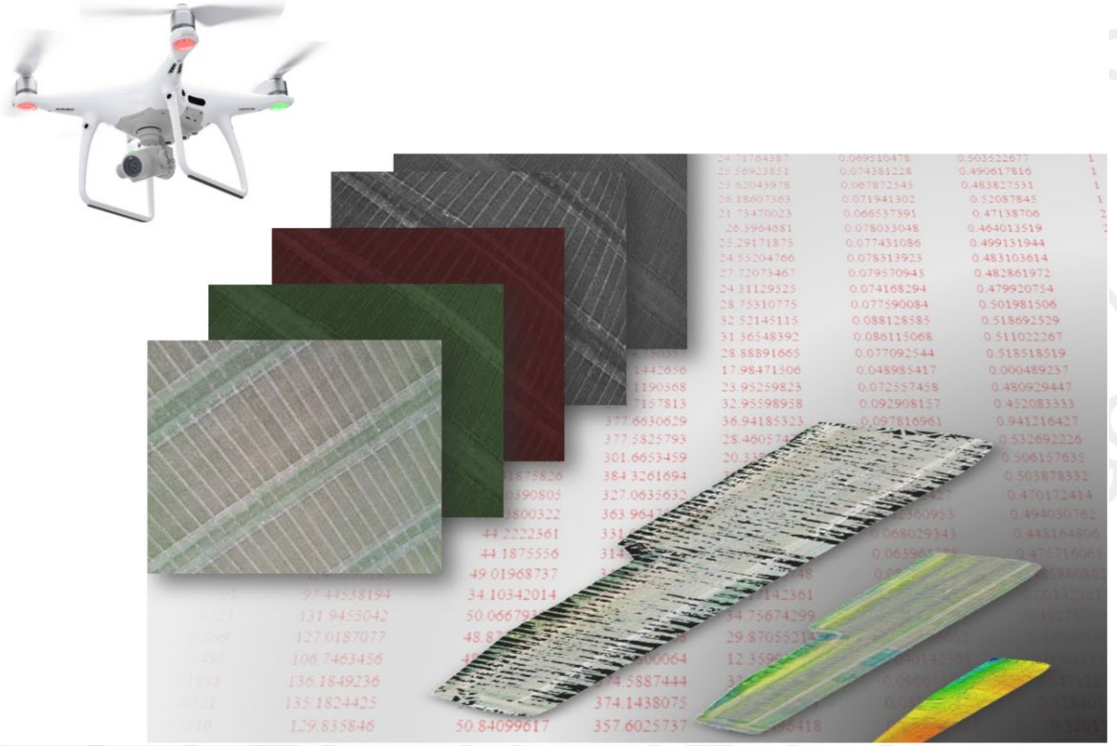
Phenotyping in breeding using UAV and consumer-grade cameras

Key reflections/results from a Ph.D. study.

Jesper Svensgaard



KØBENHAVNS UNIVERSITET

Questions and research

- **Is phenotyping reliable if you use different RGB cameras under different conditions (reality check!), and is there a need to use spectral correction?**

- **Are there any added value from multispectral and thermal measurements to select rescilient genotypes?**

Traits	Tools					Technological readiness level (TRL)								
	RGB ☺	Multi/hyperspectral 😐	LIDAR	Thermal ☹	Fluorescence	1	2	3	4	5	6	7	8	9
Plant density, plant emergence	■					■	■	■	■	■	■	■		
Cover fraction	■					■	■	■	■	■	■	■	■	
Plant/Canopy height	■		■			■	■	■	■	■	■	■		
Ear density	■					■	■	■						
Fruit/inflorescence size	■		■			■	■	■	■					
Grain number and size	■					■	■	■	■					
Leaf/plant glaucousness	■					■	■							
Phenology (heading, anthesis etc.)	■	■		■		■	■							
Lodging	■		■			■	■	■	■	■	■	■		
Weed infestation	■					■	■	■	■	■	■	■		
Diseases	■	■		■	■	■	■							
Vegetation index (VI) monitoring	■	■				■	■	■	■	■	■	■		
Green area index (GAI)	■	■	■			■	■	■	■	■				
Senescence	■	■				■	■	■	■	■	■			
Fraction of intercepted radiation	■	■	■			■	■	■	■	■	■			
Leaf orientation	■	■	■			■	■	■	■	■				
Leaf rolling	■	■	■			■	■	■	■					
Chlorophyll content	■	■				■	■	■	■	■	■			
Leaf/canopy temperature		■		■	■	■	■	■	■	■				
Leaf/Canopy chlorophyll fluorescence					■	■	■	■	■					

RGB imaging and spectral correction

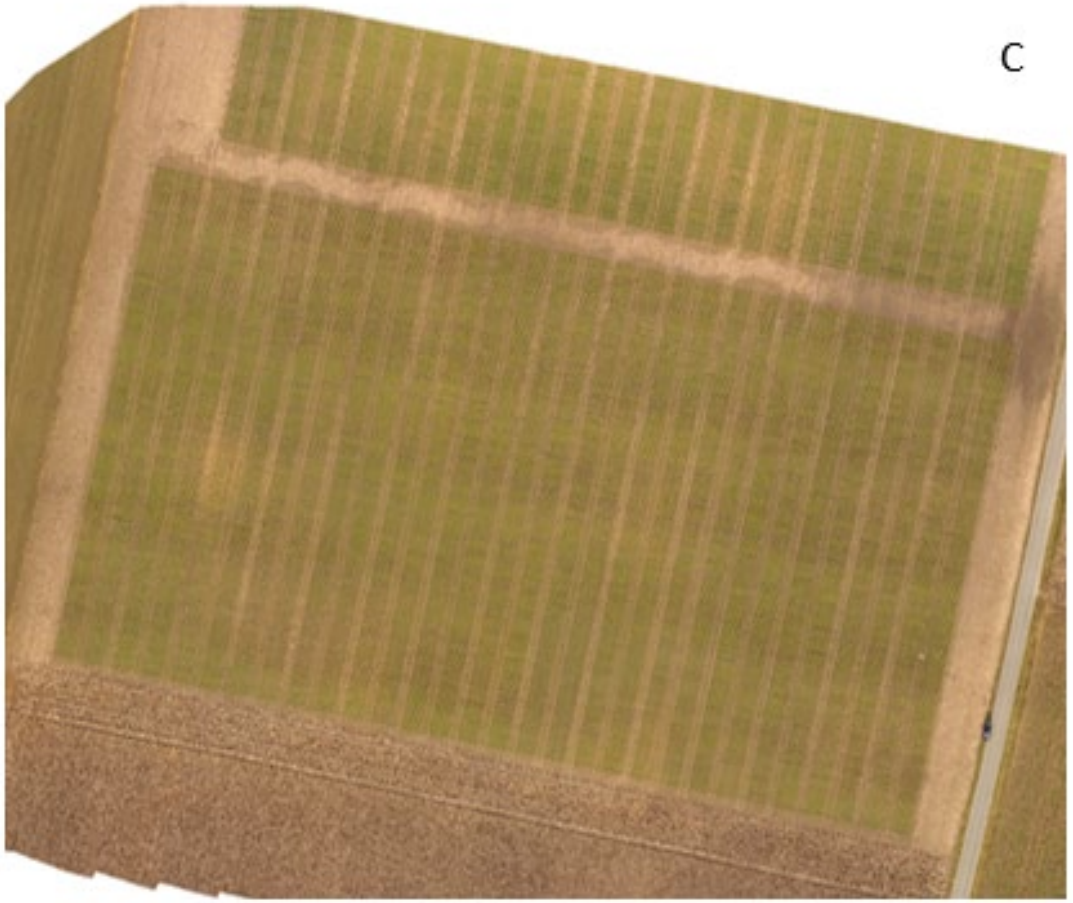


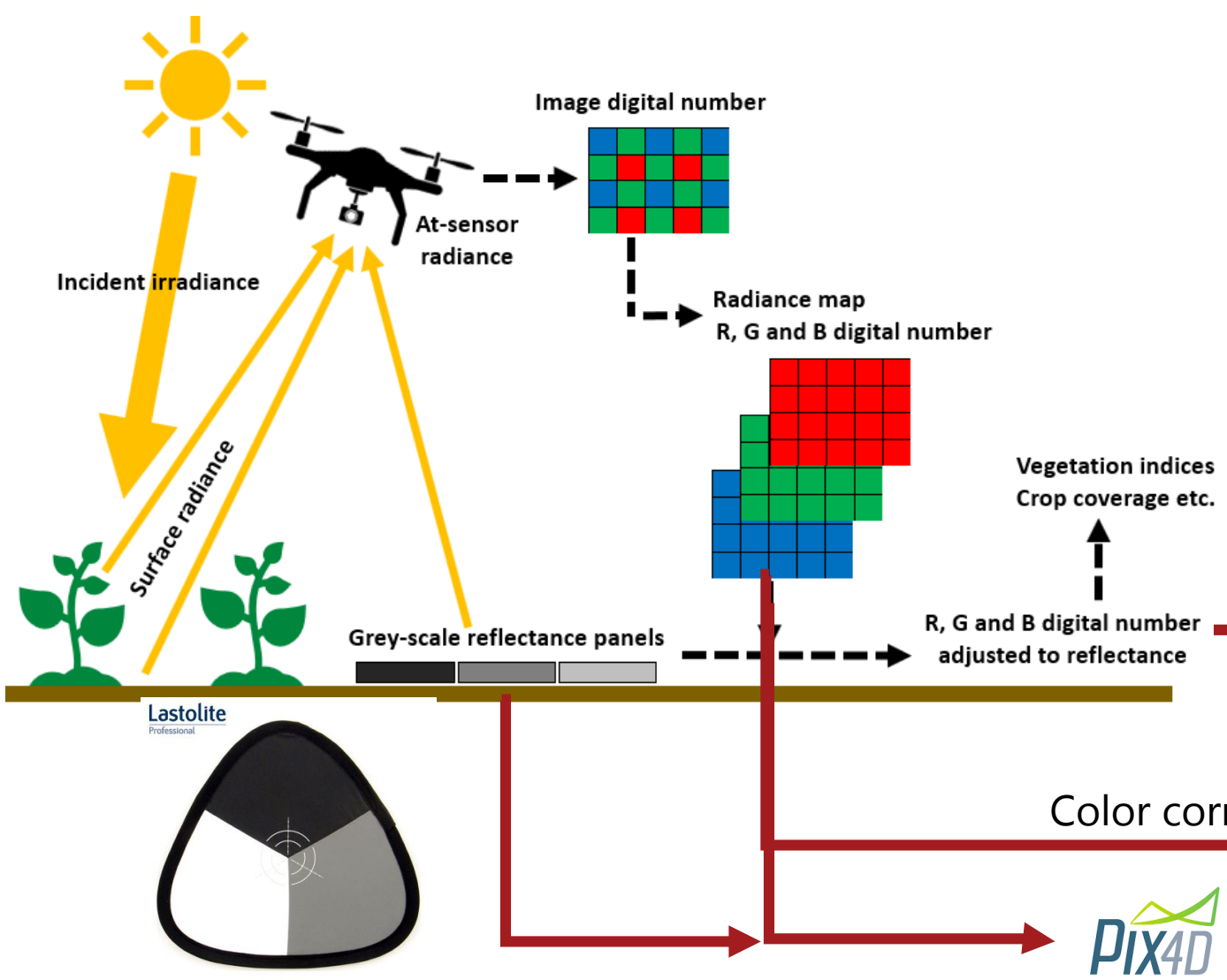
Table 1: Combination of experiment, date of image acquisition, camera, exact time of image acquisition of grey-scale panels (low altitude 1.5-10 m) and timespan of images for mosaicking (90 m and 50 m altitudes)

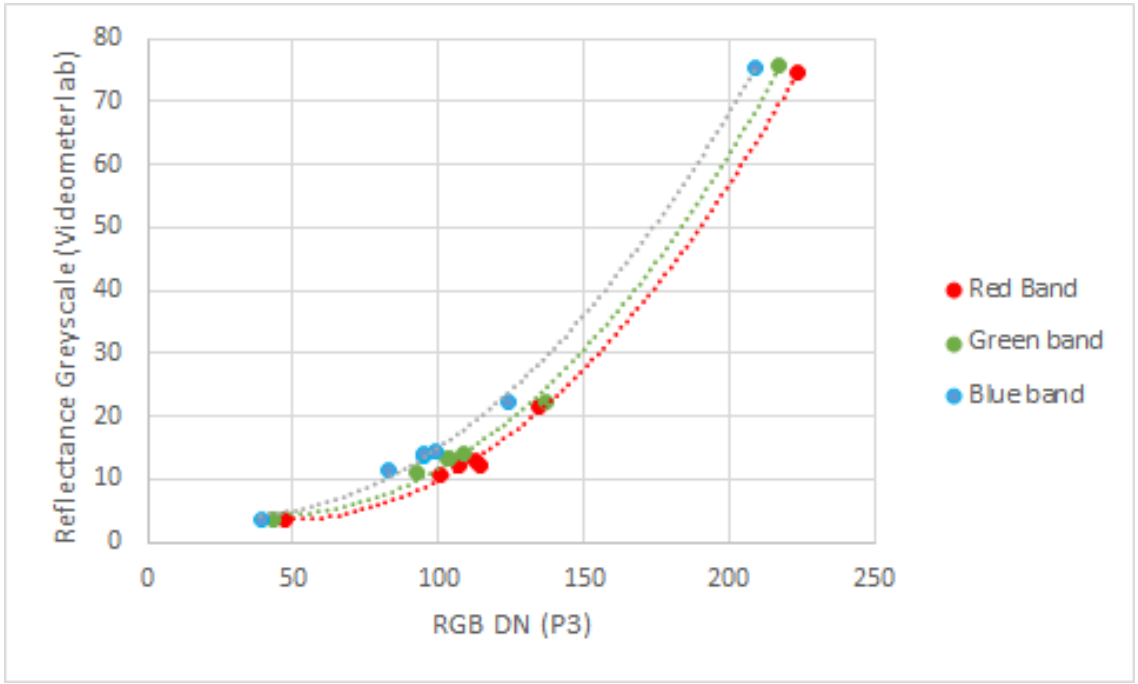
Experiment	Crop	Date	Camera	Image capture time (CET)			
				Grey panels, 1.5-10 m	Mosaic 1, 90 m	Mosaic 2, 90 m	Mosaic, 50 m
1	Winter wheat	14 April	X5	10.05	10.01-10.02	10.07-10.09	10.18-10.21
1	Winter wheat	14 April	P3	11.04	11.10-11.11	11.15-11.16	11.21-11.24
1	Winter wheat	18 April	X5	12.16	12.14-12.15	12.22-12.23	13.15-13.18
1	Winter wheat	18 April	P3	12.55	12.52-12.54	12.57-12.58	13.40-13.43
2	Winter barley	7 April	X5	12.15			12.15-12.23
2	Winter barley	7 April	P3	13.27			13.21-13.26

- 59 W. barley genotypes
- 2 RGB cameras (P3, X5)
- Sunny conditions, 50 m
- Diverse genotypes in color and vigor

- **Datasets with and without spectral correction**
- **Estimating coefficients for accuracy and precision**
- **Testing camera*light*altitude*genotype interactions**

Spectral correction procedure





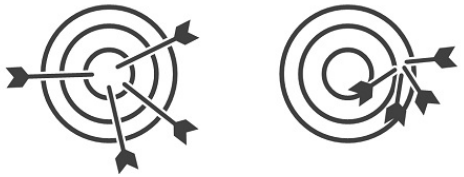
ELM

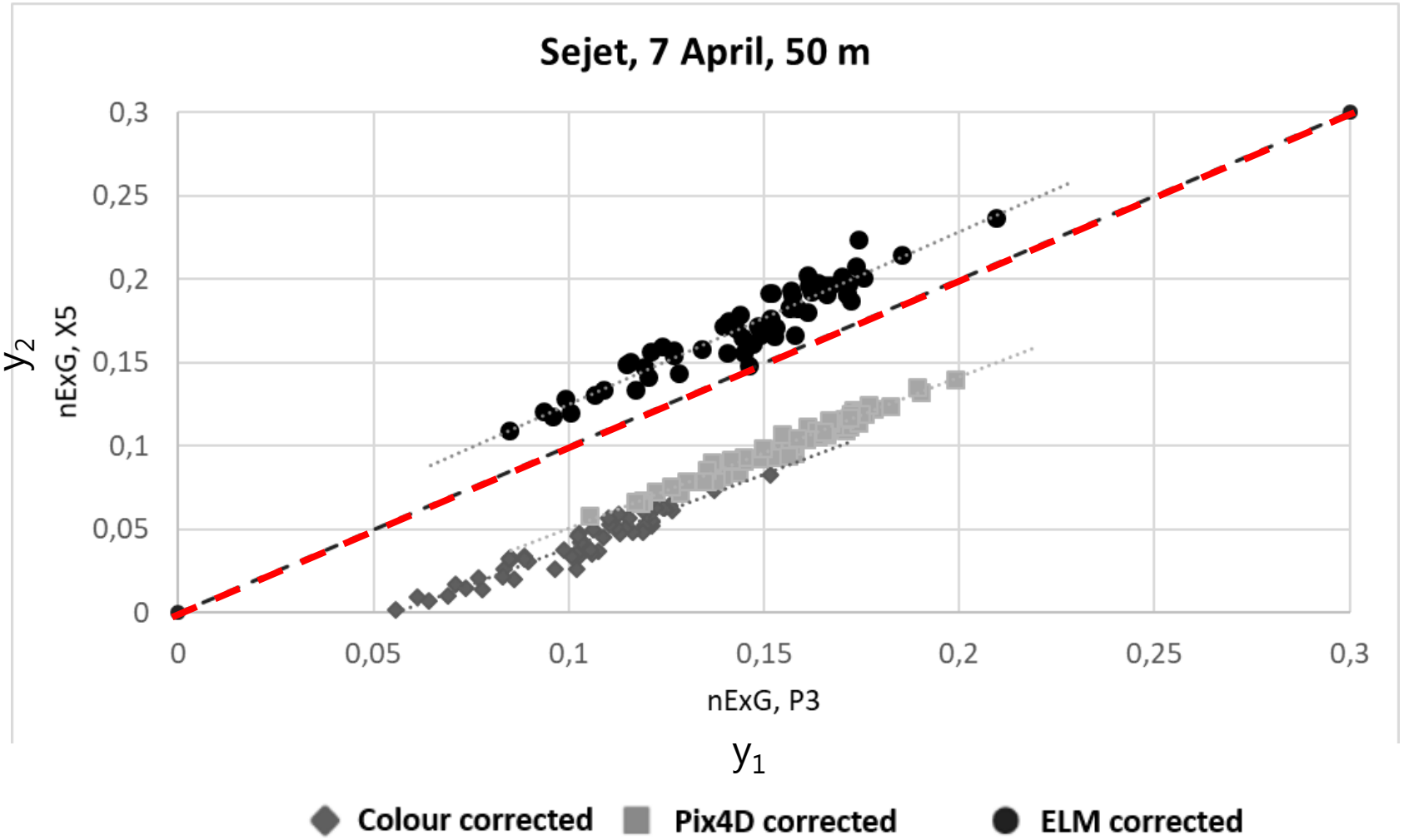
Color corrected

PIX4D

$$ExG = \frac{(2G - R - B)}{G + R + B}$$

Precision and accuracy with/without correction





$$r = \frac{\sum(y_1-\bar{y}_1)(y_2-\bar{y}_2)}{\sqrt{\sum(y_1-\bar{y}_1)^2}\sqrt{\sum(y_2-\bar{y}_2)^2}}$$

- **Overall high r (0.96-0.99)**

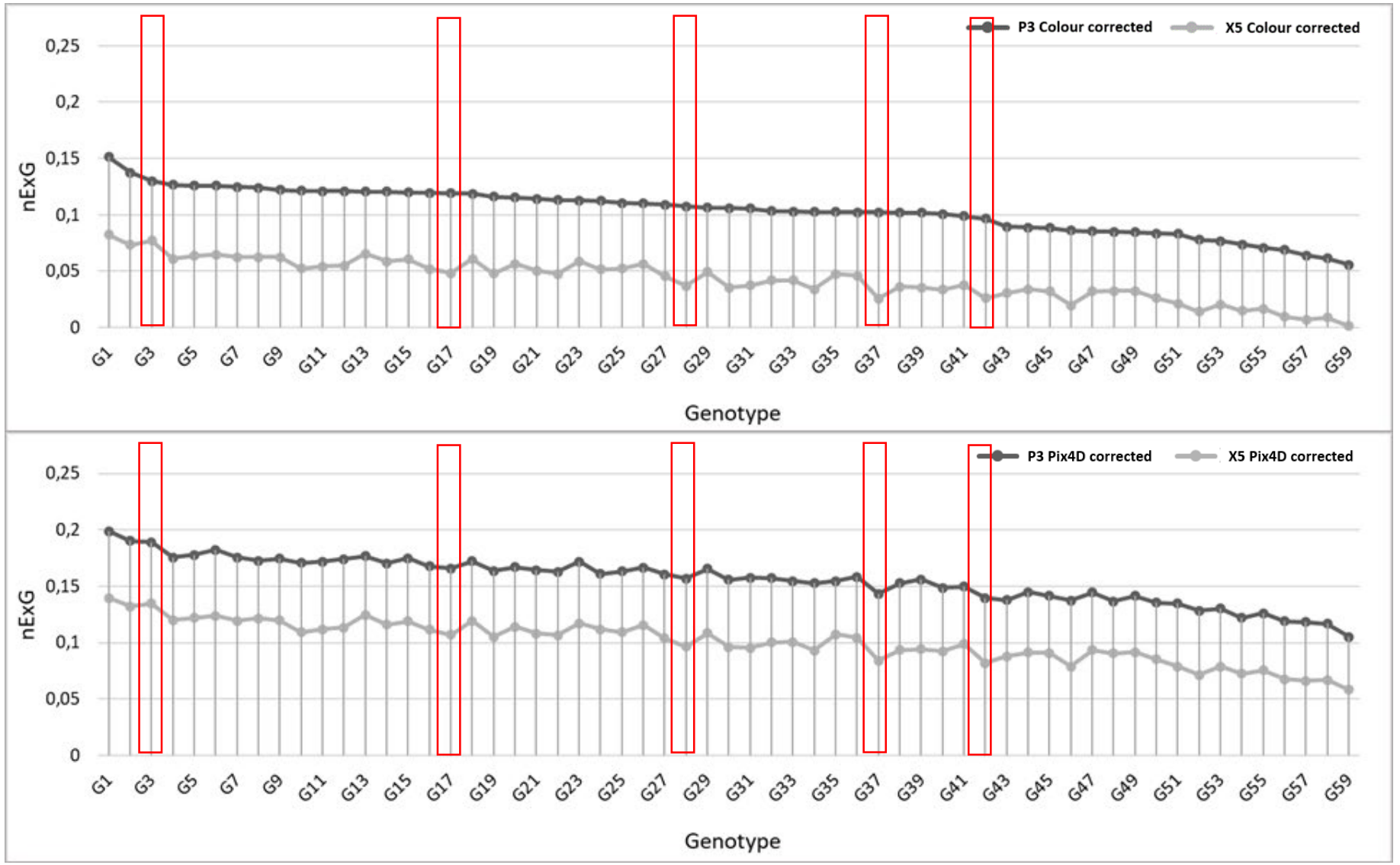
$$NSE = 1 - \frac{\sum(y_1-y_2)^2}{\sum(y_1-\bar{y}_1)^2}$$

- **NSE improved from correction, esp ELM (-8.68 to 0.19)**

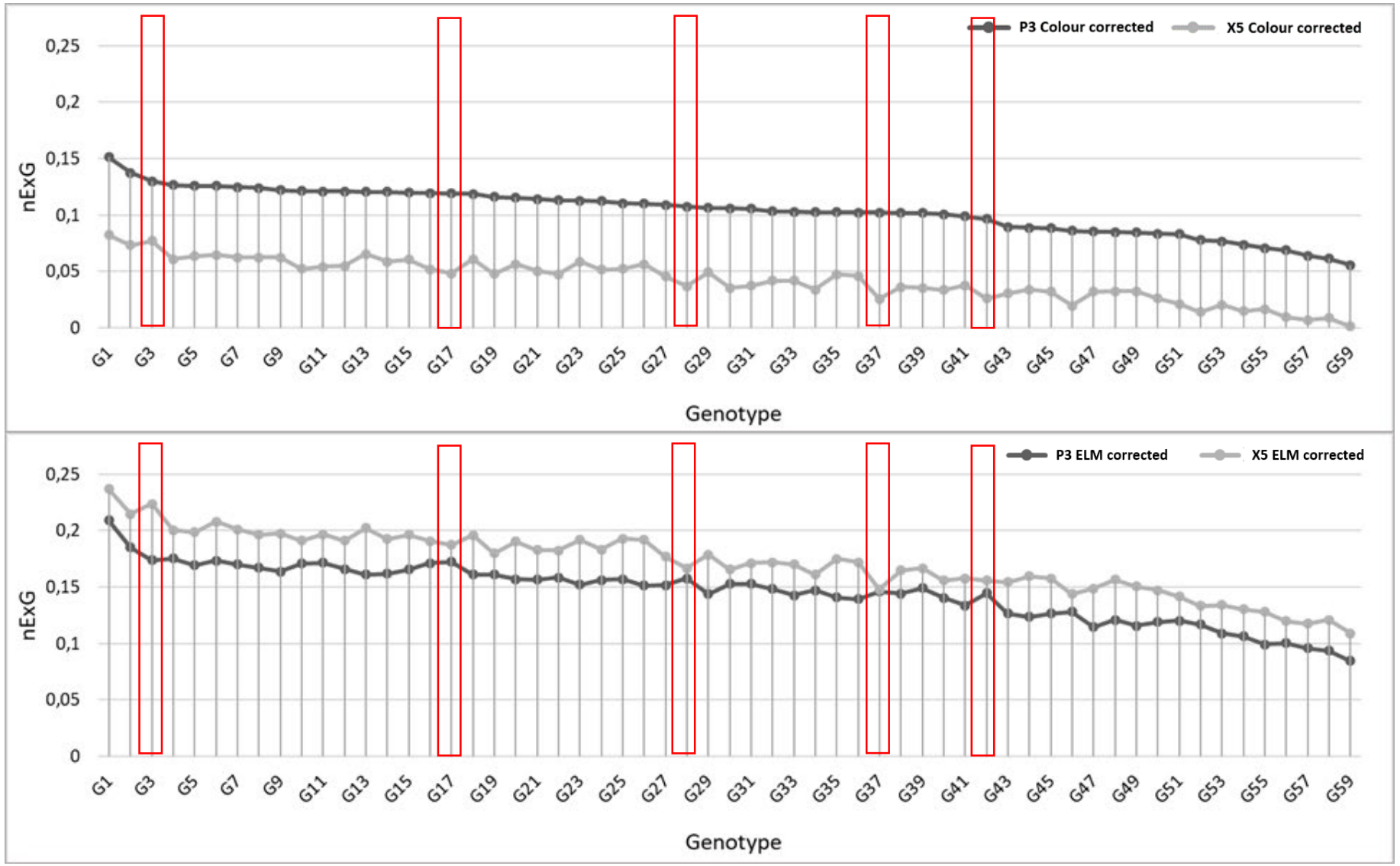
$$SRD = 1.96\sqrt{2\sigma_R^2}$$

- **Overall SRD decreased using calibration (0.12 to 0.06)**

Interaction between camera and genotype



Interaction between camera and genotype



Mixed anova analysis showed, that

-Several cases with camera by genotype interaction

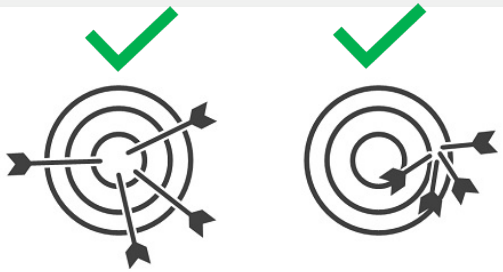
-High r (=1.00) and spectral correction not enough to remove interaction

-Minute differences between genotypes = challange – important?

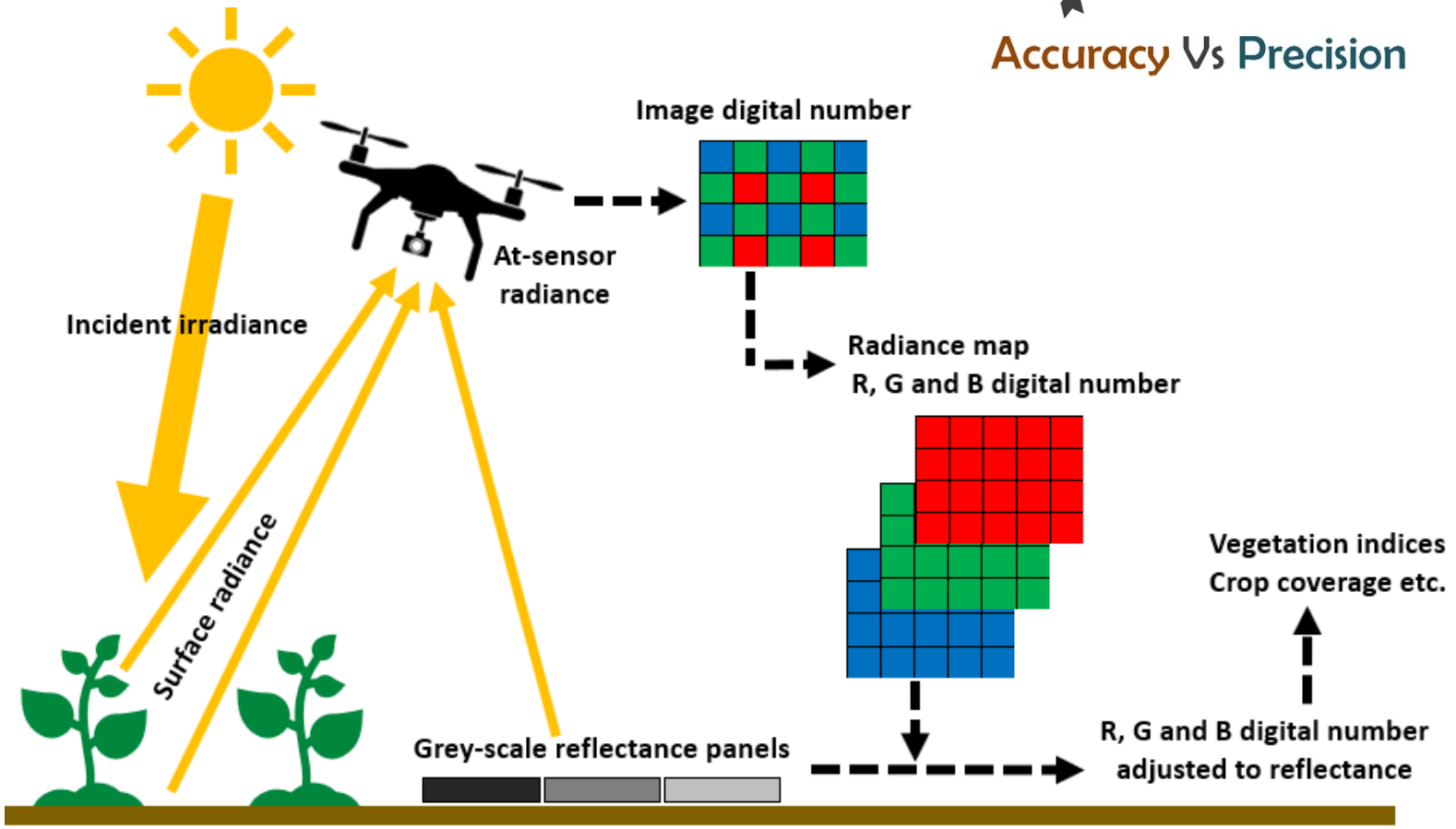
-Light changes during flight, SfM and procedure not optimal

- Crop color, soil

Conclusions of paper

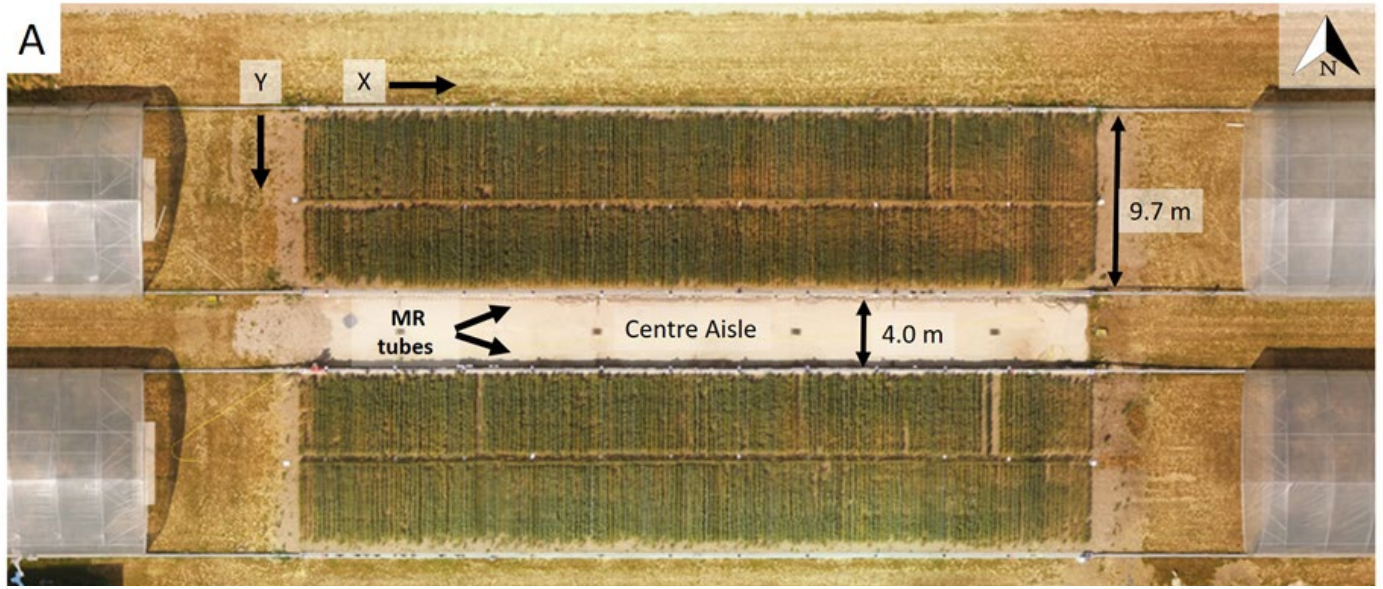


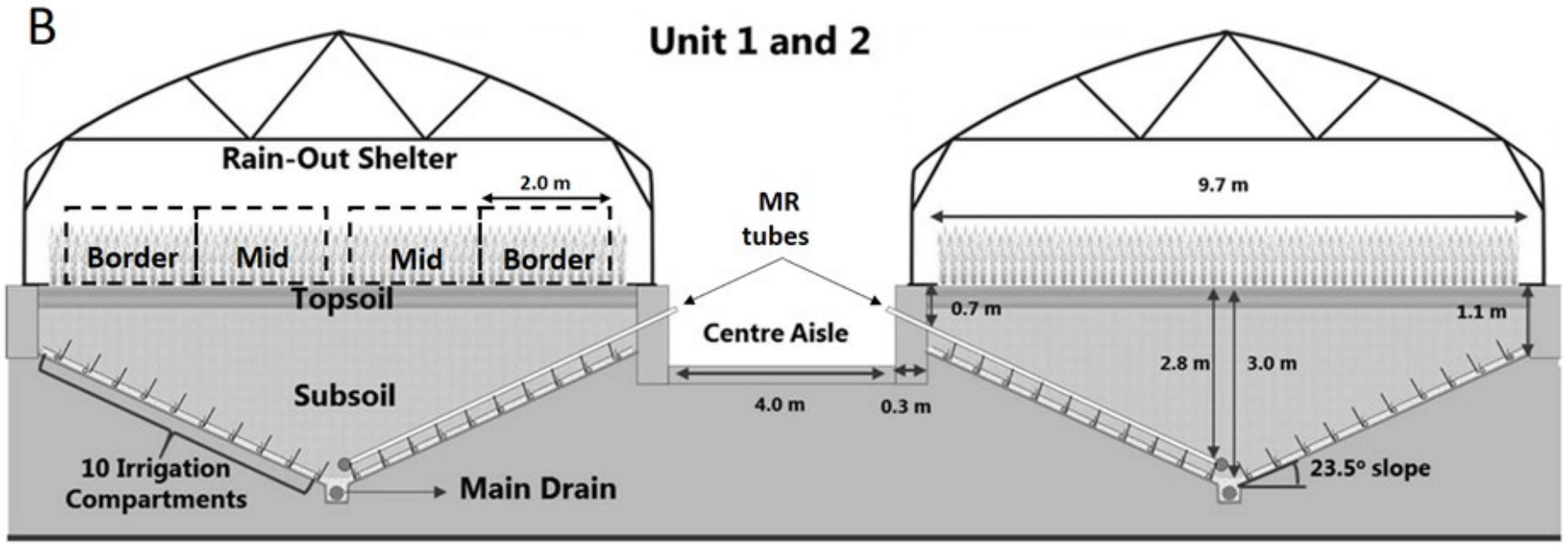
Accuracy Vs Precision



- **Overall precise measurements seen from pearson corr. coeff.**
- **Overall especially ELM improved accuracy and reproducibility – close to benchmark**
- **Light is an issue, altitude is not**
- **Correction did not remove camera effect despite good r and NSE**
- **Interaction between camera and genotype due to minute differences between genotypes with no practical importance**
- **Spectral correction may be overrated from agronomical/breeding pov**

Drought – RGB vs MS vs Thermal

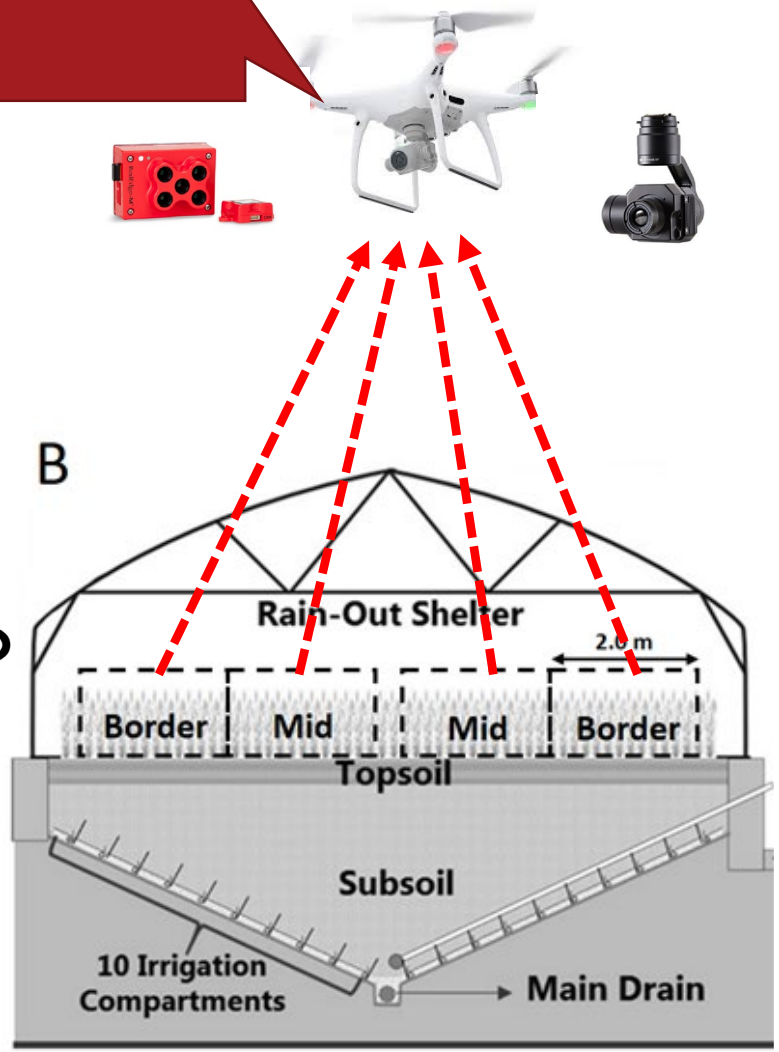




Drought – RGB vs MS vs Thermal

T canopy (°C)
nExG
NDRE
NDVI

TKW
^{13}C
Yield

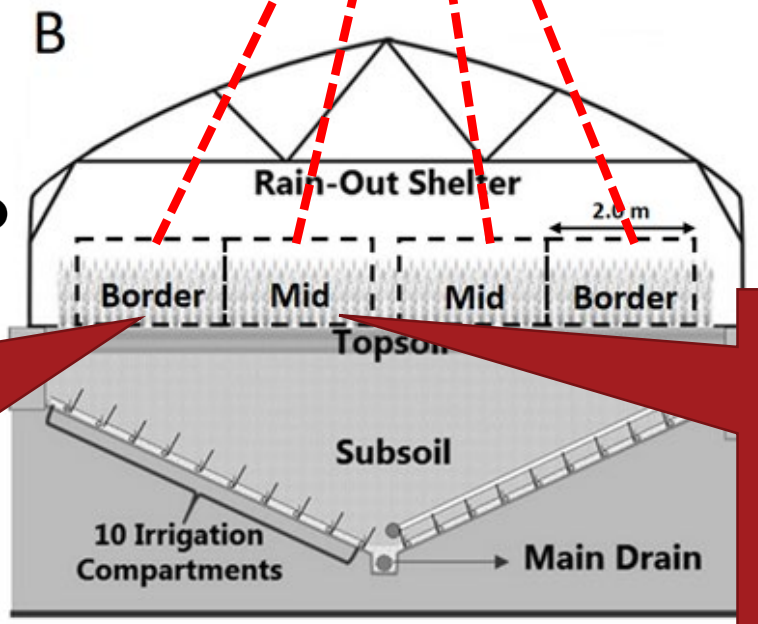


Camera	Date	Time (CET)	Wheat Growth stage
RedEdge	12 June		Mid grainfill
	15 June		Mid grainfill
	18 June	At noon	Mid grainfill
	27 June		Late grainfill
	3 July		Start Maturity
Sequoia	25 May		End heading
	31 May	At noon	Anthesis
	7 June		Early grainfill
XTR	25 May	14.00	End heading
	31 May	14.00	Anthesis
	5 June*	11.00, 13.30	Early grainfill
	15 June*	11.00, 13.30	Mid grainfill
	27 June*	11.30, 14.00	Late grainfill
P4	2 June		Anthesis/early
	5 June		grainfill
	12 June	At noon	Early grainfill
	18 June		Mid grainfill
	6 July		Mid grainfill
			Start Maturity
P3	26 June	At noon	Late grainfill

Drought – RGB vs MS vs Thermal

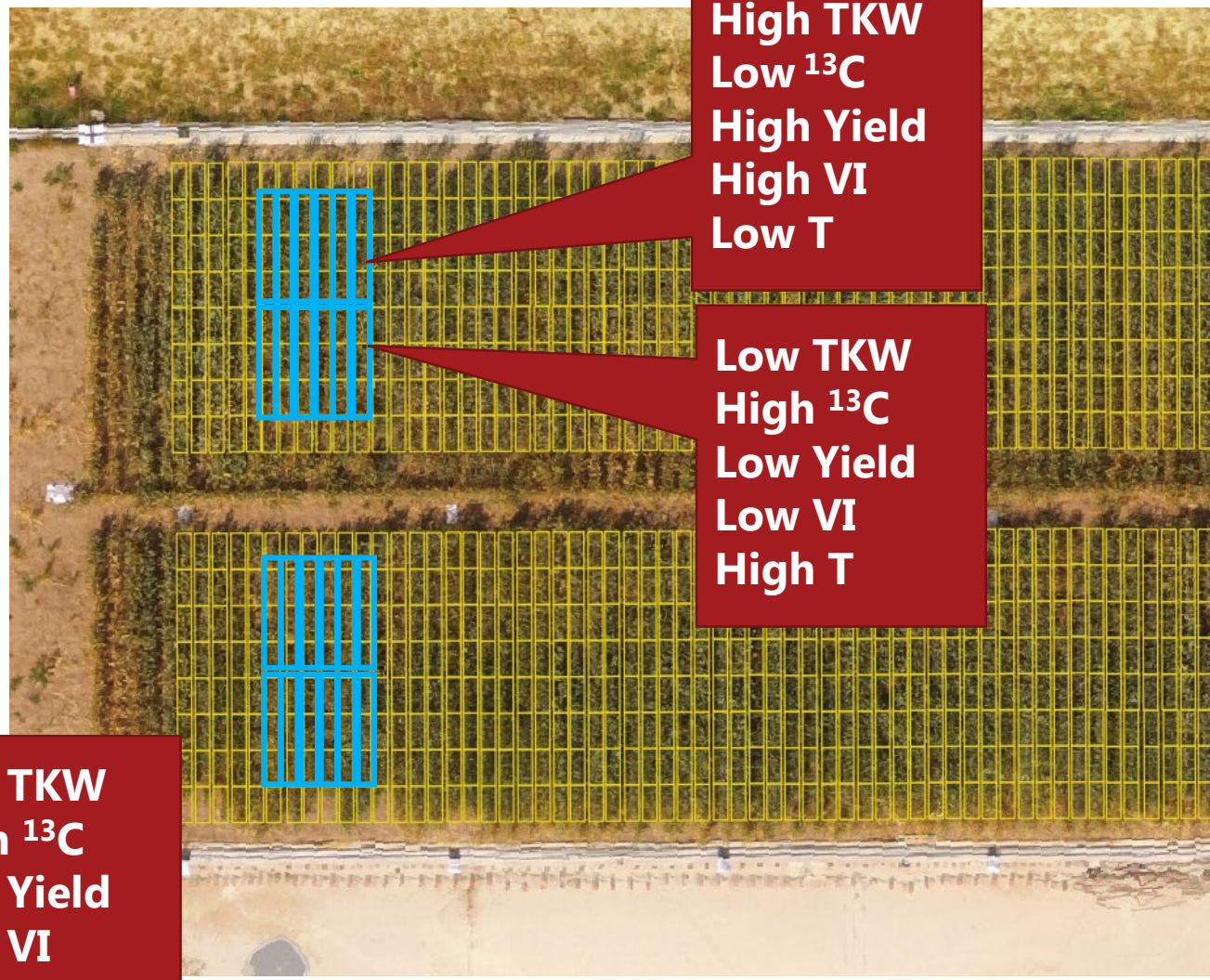
T canopy (°C)
nExG
NDRE
NDVI

TKW
^{13}C
Yield



High TKW
Low ^{13}C
High Yield
High VI
Low T

Low TKW
High ^{13}C
Low Yield
Low VI
High T



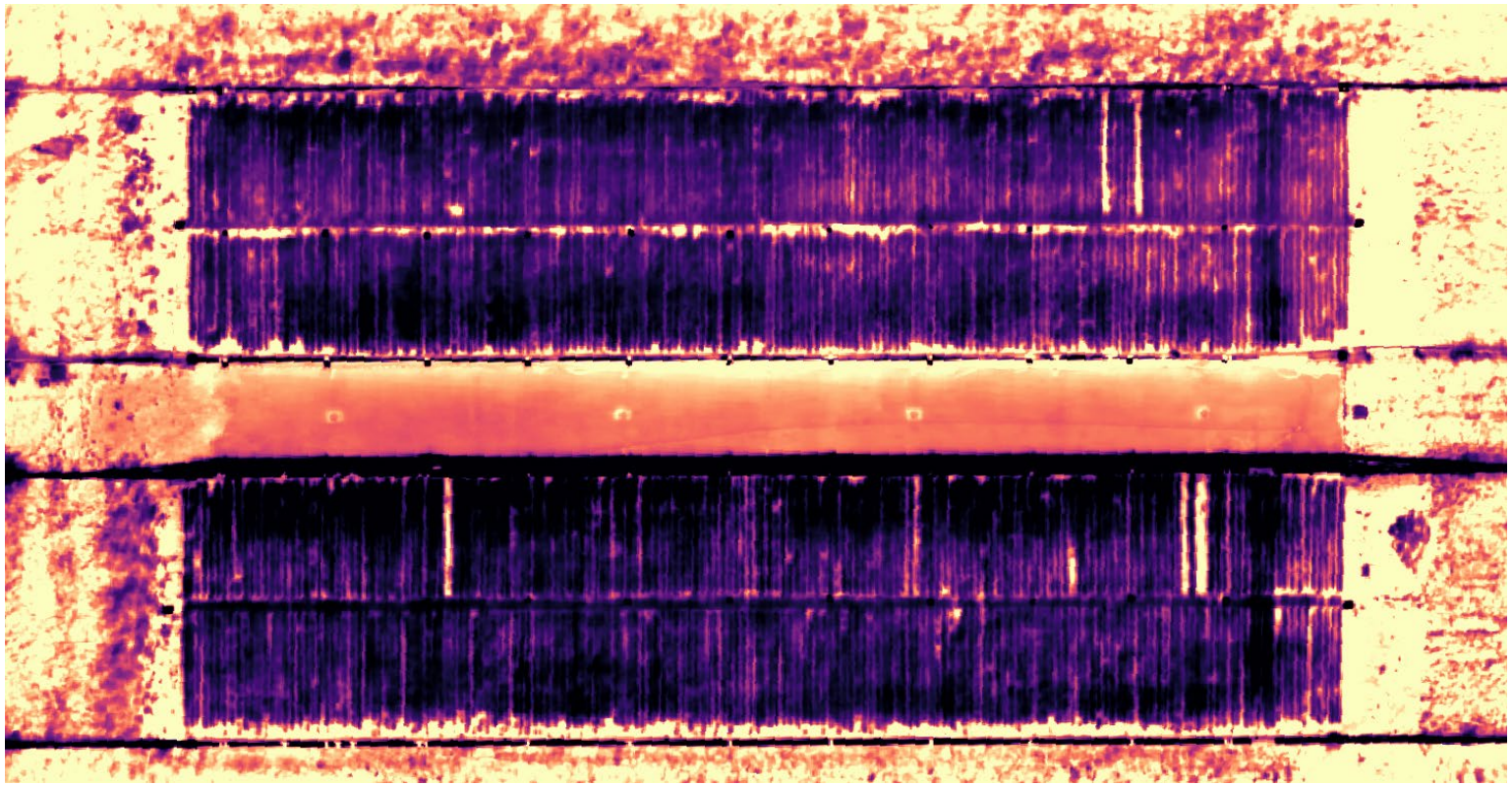
High TKW
Low ^{13}C
High Yield
High VI
Low T

Low TKW
High ^{13}C
Low Yield
Low VI
High T

Overall results

Thermal measurements:

- No early symptoms
- No treatment x genotype
- Low genotype repeatability
- Fine correlation to genotype yield



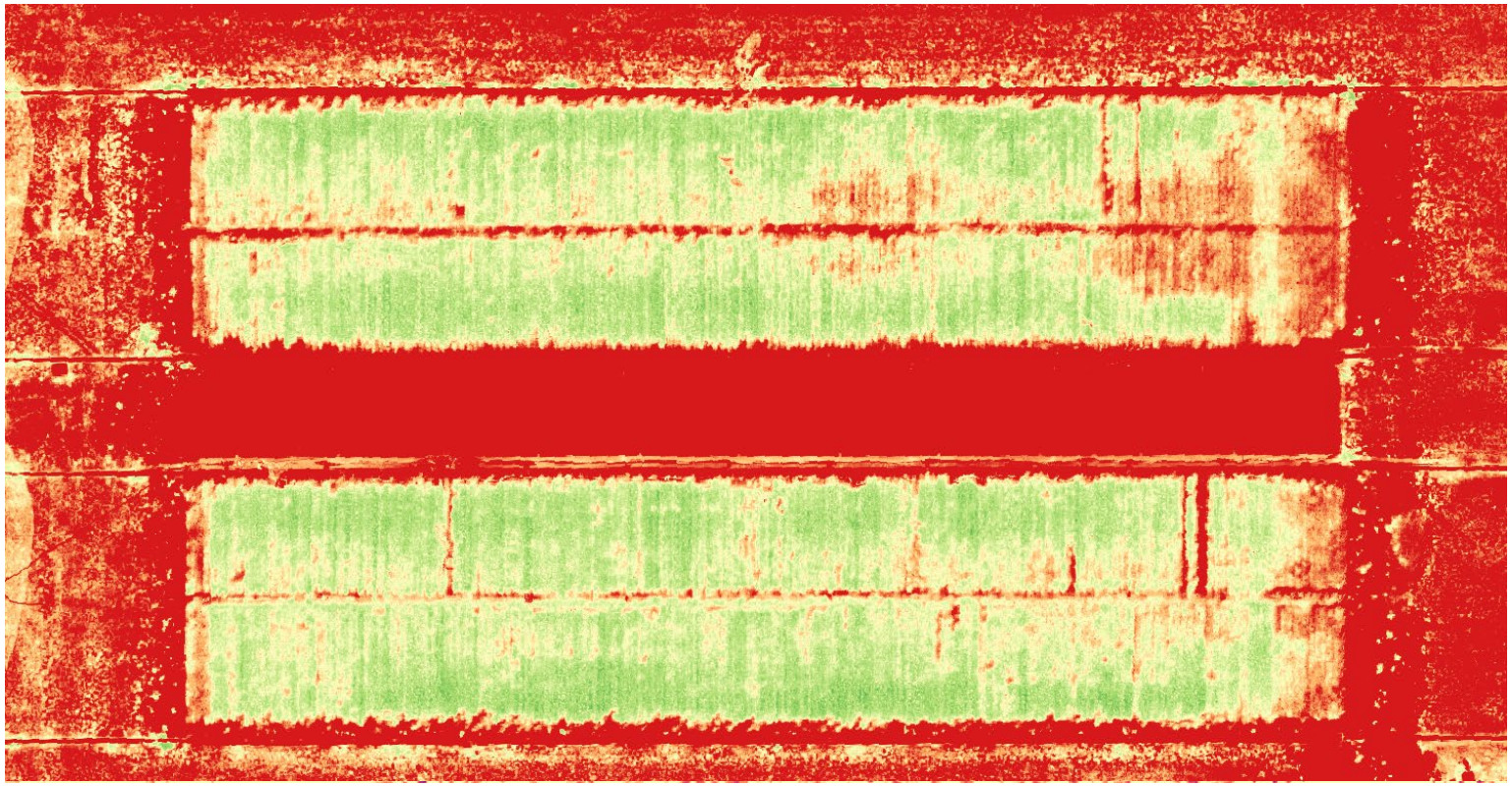
Overall results

Thermal measurements:

- No early symptoms
- No treatment x genotype
- Low genotype repeatability
- Fine correlation to genotype yield

Vegetation indices:

- NDVI and nExG best, treatment effect from 2 June (tiny difference)
- nExG late treatment x genotype
- nExG (and NDVI) higher genotype repeatability



Overall results

Thermal measurements:

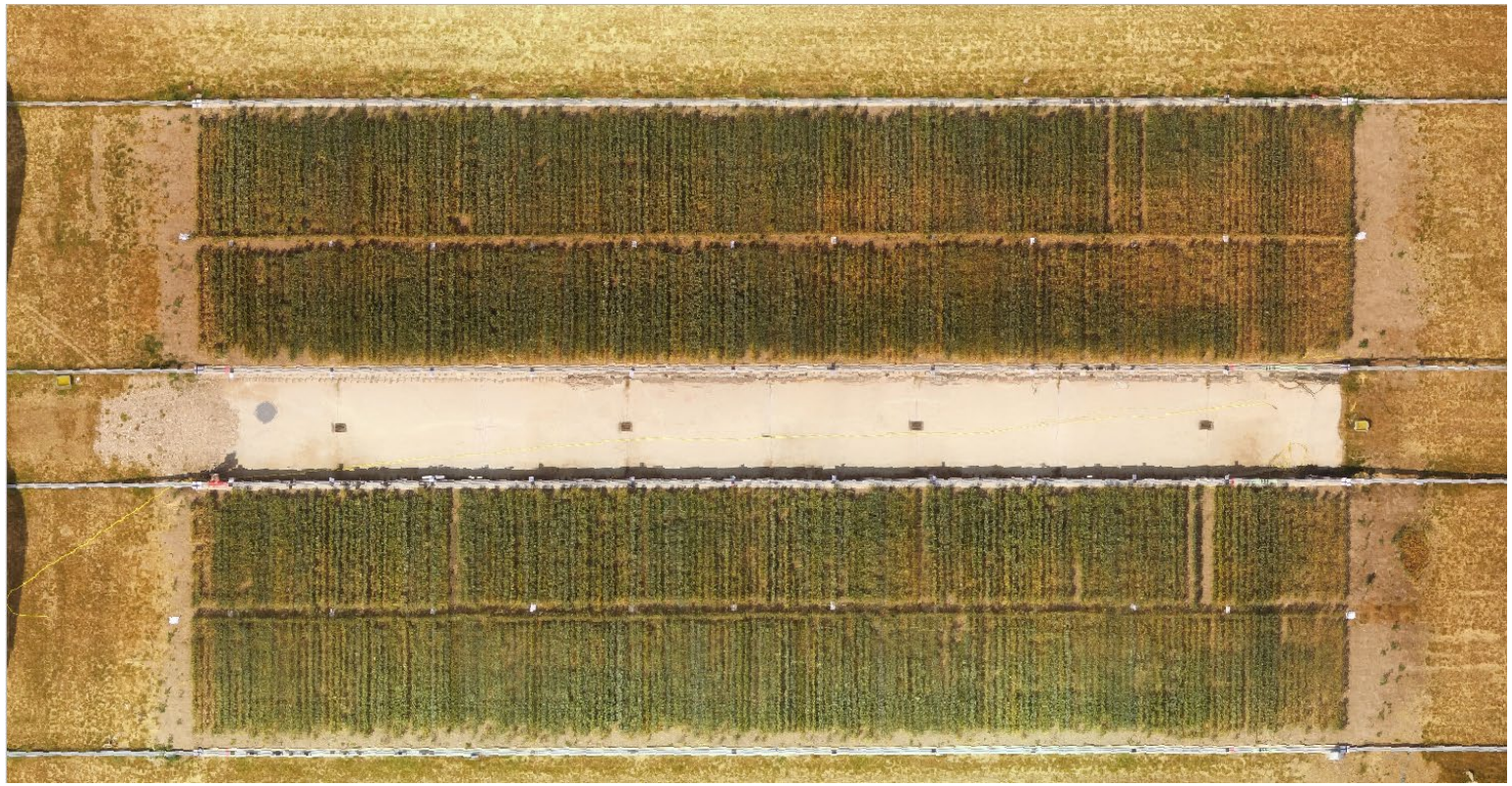
- No early symptoms
- No treatment x genotype
- Low genotype repeatability
- Fine correlation to genotype yield

Vegetation indices:

- NDVI and nExG best, treatment effect from 2 June (tiny difference)
- nExG late treatment x genotype
- nExG (and NDVI) higher genotype repeatability

Overall:

- Surface roughness problematic
- Facility + soil surface problematic
- Single rows difficult
- Stay-green interesting – both RGB and MS; Thermal challanging
- 2020 data being analysed now!!

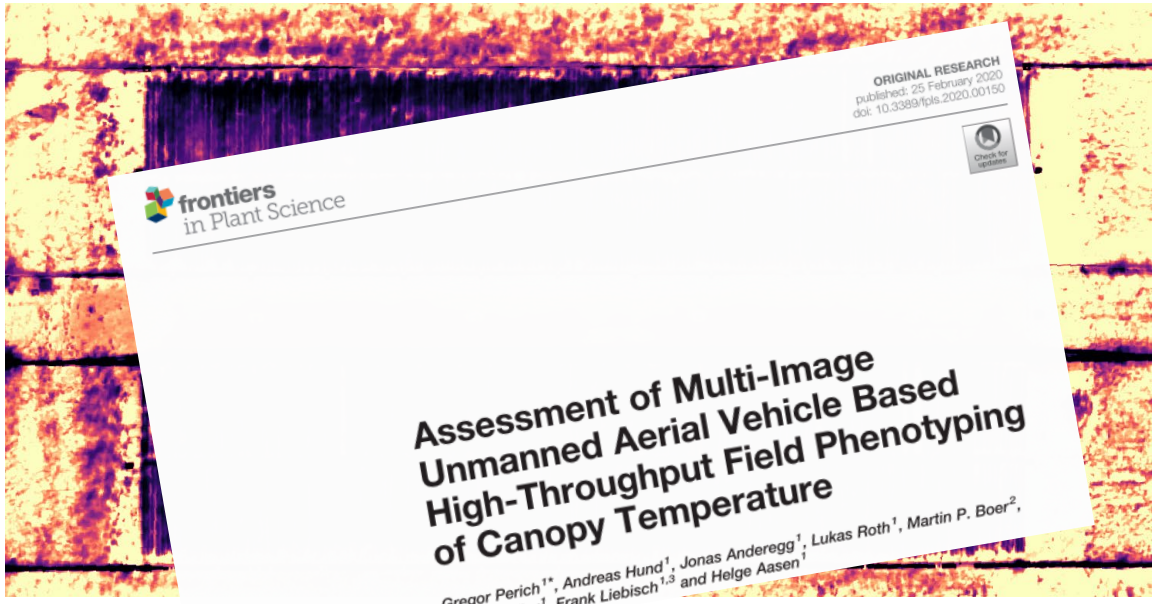


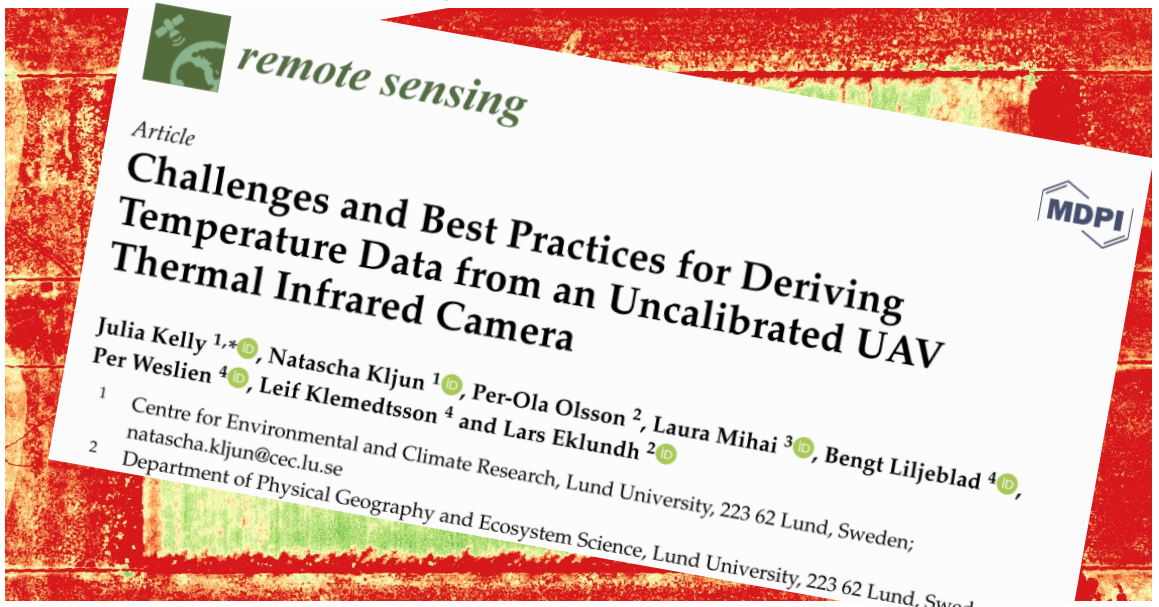
Overall results

Thermal measurements:
- No early symptoms
- No treatment x genotype
- Low genotype repeatability
- Fine correlation to genotype yield

Vegetation indices:
- NDVI and nExG best, treatment effect from 2 June (tiny difference)
- nExG late treatment x genotype
- nExG (and NDVI) higher genotype repeatability

Overall:
- Surface roughness problematic
- Facility + soil surface problematic
- Single rows difficult
- Stay-green interesting – both RGB and MS; Thermal challanging
- 2020 data being analysed now!!





Some main conclusions of the Ph.D.

- RGB cameras are reliable, and camera effect most likely overestimated in breeding – camera setup IMPORTANT
- Light during flight need attention, fly high!
- Cheap consumergrade UAVs add value – lot's of applications, however need finetuning
- Include spectral correction if possible during repeated flights, however no need if single campaigns. Stick to the same camera.
- Multispectral needs to become cheaper and higher resolution, however have advantages for some purposes
- Thermal imaging have potentials, however so does stay-green - multisensor
- First step = validation of UAV done! Next step: How to use data and variation…not yet unfolded (Reynolds et al 2020 is inspirational)

Thank you for your attention

- Thank you to enthusiastic partners and colleagues

UNIVERSITY OF COPENHAGEN

- **Jesper Rasmussen**
- **Fulai Liu**
- **Eva Rosenqvist**

- **Svend Christensen**

- **Signe Jensen**
- **Jesper Cairo Westergaard**
- **Simon Fiil Svane**
- **Kristian Thorup Kristensen**
- **Mira Arpe Bendevis**
- **Saiful Azim**
- **Jon Nielsen**
- **Kasper Jakob Jensen**
- **Tomke S. Wacker**

- **All at CROP SCIENCE**

Jesper Svensgaard
Mail: jsv@concito.dk
Mobile: +45 27205024