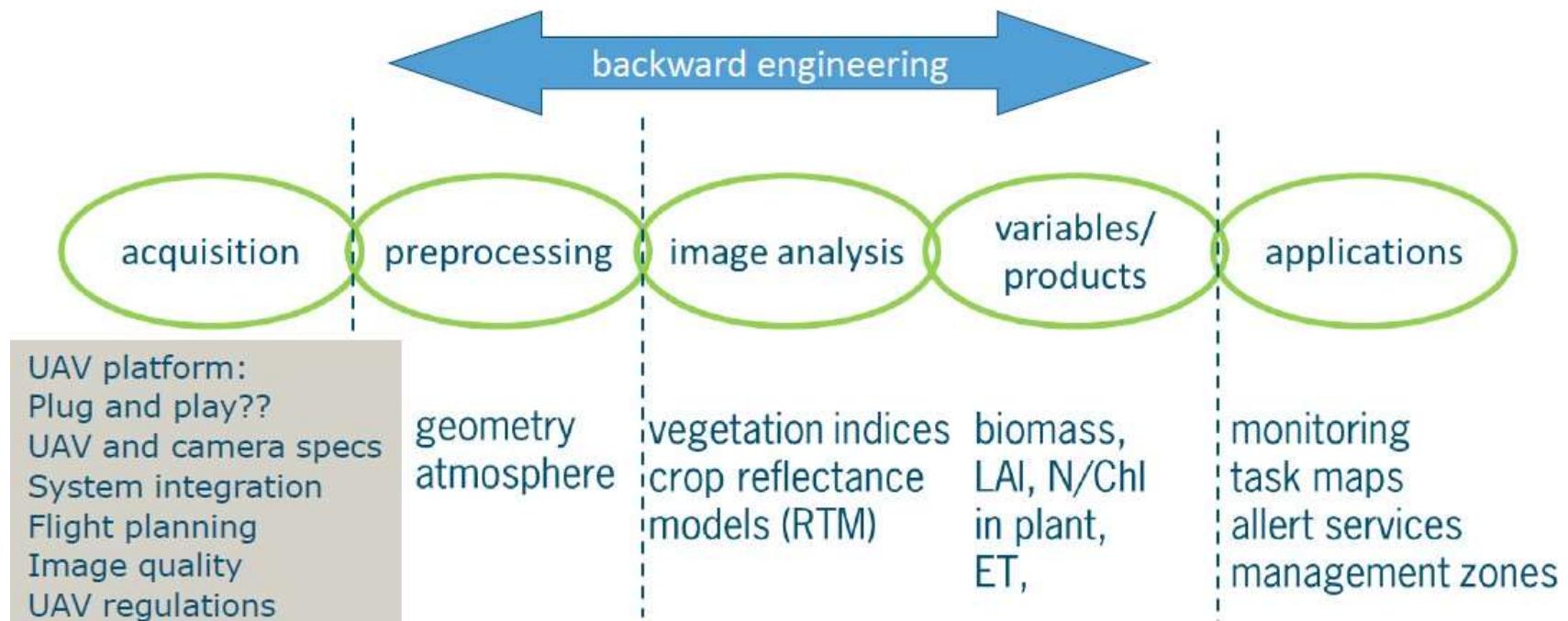


Micasense RedEdge



Matrix 100

UAV processing chain





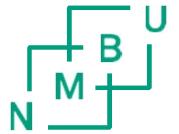
Photogrammetry

Thousands of images are converted to

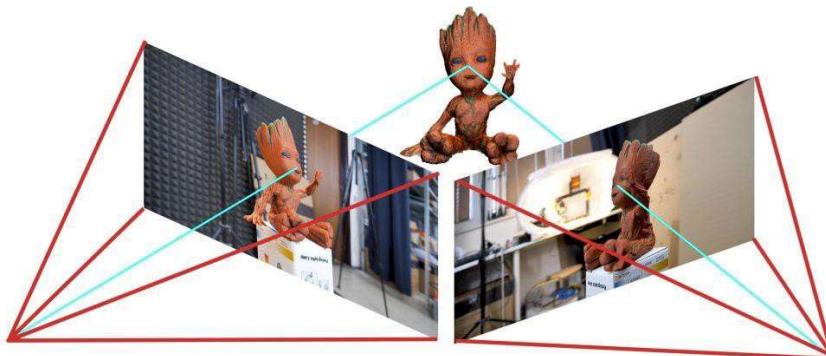
- 3D point clouds
- 3D Digital Surface Model
- Mesh
- Orthomosaic

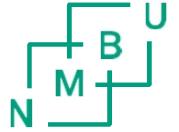


What is Photogrammetry?



- **Photogrammetry** is the science and technology of obtaining reliable information about physical objects and the environment through recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena.



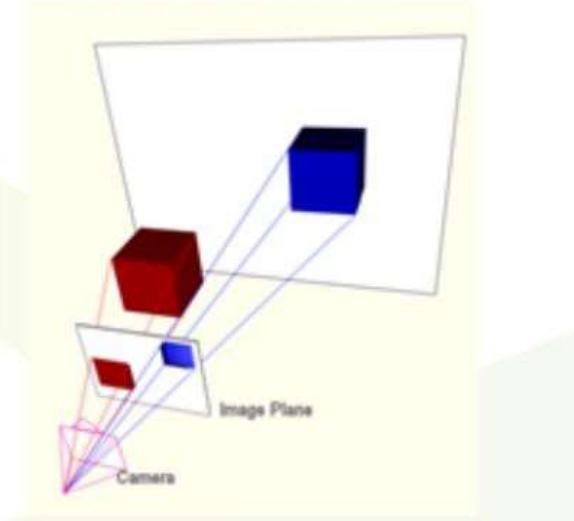


From 2D to 3D- Stereo vision

From 3D to 2D

One camera

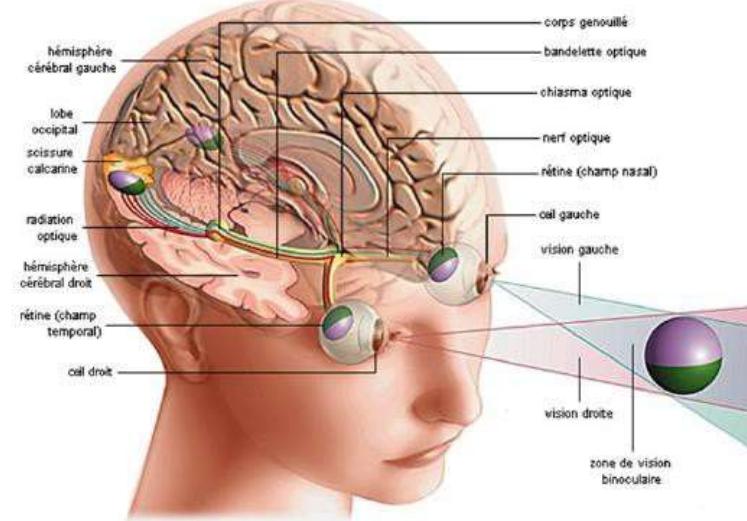
Far appears smaller
than near on image



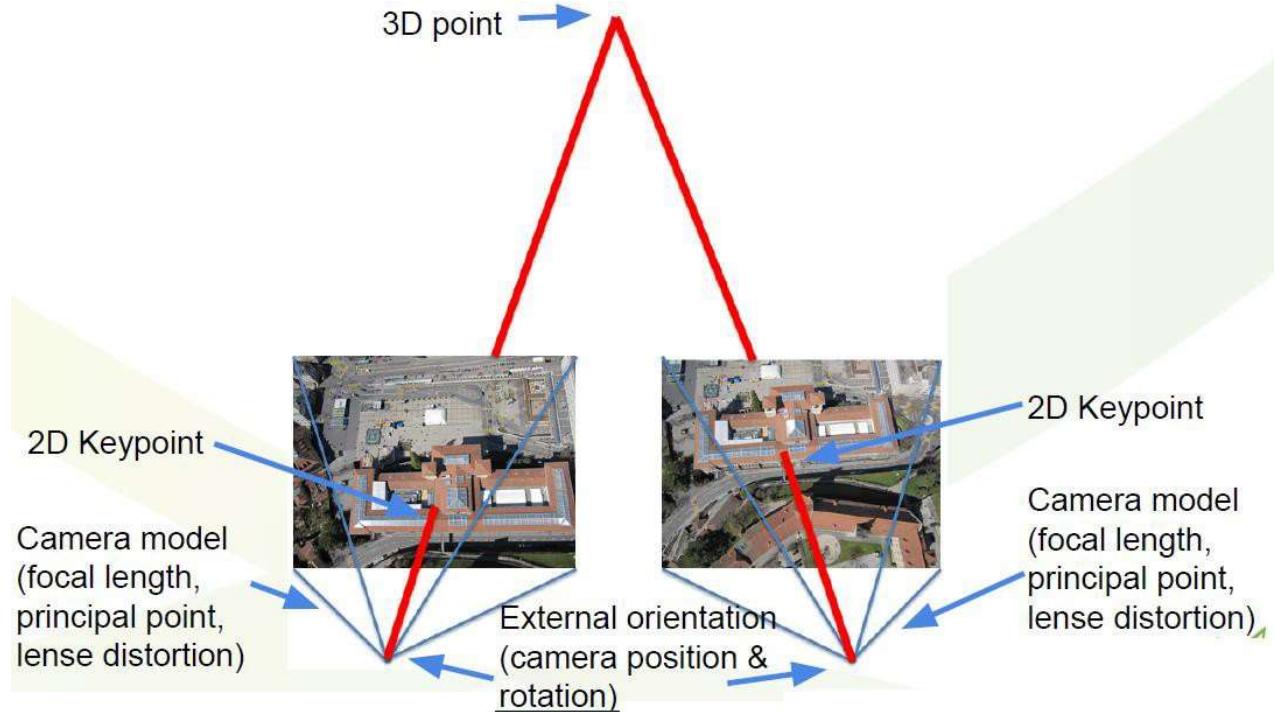
From 2D to 3D

Two images

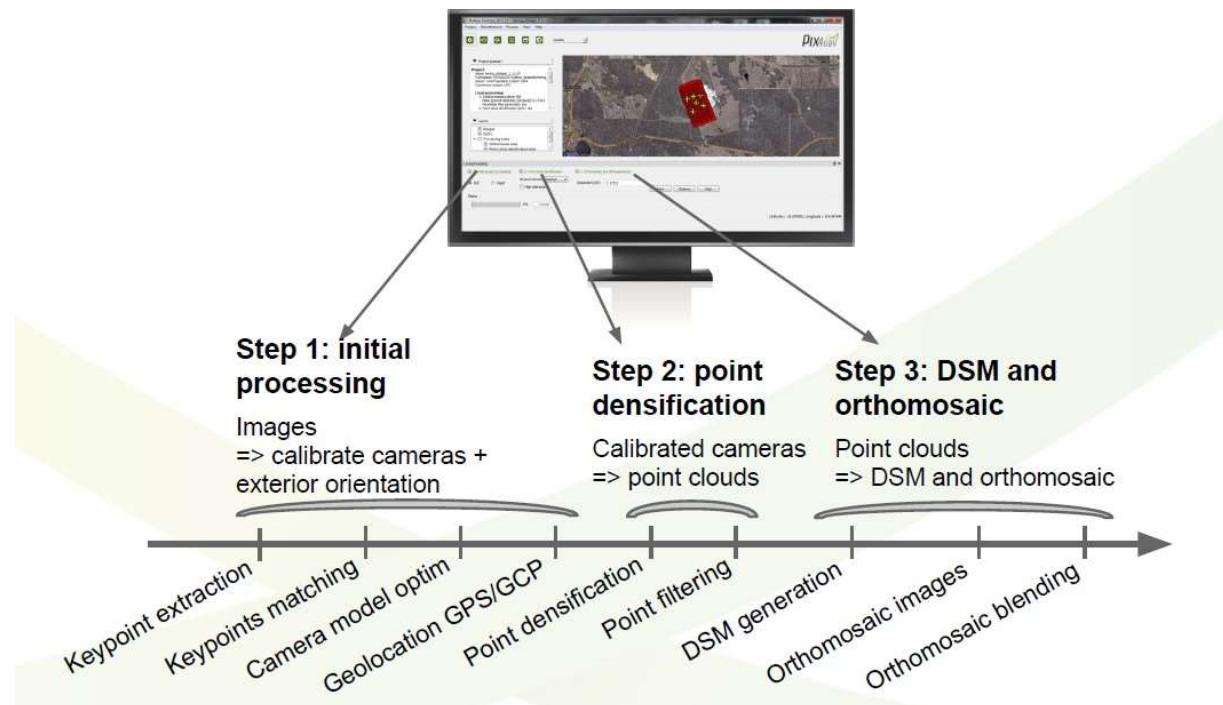
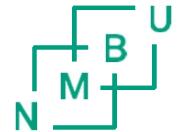
Triangulate to get
sense of depth

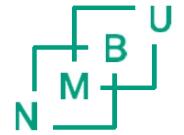


From 2D to 3D Stereoscopy

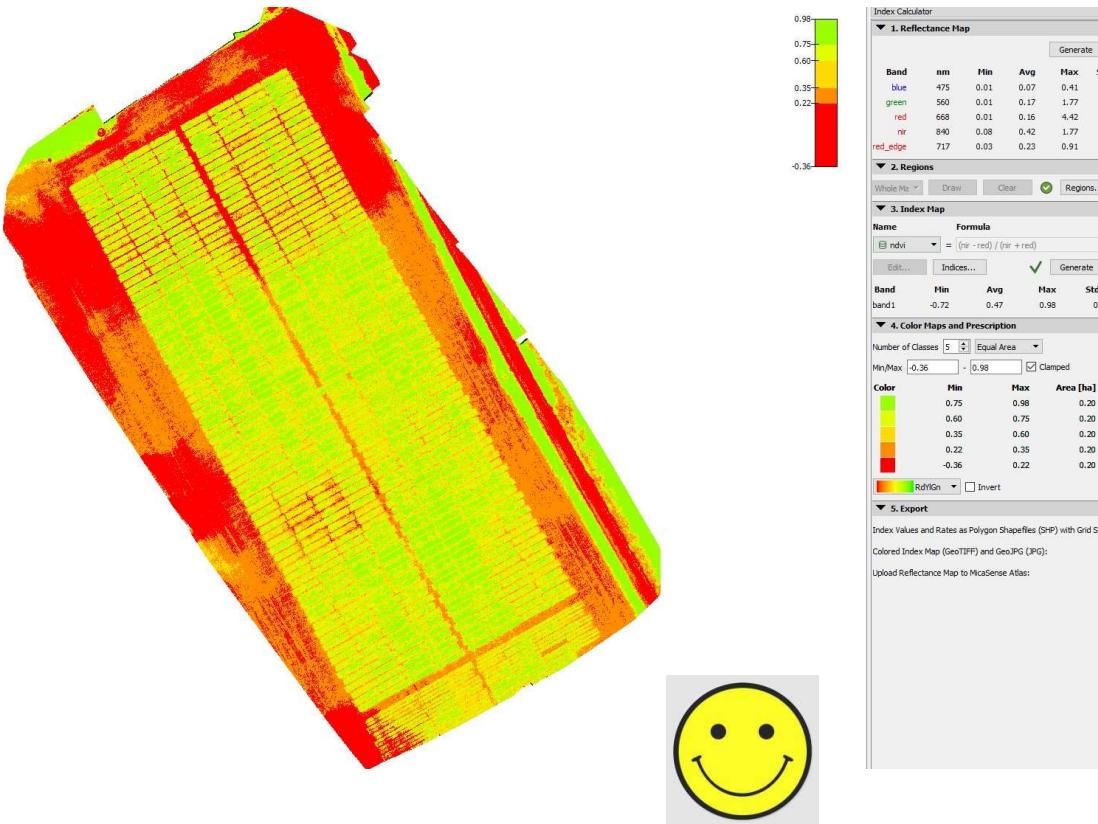


Main processing steps

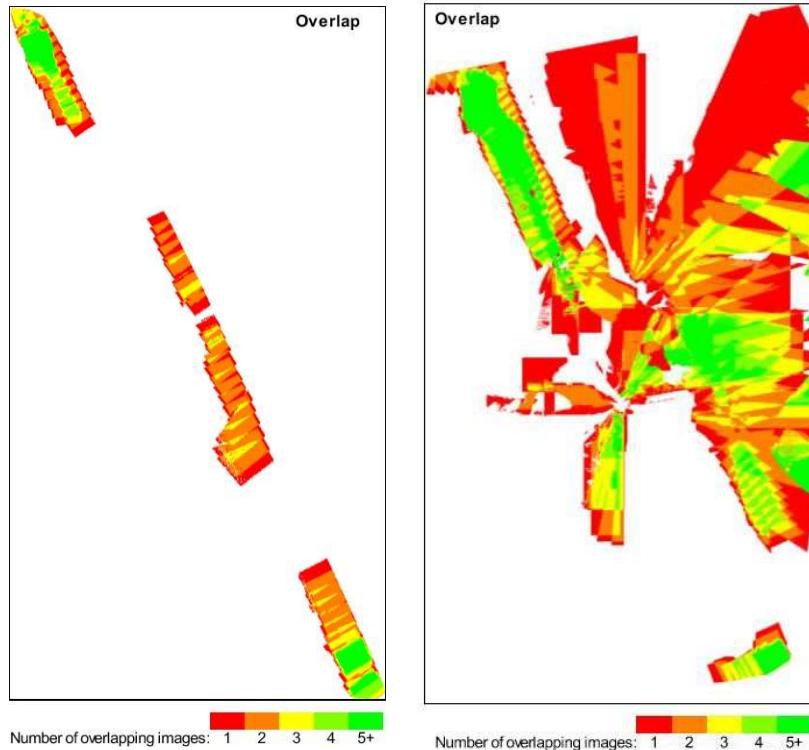




Indices maps: NDVI



Not enough coverage



Part II: Examples from field phenotyping at NMBU



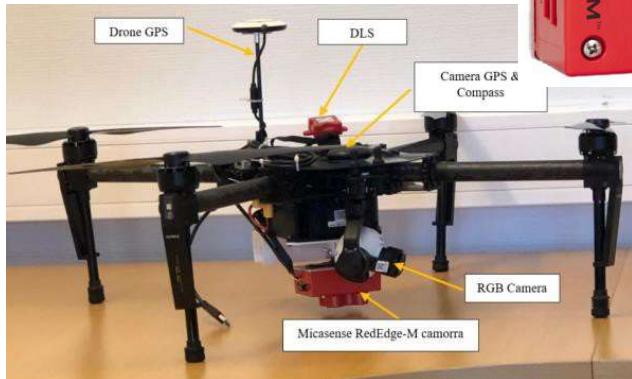
NMBU strategic alliance



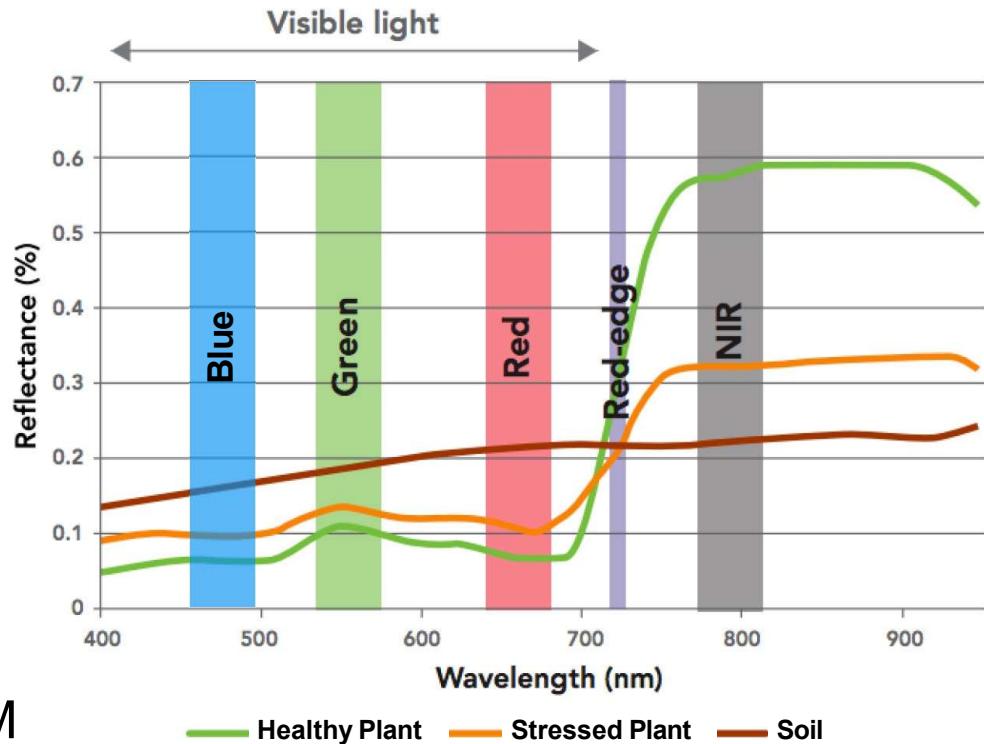
- Faculty of Biosciences
- Faculty of Mathematical Sciences and Technology



Multispectral imaging



Micasense
RedEdge-M



Phantom 4
Multispectral
(P4M)

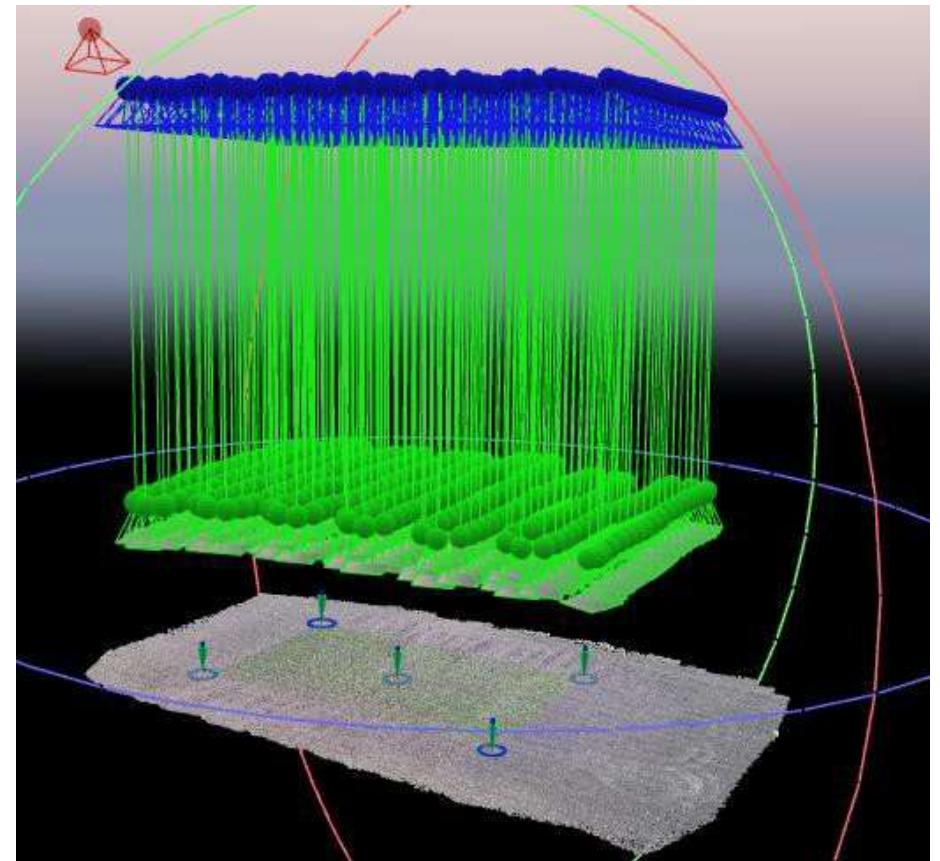


Thorvald II

Flight planning and building orthomosaics

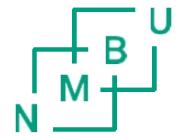


Altizure



Pix 4D

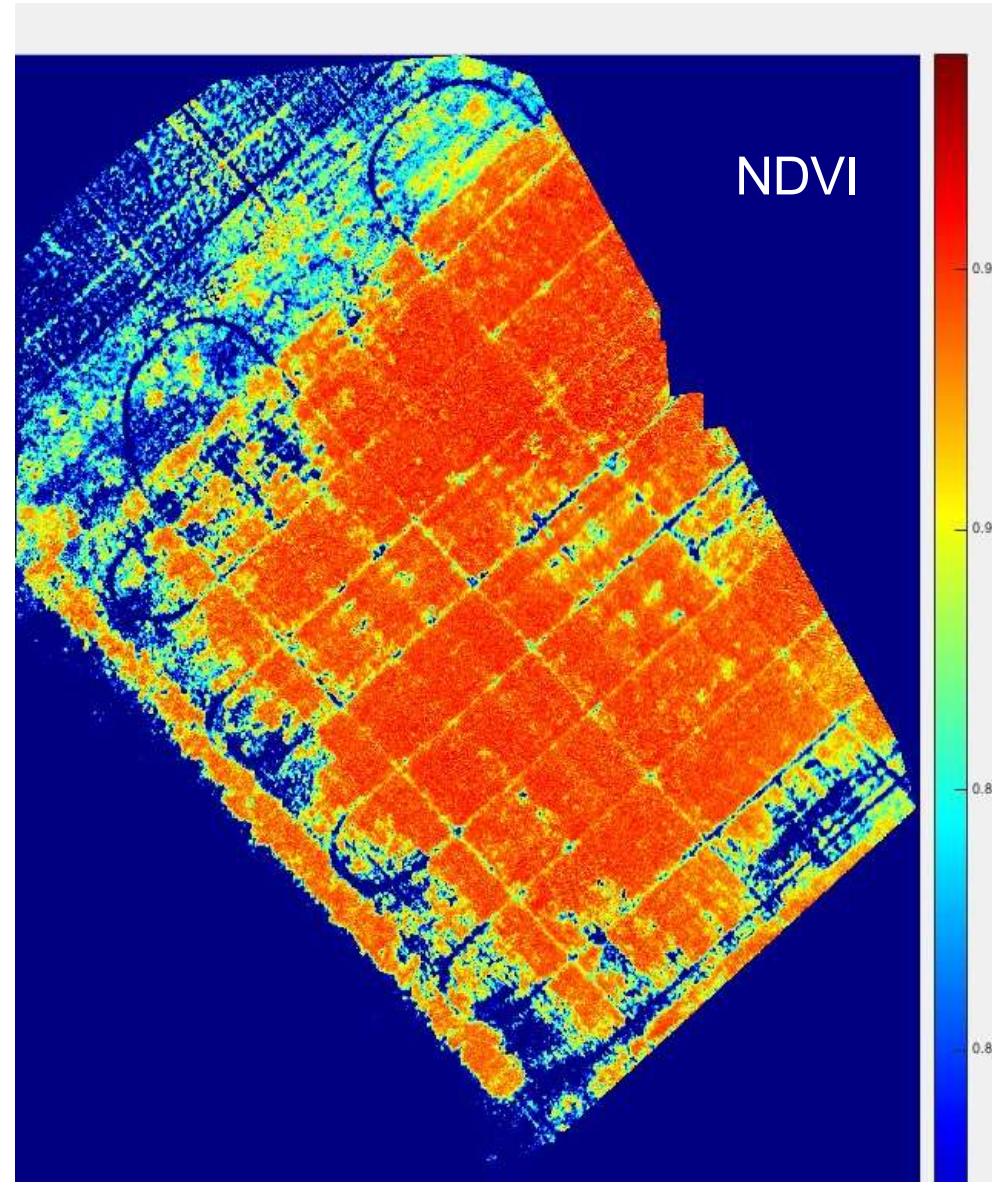
Multispectral orthomosaics



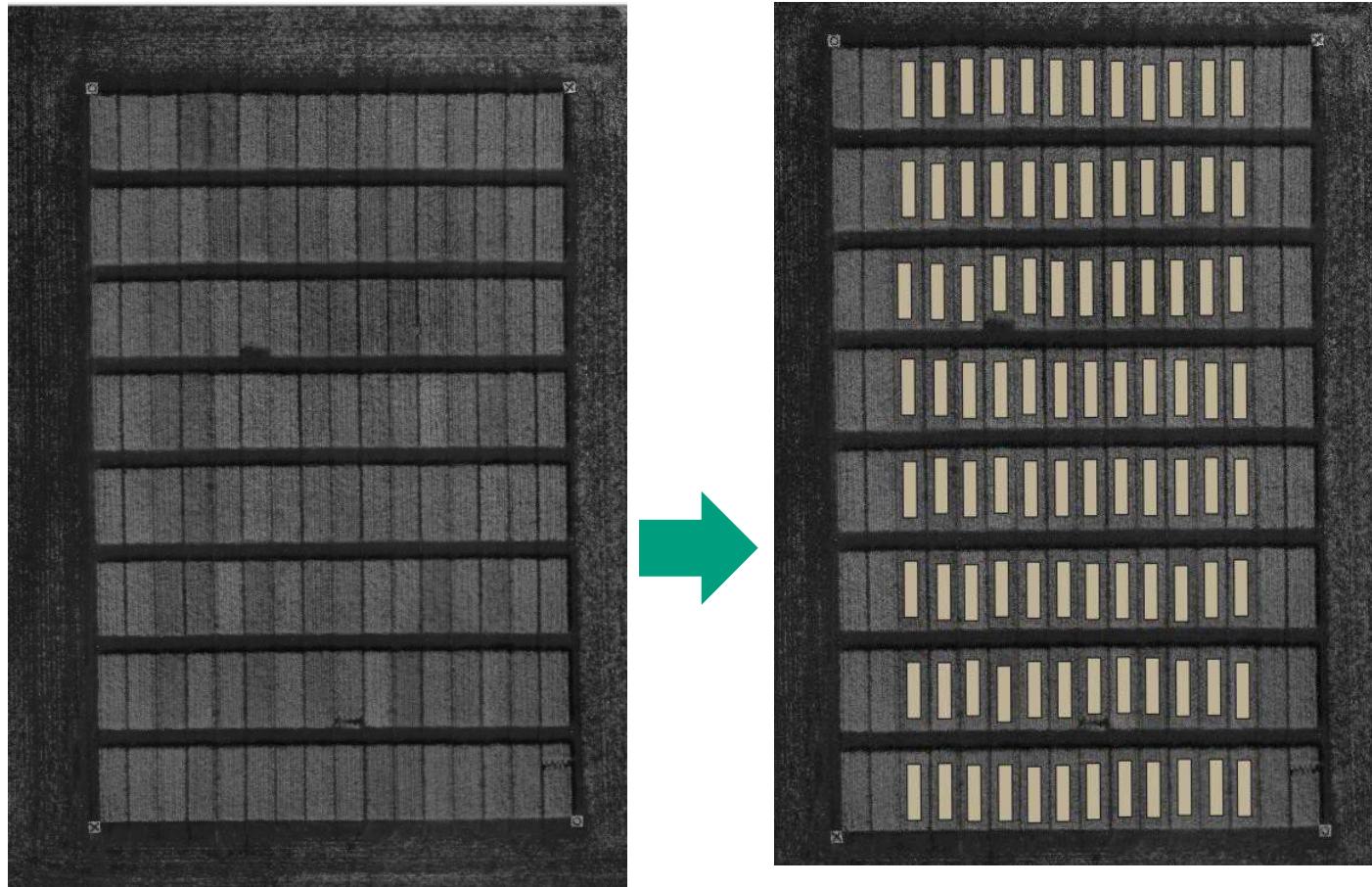
RGB



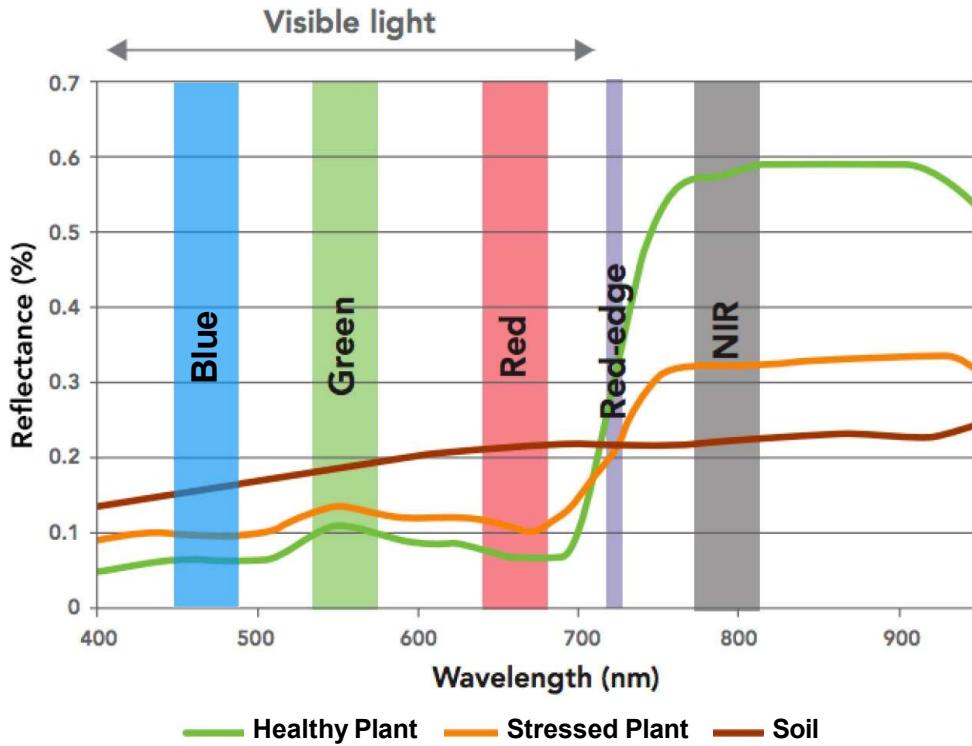
NDVI



Plot extraction in QGIS



Estimation of healthy biomass



- Normalized Difference Vegetation Index (NDVI):

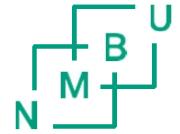
$$NDVI = \frac{NIR - Red}{NIR + Red}$$

- MERIS Terrestrial Chlorophyll Index (MTCI):

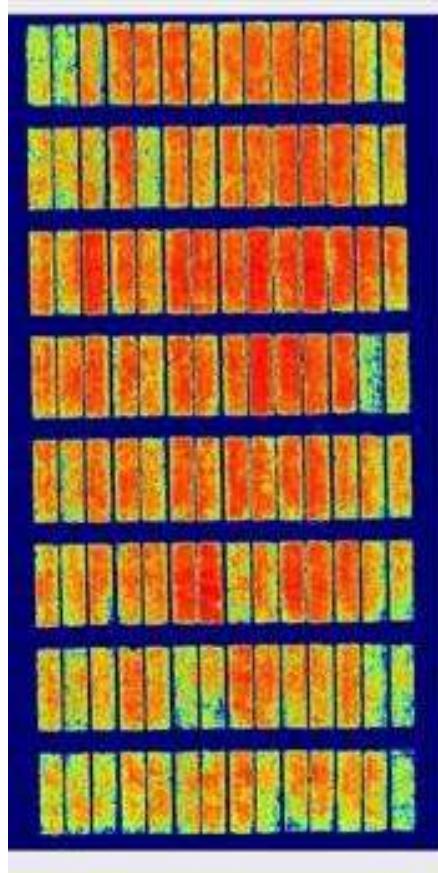
$$MTCI = \frac{NIR - Rededge}{Rededge - Red}$$



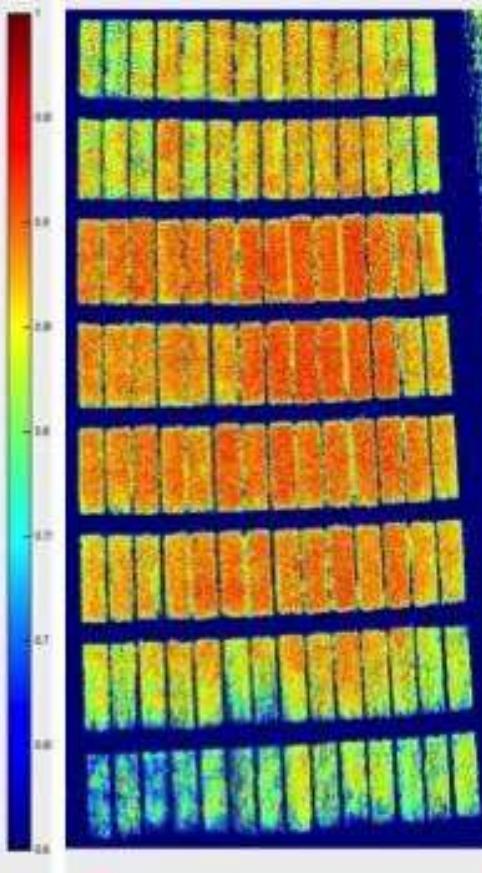
NDVI maps based on drone images



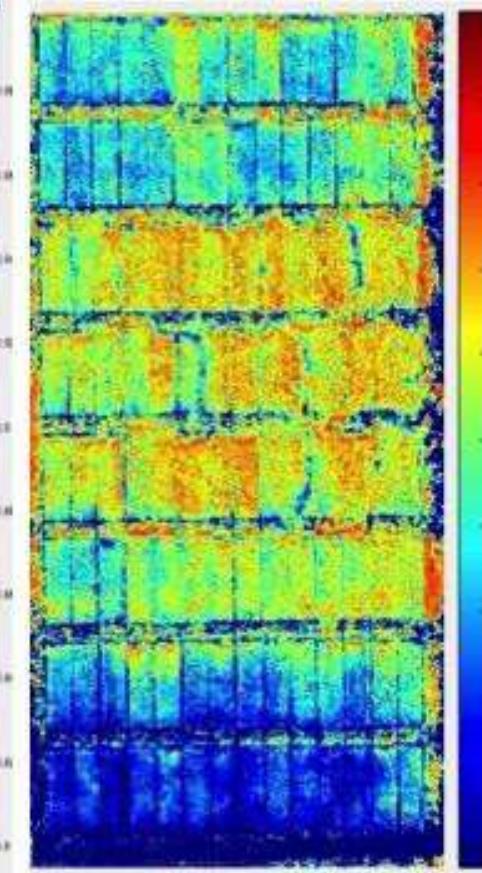
June 17



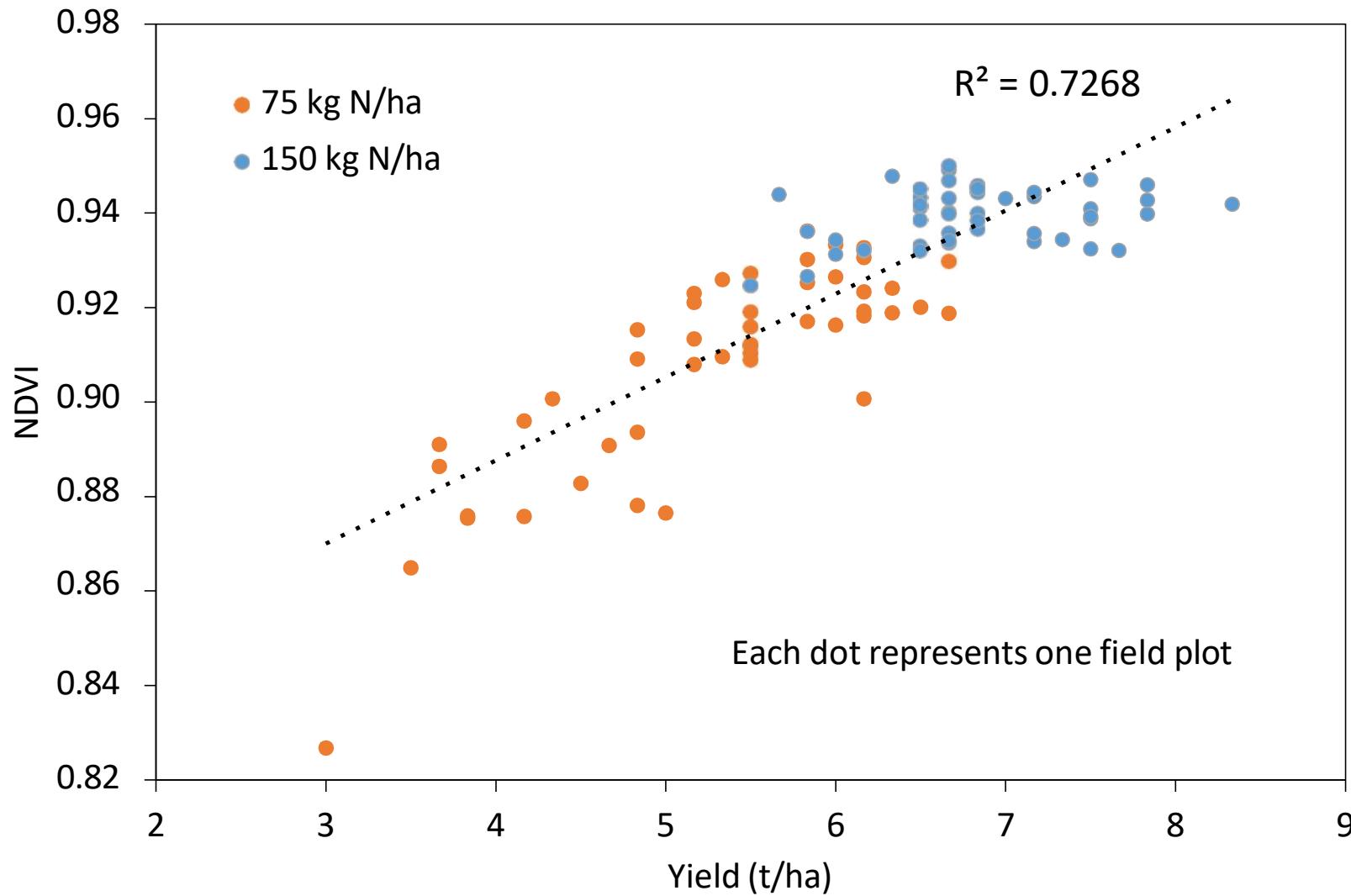
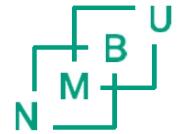
July 8



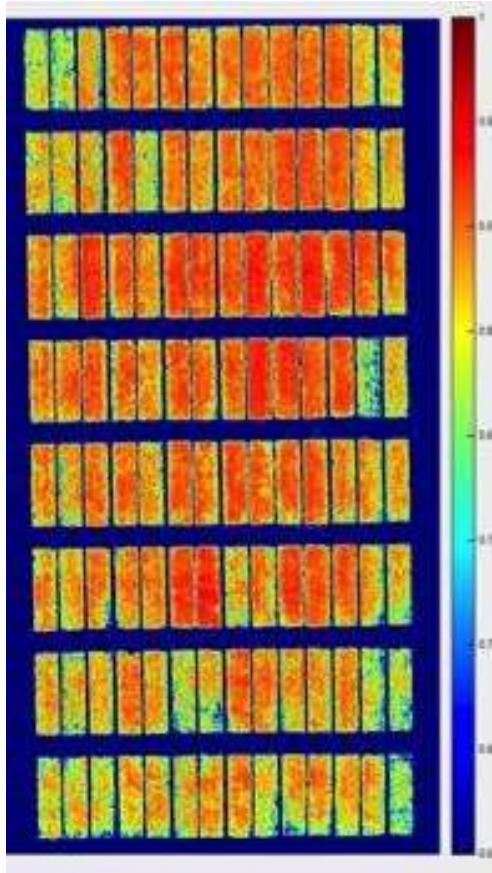
Aug 10



NDVI just after heading correlates with yield



Can vegetation indices explain cultivar differences in yield?

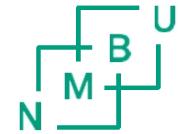


		NDVI
Grain yield	75 kg N/ha	0.37
	150 kg N/ha	0.08

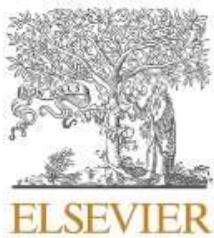


Eivind Bleken MSc thesis 2017

Grain yield prediction based on multitemporal multispectral data



Computers and Electronics in Agriculture 183 (2021) 106036



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journal homepage: www.elsevier.com/locate/compag



Original papers

Sequential forward selection and support vector regression in comparison to LASSO regression for spring wheat yield prediction based on UAV imagery



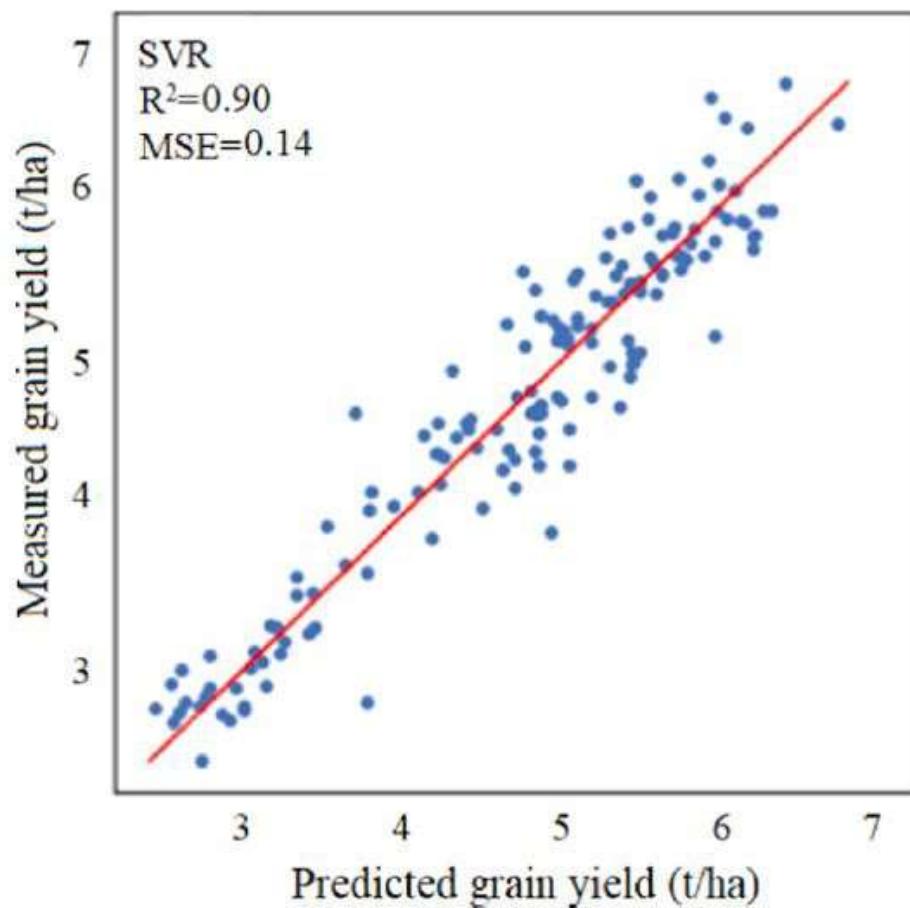
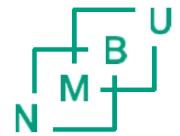
Sahameh Shafiee^a, Lars Martin Lied^b, Ingunn Burud^b, Jon Arne Dieseth^c, Muath Alsheikh^{a,c}, Morten Lillemo^{a,*}

^a Norwegian University of Life Sciences, Faculty of Biosciences, P.O. Box 5003, NO-1432 Ås, Norway

^b Norwegian University of Life Sciences, Faculty of Science and Technology, P.O. Box 5003, NO-1432 Ås, Norway

^c Graminor AS, Hommelstadvegen 60, NO-2322 Ridabu, Norway

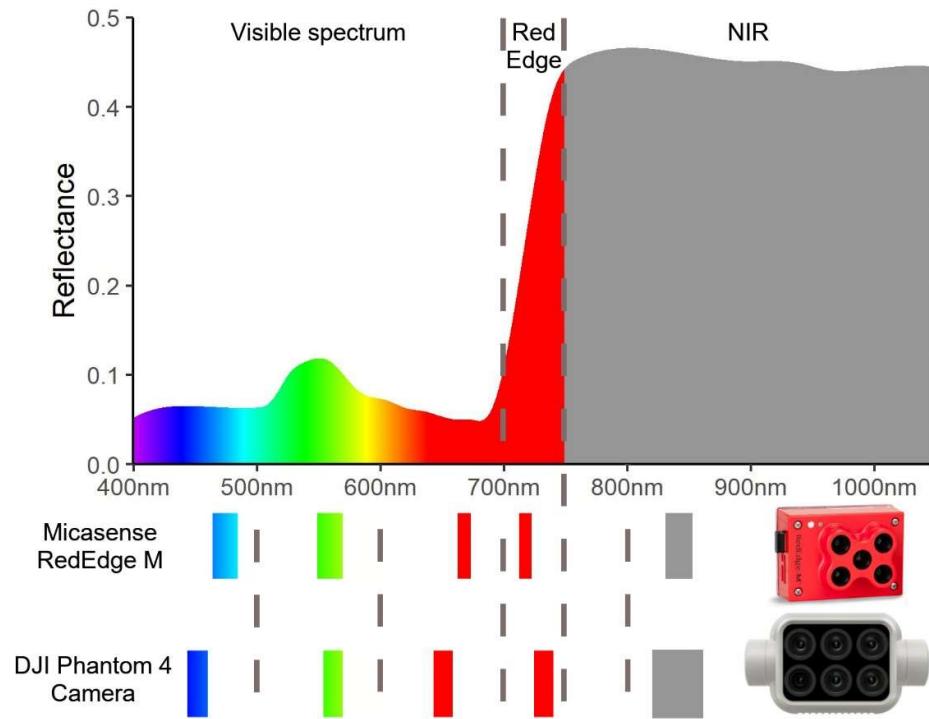
Grain yield prediction based on multitemporal multispectral data



- 300 spring wheat lines at two reps
- 3 flights with multispectral camera

Date	Selected Features
26.06.2018	Blue, NIR, NDVI, MTCI
02.07.2018	Blue, NDVI
19.07.2018	Blue, Green, RedEdge, NDVI, MTCI, EVI

Comparison of multispectral cameras for yield predictions



	P4 Multispectral	Micasense RedEdge M
Red	$650 \pm 16 \text{ nm}$	$668 \pm 5 \text{ nm}$
Green	$560 \pm 16 \text{ nm}$	$560 \pm 10 \text{ nm}$
Blue	$450 \pm 16 \text{ nm}$	$475 \pm 10 \text{ nm}$
Red Edge	$730 \pm 16 \text{ nm}$	$717 \pm 5 \text{ nm}$
NIR	$840 \pm 26 \text{ nm}$	$840 \pm 20 \text{ nm}$

- Parallel flights during the 2020 and 2021 seasons
- Tested for prediction of in-season biomass and grain yield using machine learning
- **Overall, no significant difference in trait prediction performance**
- **P4M is cheaper and more user-friendly**

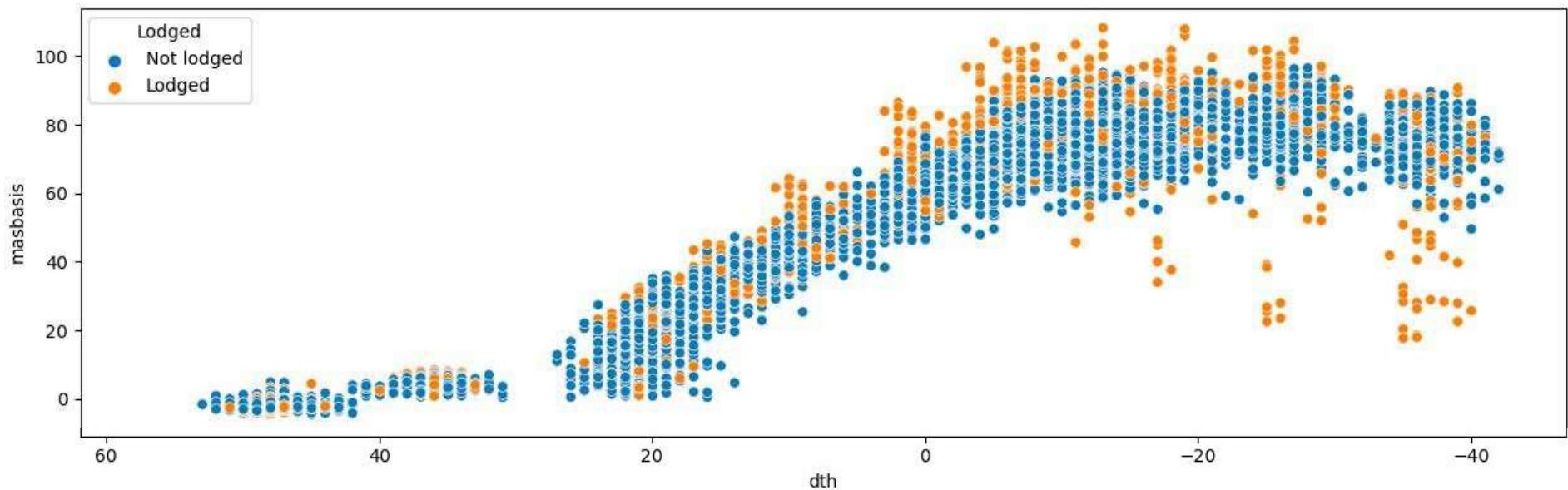
Shafiee *et al.*, submitted

Plant height estimation using RGB imaging



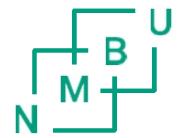
Phantom 4 (P4)

- Promising results based on Phantom 4 RGB
- Growth dynamics can be followed in high resolution based on time series data

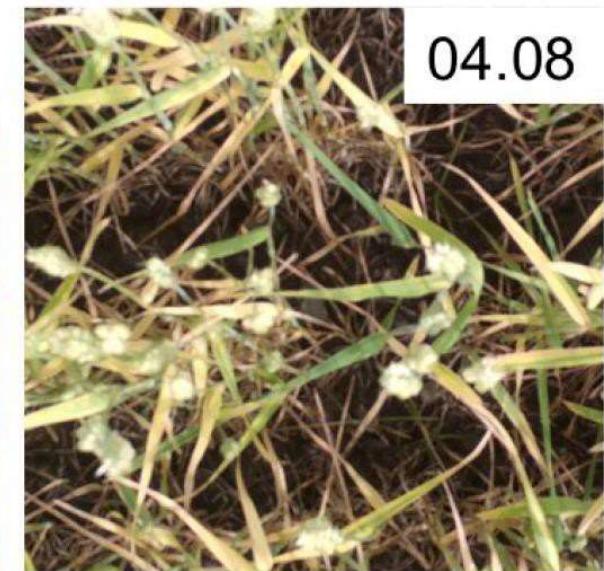
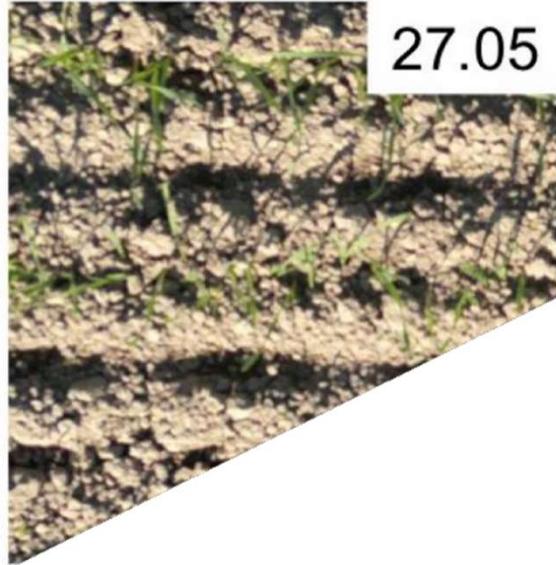
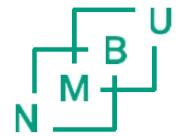


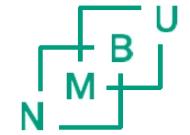
Henrik Lassegård master thesis, 2021

Phenotyping with robot



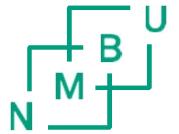
Close-up images from robot





Imaging with RGB and 360 cameras





Imaging with RGB and 360 cameras

RGB camera (17.07.2019)



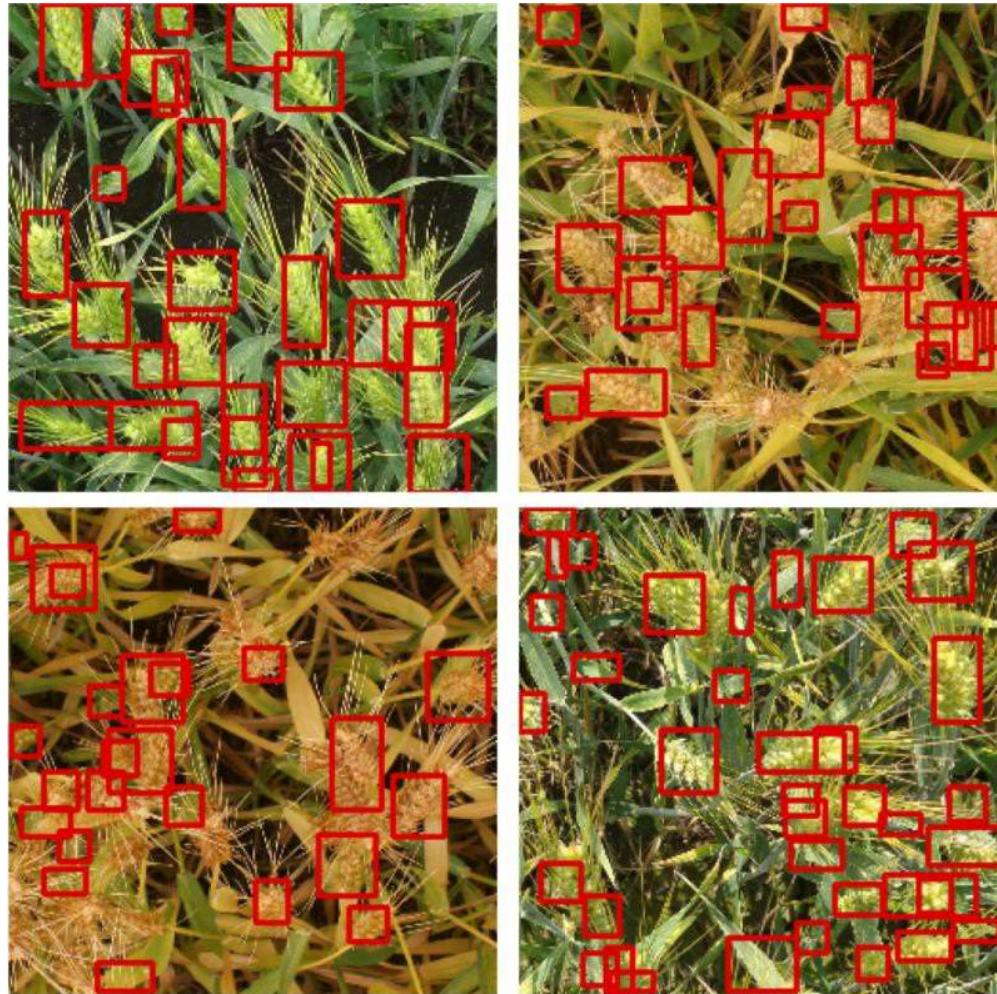
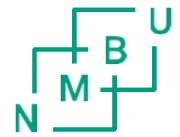
360 camera (17.07.2019)



→ Use for counting heads/m²

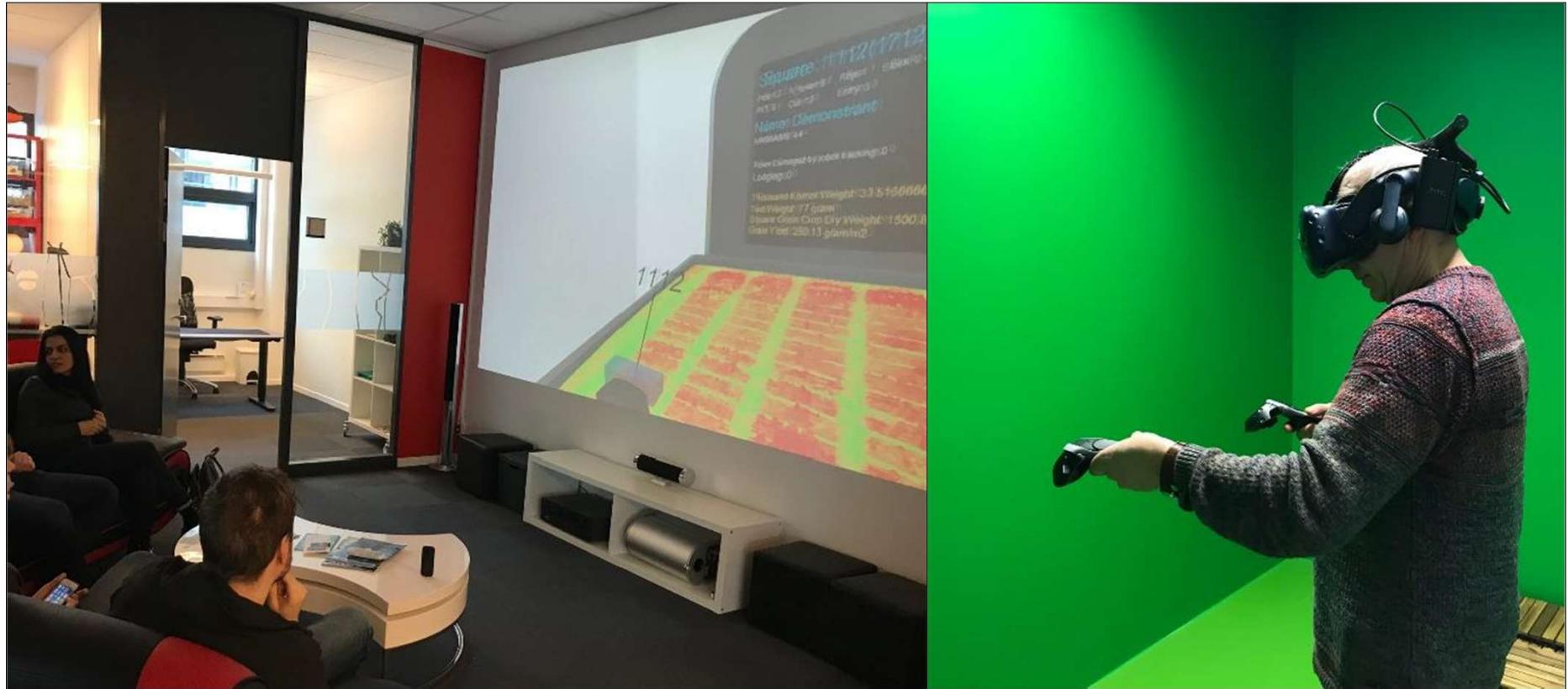
→ Detection of plant diseases inside the canopy

Use of deep learning to identify and count wheat heads

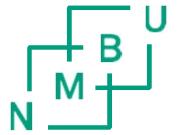


- Important yield component that is too difficult to measure manually on many field plots

Virtual Reality - bringing the field to the breeder



VR prototype workshop February 2019



<http://www.clipartkid.com/>

Sahameh.shafiee@nmbu.no