ESA-MOST 2017 Dragon 4 Symposium

FIELD-BASED HIGH-THROUGHPUT PHENOTYPING (FBP) IN CROP BREEDING USING UAV PLATFORMS

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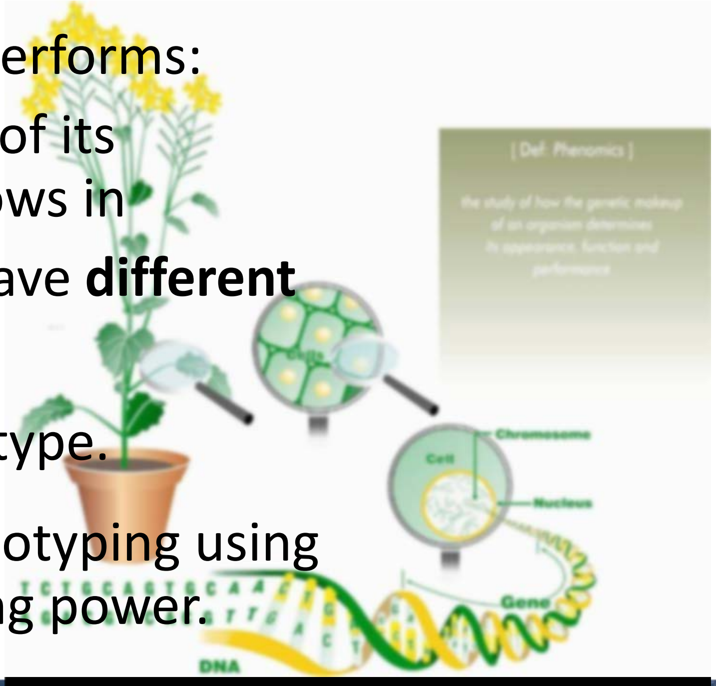
Kobenhavn, DANMARK

What is crop phenotype?

Phenome = Genome X Environment

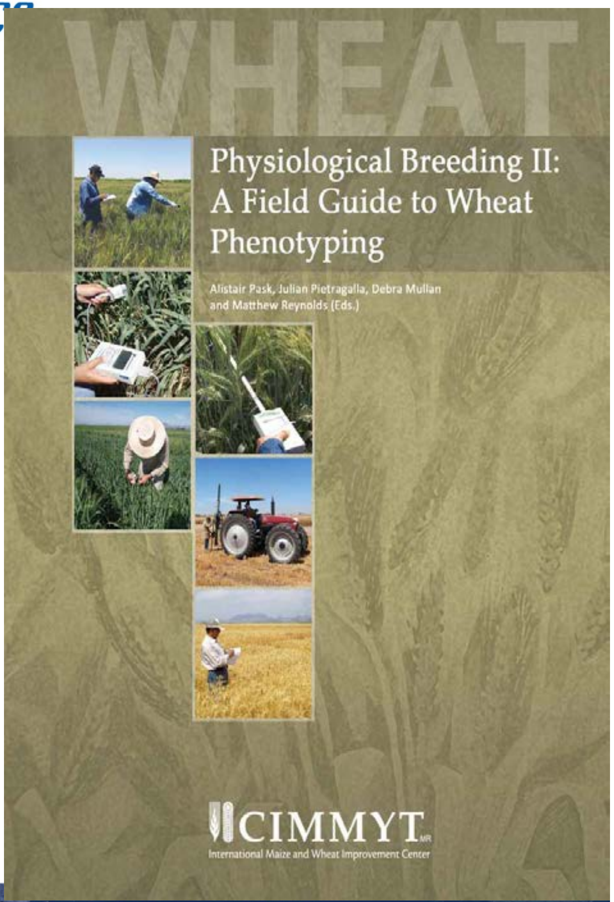
- A crop’s **phenotype** is how it looks and performs:
  - a crop’s phenotype is a combination of its genotype and the environment it grows in
  - crops with the **same** genotype can have **different** phenotypes.
- **Phenotyping** is analysing a crop’s phenotype.
- **Phenomics** is a way of speeding up phenotyping using high-tech imaging systems and computing power.



Phenotype: bottleneck of molecular breeding

- *135 million* sequence data in traditional GenBank data store which contains ***126.5 billion*** base pairs (*2011*);
- BGI China's amount of sequence data is about ***30PB*** every year;
- **Speeding up phenotyping and linking phenotype with vast amount of genotype is in urgent need, especially in the field phenotype.**

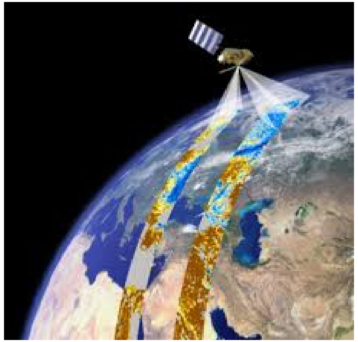
Robert T. Furbank , Mark Tester,Phenomics – technologies to relieve the phenotyping bottleneck, Trends in Plant Science， 2011



CID = carbon isotope discrimination; NDVI = Normalized difference vegetation index; TE = transpiration efficiency.

Key: Most typical time to take measurements; Measurements taken related to objectives; Not recommended for measurements taken on the same day where phenology range >5 days, or during senescence

Remote Sensing Platforms for High Throughput Above Ground Phenotyping



"Traditional" Spacecraft

Constellations of Small Satellites

Proximal Platforms

Manned Aircraft and UAV

UAV as an airborne Phenotyping Platform

Justification:

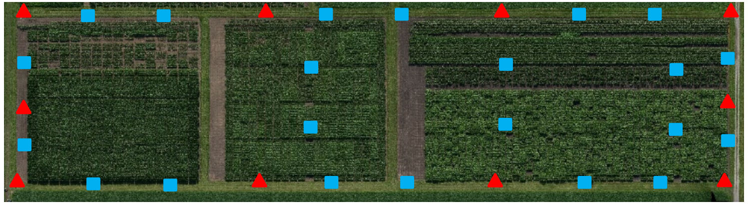
- In-field monitoring is expensive and access is limited during most of the growing season.
- Space-based sensors have fixed orbits and many are impacted by cloud cover
- Manned aircraft are costly and limited in availability.
- UAV can provide low cost information “on demand” for targeted problems.

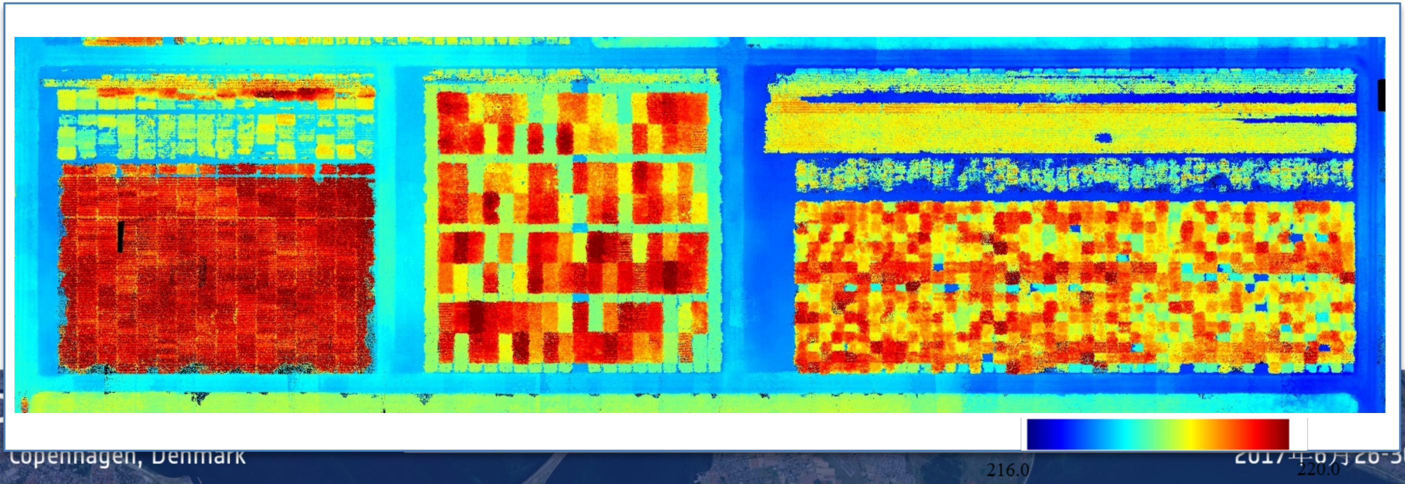
Government agencies, universities, commercial companies are all players

Remote Sensing for Phenotyping vs Crop monitoring: How is it different?

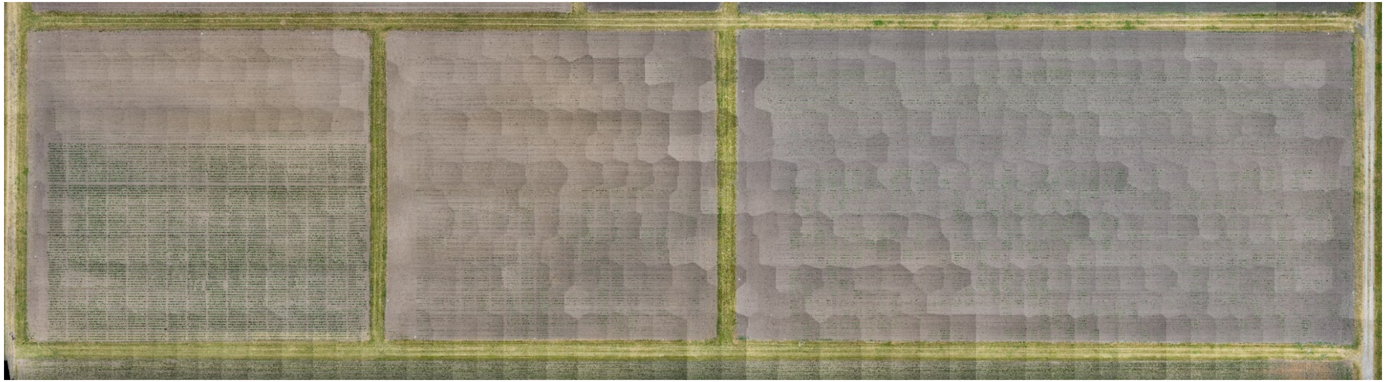
Improved positioning required for multi-temporal acquisitions

- Surveyed targets provide improved positioning for frame cameras whose positioning is determined by autopilot with consumer grade GPS/IMU





RGB-based Orthophoto June 13, 2016



RGB-based Orthophoto June 21, 2016

RGB-based Orthophoto June 30, 2016

RGB-based Orthophoto July 15, 2016

RGB-based Orthophoto July 19, 2016

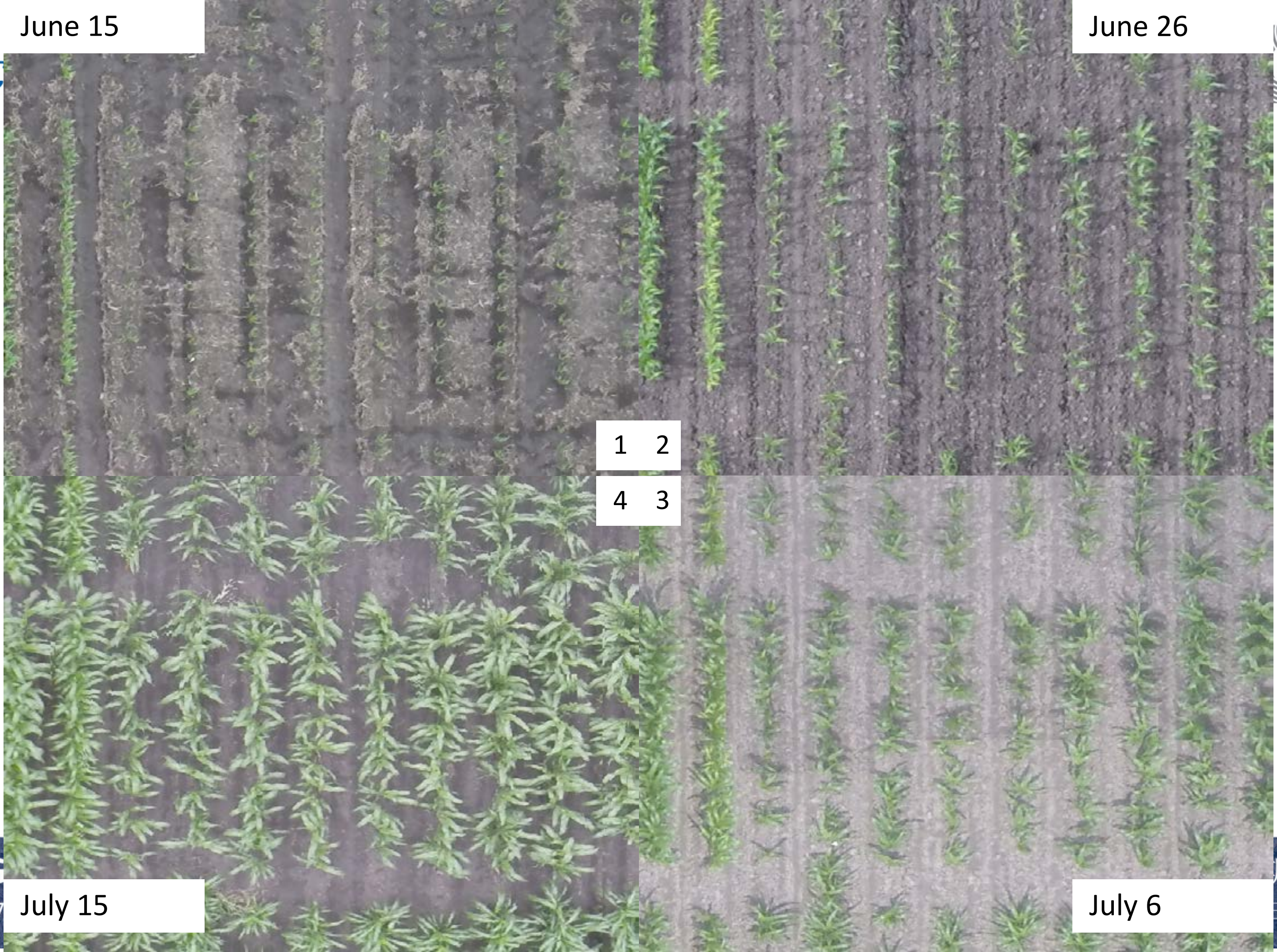
RGB-based Orthophoto July 27, 2016

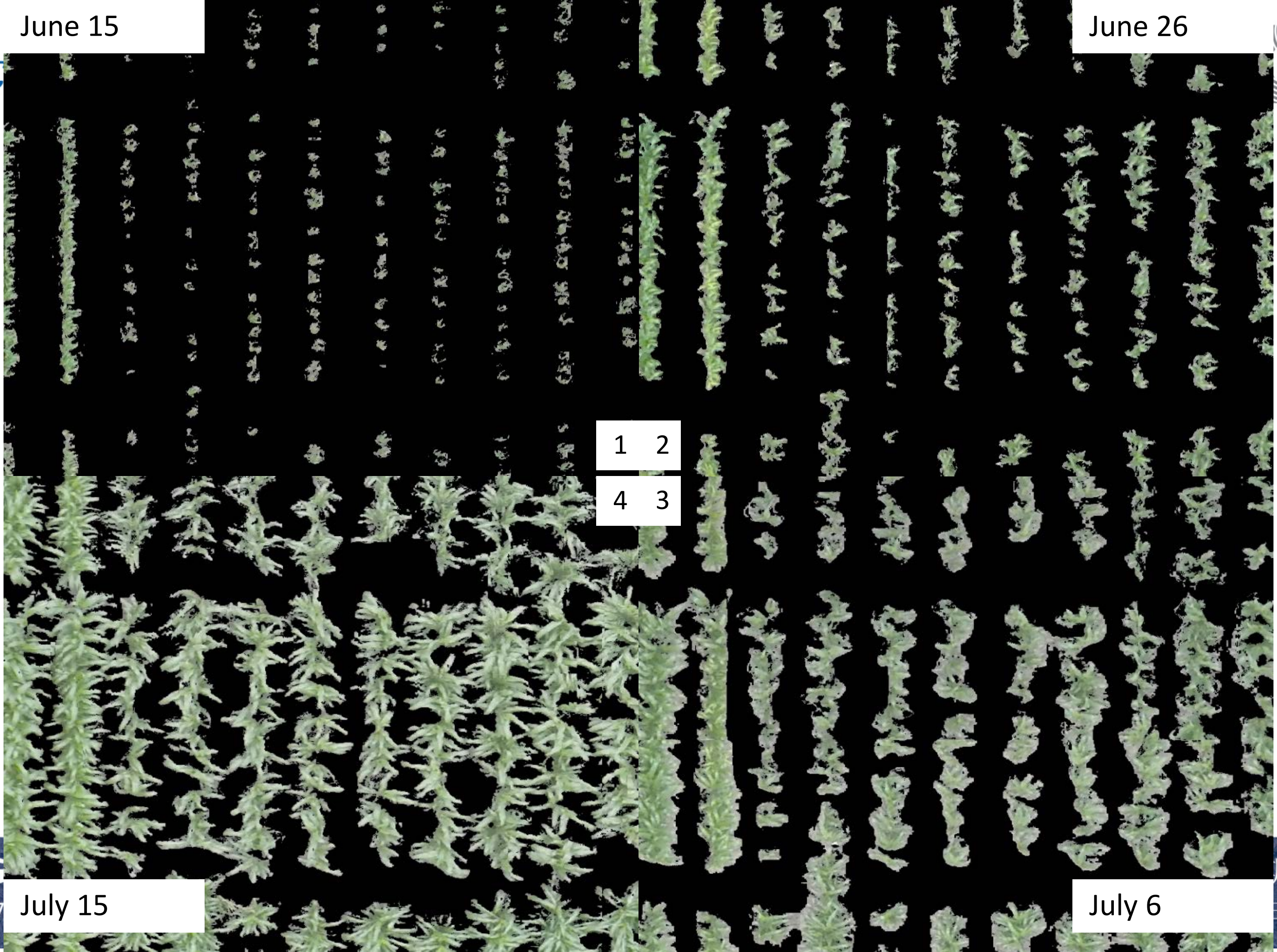
RGB-based Orthophoto August 9, 2016

Pre-lodging

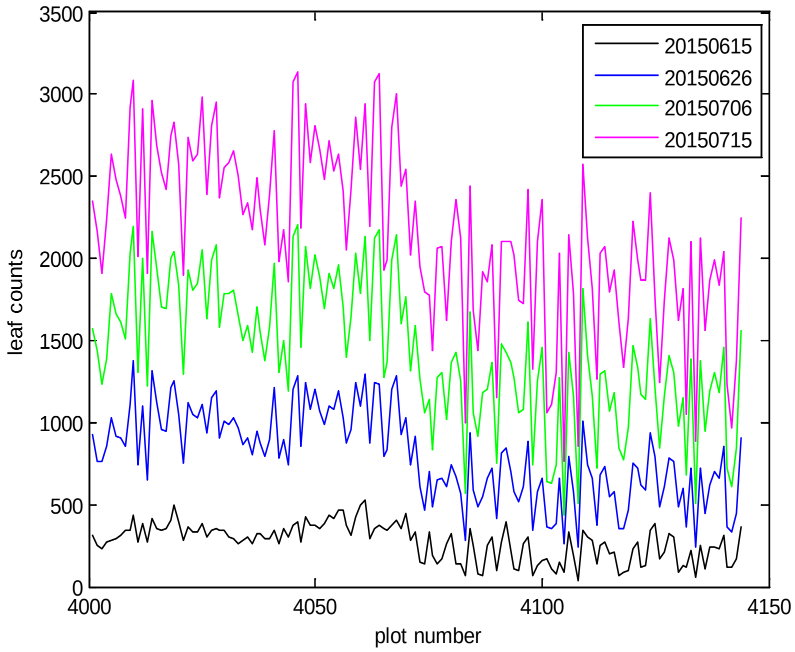
RGB-based Orthophoto aug 17, 2016

Post-lodging


June 15
June 26
1 2
4 3
July 15
July 6

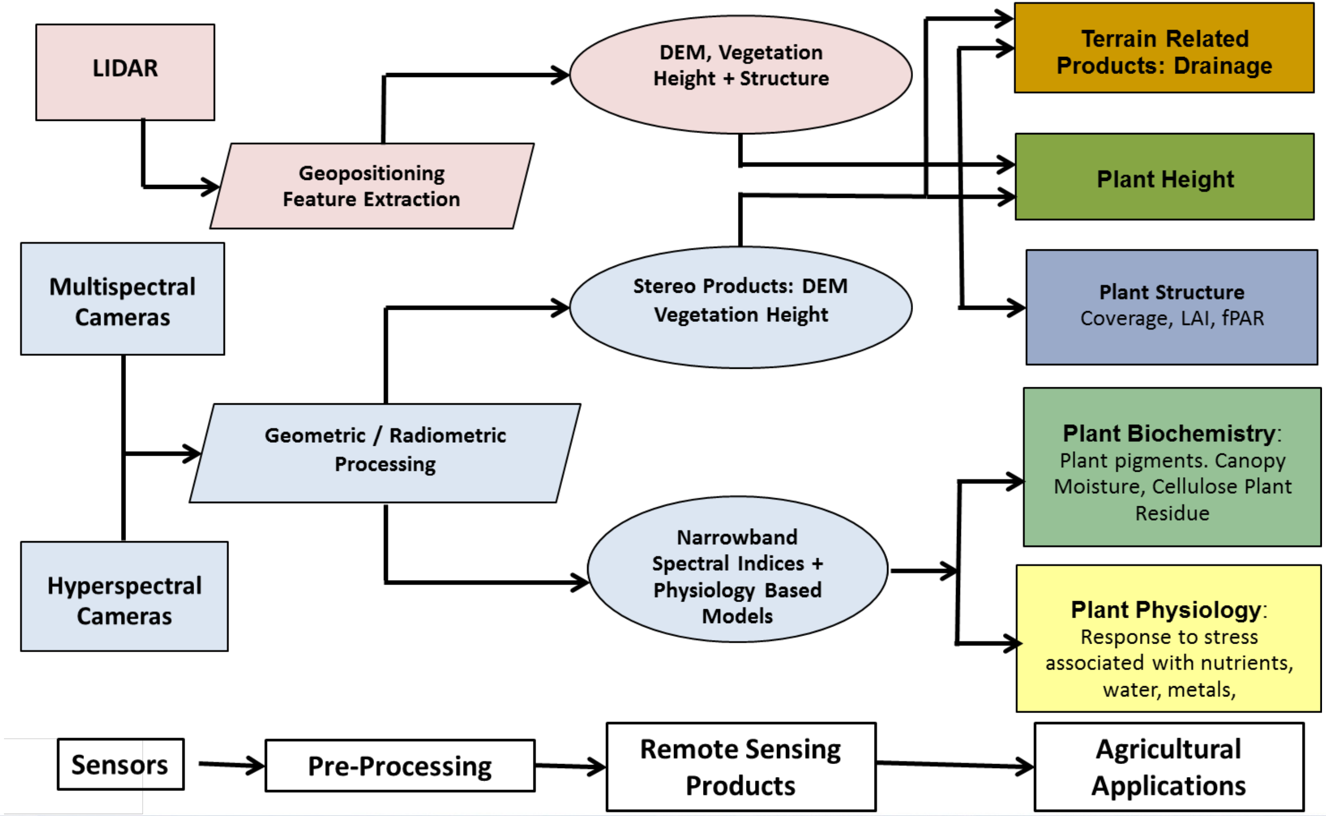

June 15
June 26
1 2
4 3
July 15
July 6

Accumulated Leaf Counts Over Time

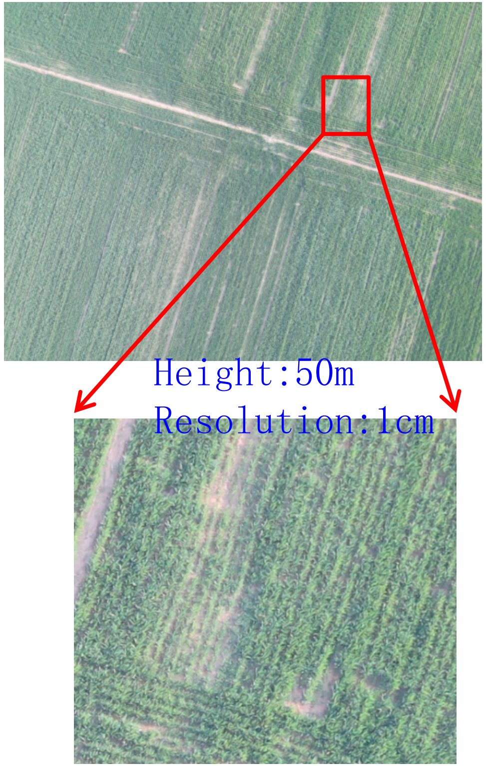


Average	20150615	20150626	20150706	20150715
Accumulated Leaf counts	271.9	802.8	1431.7	2146

Workflow： Remote Sensing Inputs for Above Ground Phenotyping

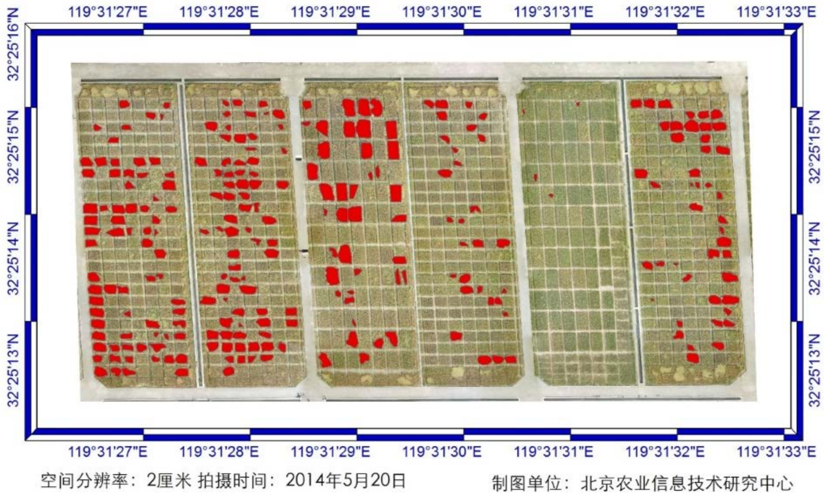


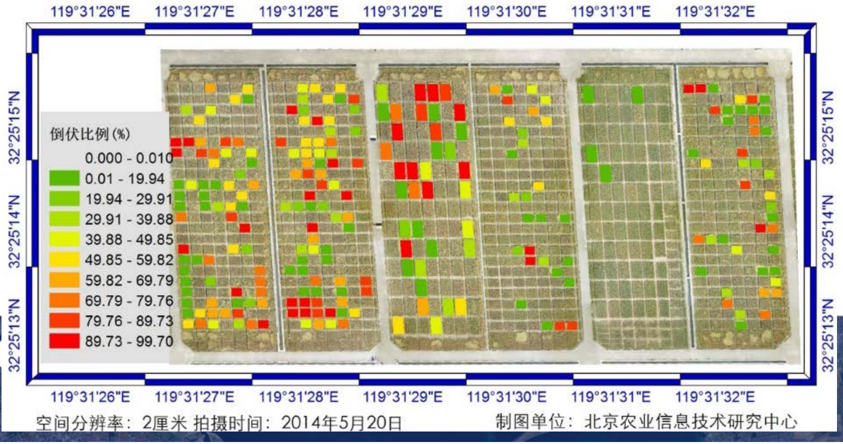
■HD camera： Can be used to map orthophoto in large scale



Pixels:4000*5000, Zoom:35mm , Weight:<500g , GPS supported

Crop lodging area monitoring- wheat





- Lodging area and distribution

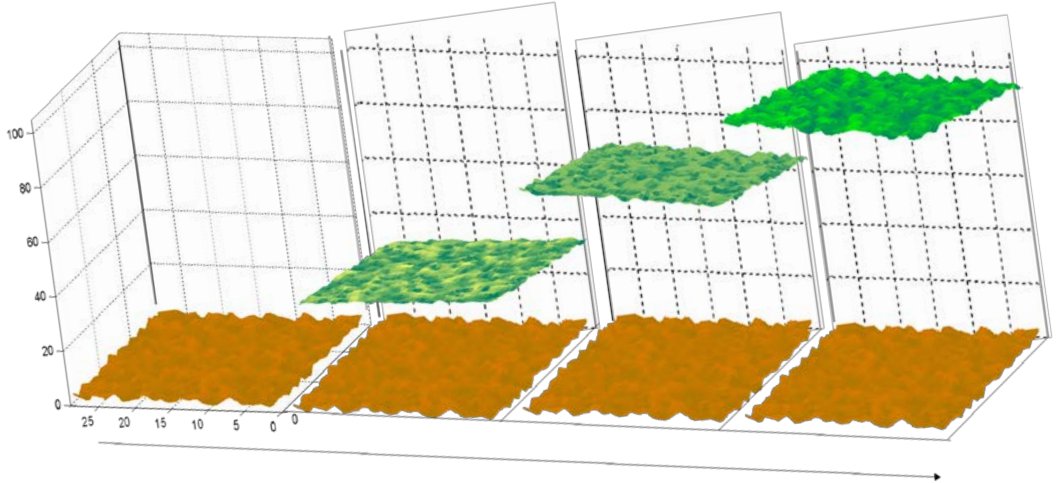
The lodging region segmentation was identified by image recognition method according to the HD Orthophoto.

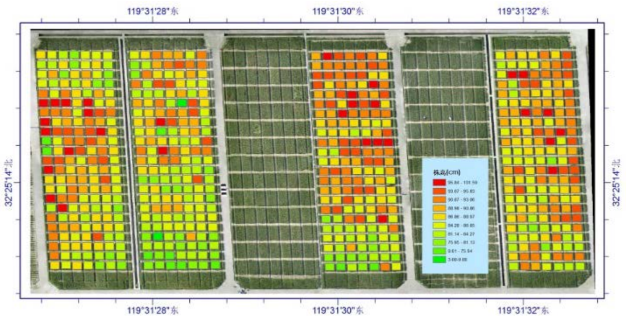
- Estimation of lodging proportion

To estimate the lodging proportion and apply classification on breeding plots.

Crop plant height estimation-winter wheat

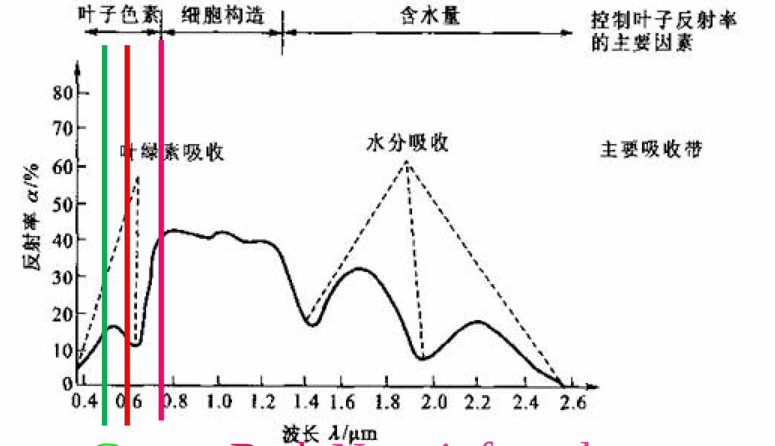
Combining high-definition digital images and POS data, DSM can be generated based on the point cloud data. The wheat height can be obtained by subtracting the DSM from ground elevation.





Wheat plant height

■ Multispectral camera: For extraction of NDVI, chlorophyll and biomass…



Green, Red, Near-infrared

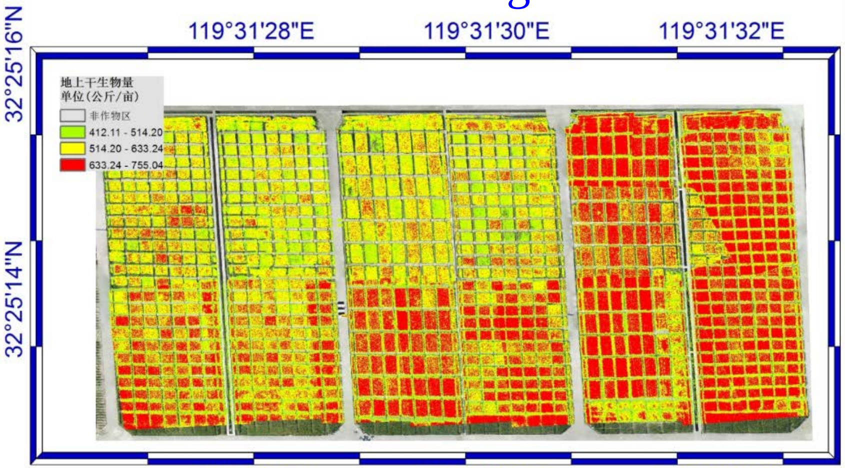
- Pixels: 2048x1536
- Focal length: 8.5mm
- Bands: 4
- Acquisition speed: 2-5 s per image

The wavelength range is 520nm-920nm, which is sensitive to crop chlorophyll, biomass and LAI. The sensor is mainly used for detecting the status of vegetation growth and coverage.

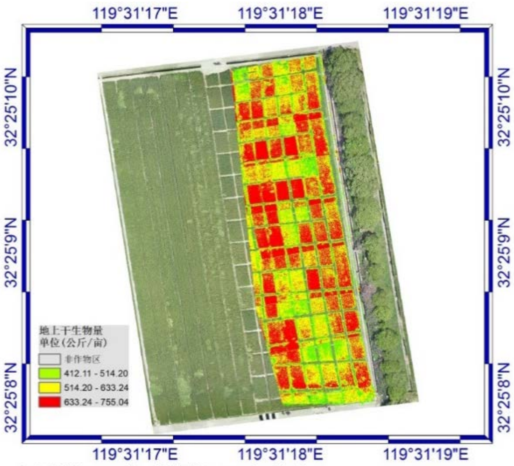
Biomass and LAI monitoring based on multispectral image

The biomass monitoring model is established by data from multiple growing stages. Here, the crop height as a key factor combination with hyperspectral imaging data to build model.

Monitoring of wheat above-ground biomass



空间分辨率：0.3米，拍摄时间：2014年5月8日 制图单位：北京农业信息技术研究中心



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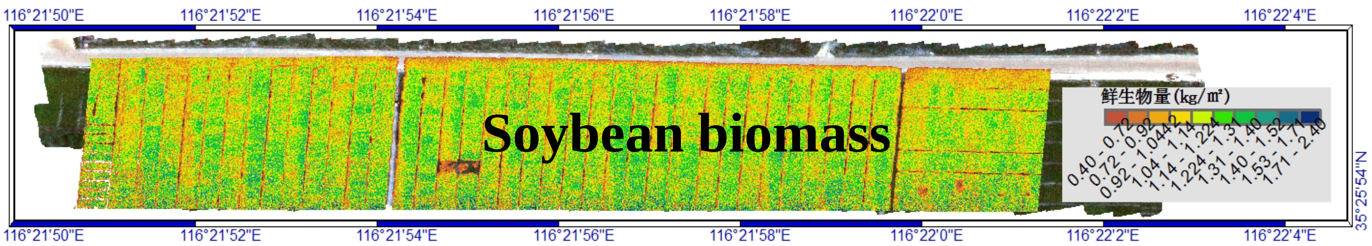
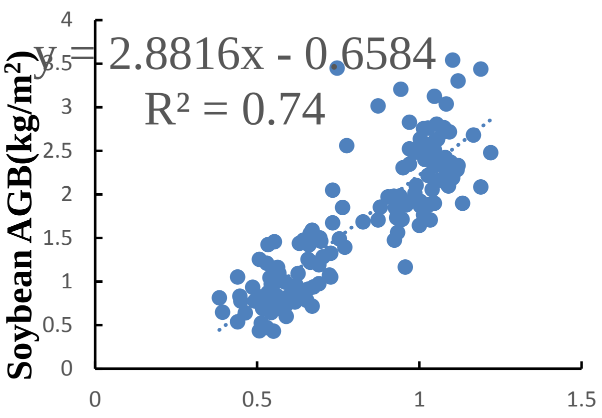
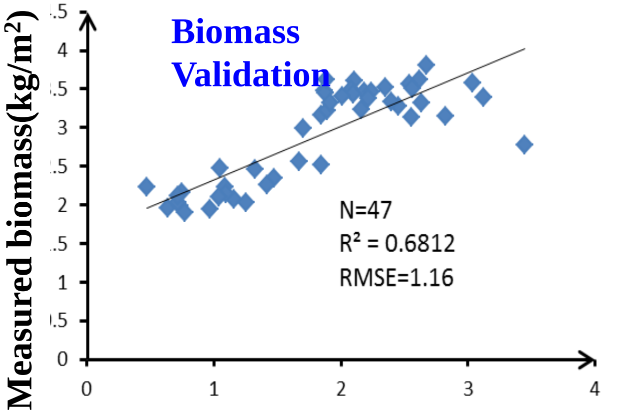
Biomass and LAI monitoring based on multispectral image

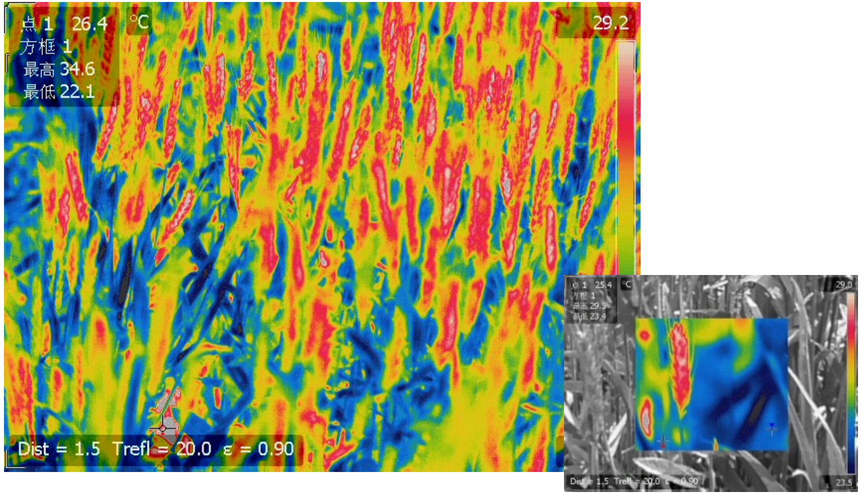






■Thermal Imager: Used for crop canopy temperature acquisition

Accuracy: ±2%
Pixels: 382×288
Angle: 38° ×29°
Frequency: 0~80Hz
Measuring range: -20~100℃
Wavelength range: 7.5~13μm

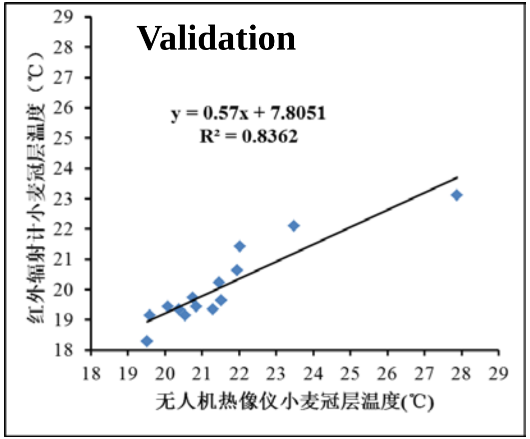


Crop canopy temperature can be obtained dynamically in video format. In which, each frame can be extracted both in image and text format.

Canopy temperature monitoring based on thermal image

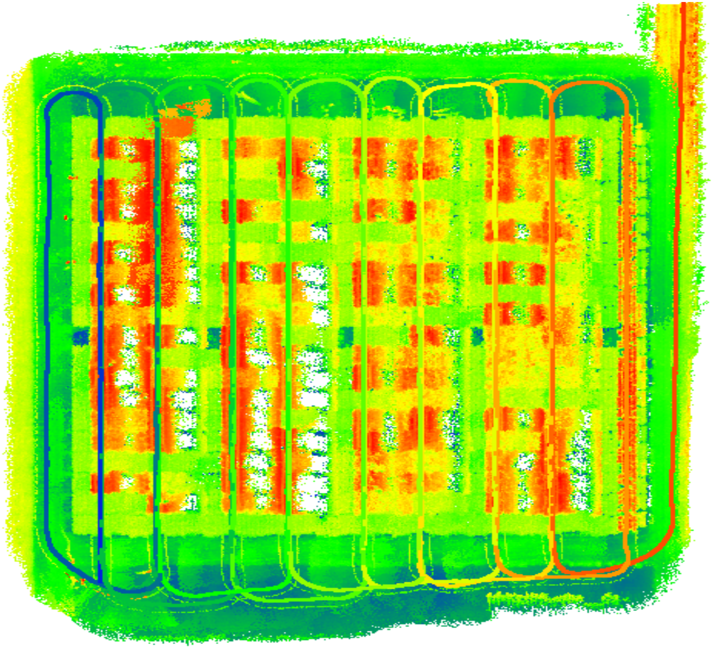
Average temperature map

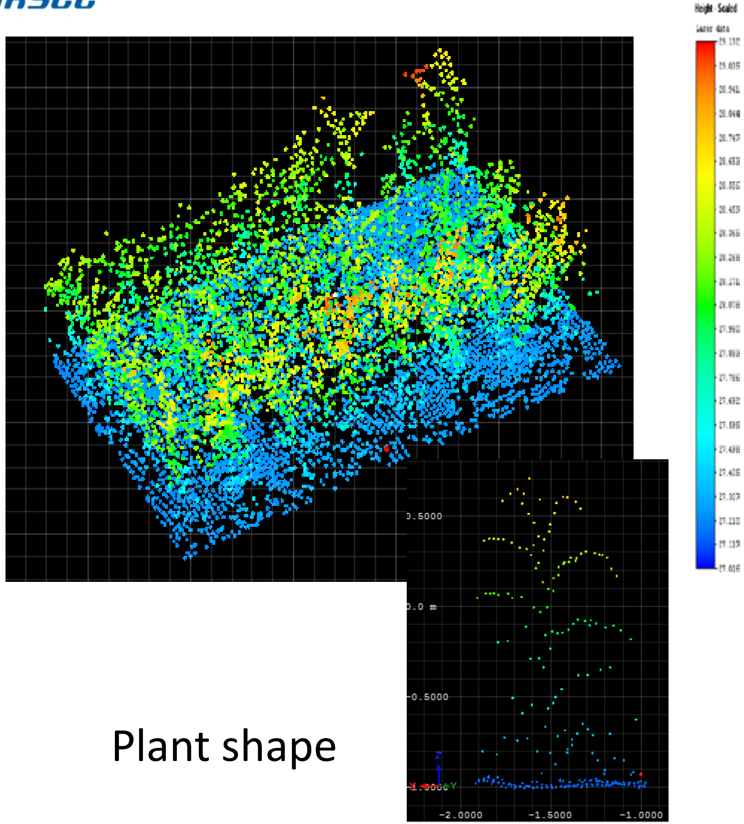
Temperature variation



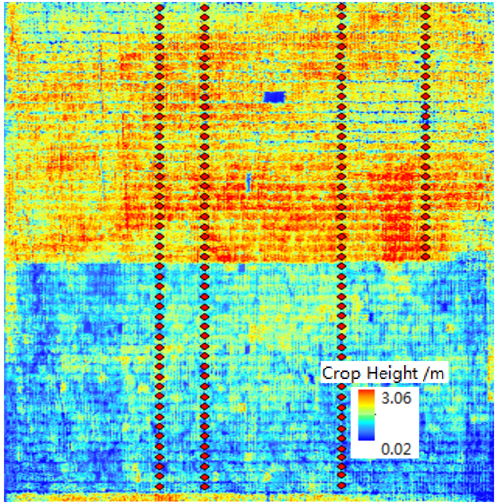
The results indicated that UAV thermal imager can be used to monitor the winter wheat canopy temperature with high accuracy (R^2=0.84, RMSE=1.77, n=14).

LiDAR for Phenotyping: Plant Height and “structure”

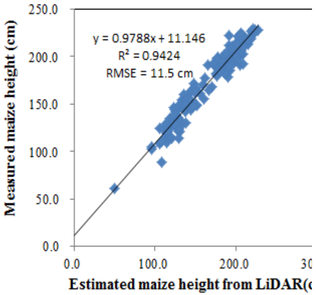


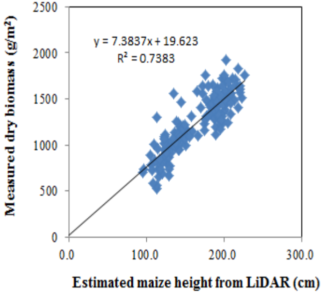


Plant shape

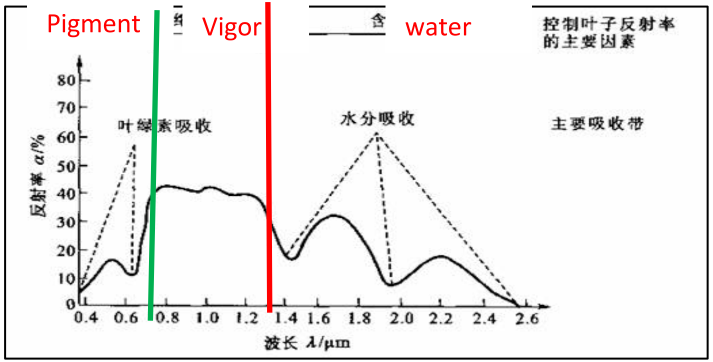


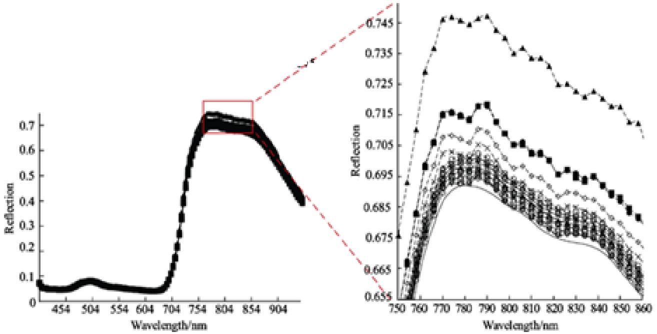
Maize height (m)

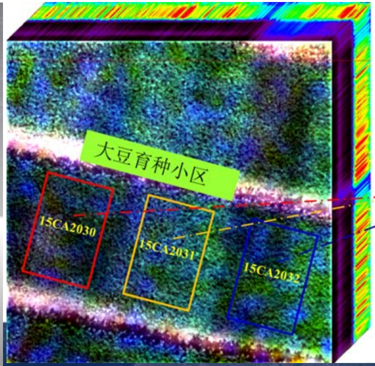


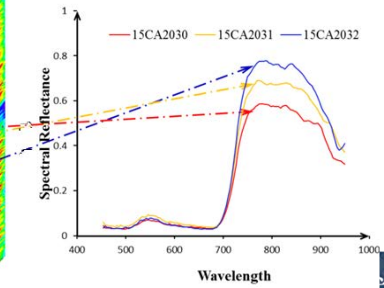


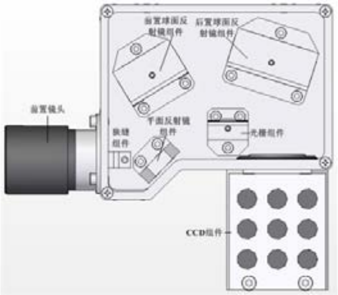
■Hyper-spectral Imager：Can accurately reflect the difference of spectral characteristics between crop breeding plots.



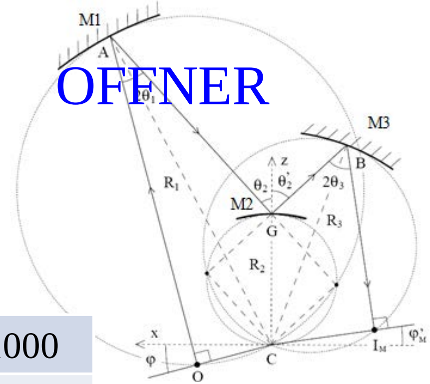








OFFNER



Wavelength range （nm）	400~1000
Spectral resolution（nm）	4@500 nm
Scanning speed（lines，images/s）	15-60
Push broom linewidth（m，10m away）	8
Pixel Resolution（m， 10m away）	0.004
focal length（mm）	25
FOV（° ）	20
Weight（g）	915

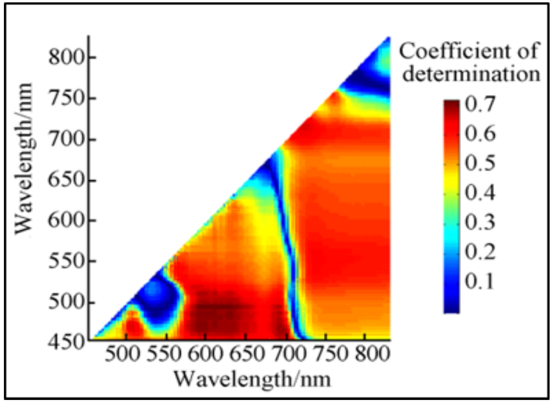
Spectral imaging :OFFNER reflective imaging spectrometer

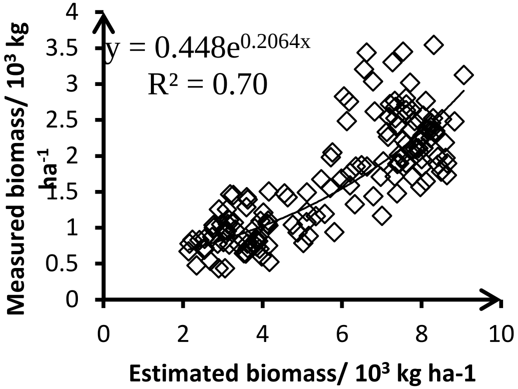
High spectral resolution, high SNR, Small size, light weight suitable for UAV platform

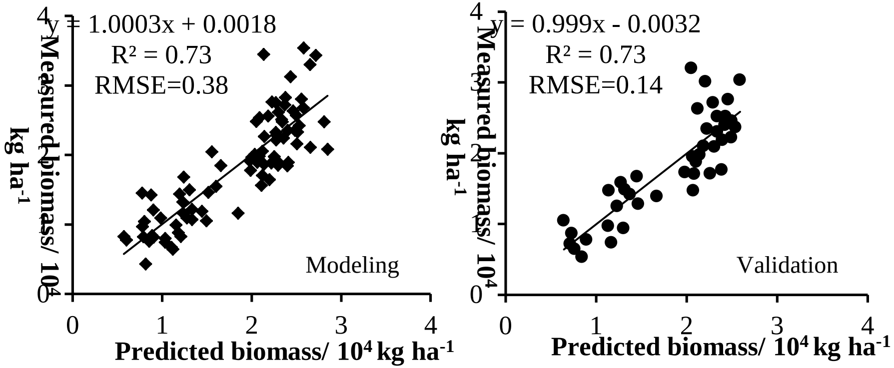
Retrieved soybean biomass

Table. Order of grey correlation degree between vegetation index and biomass

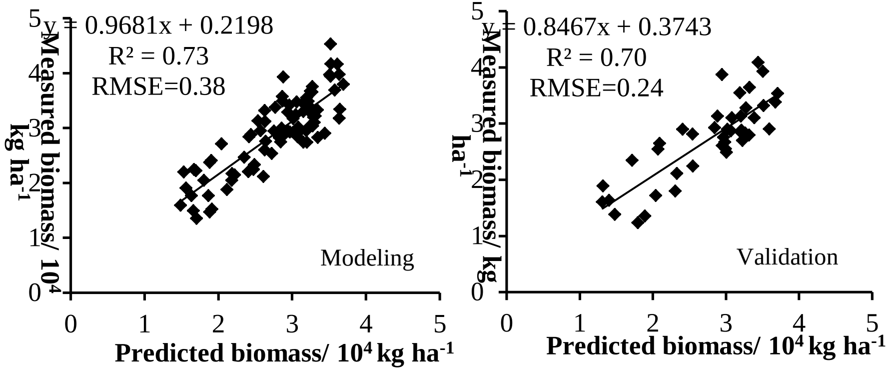
assessment index	grey correlation degree（ε=0.5）	order	assessment index	grey correlation degree （ε=0.5）	order
RVI	0.82	1	OSAVI	0.49	6
R_1	0.75	2	R_2	0.48	7
VOG1	0.64	3	DVI	0.484	8
NDVI	0.51	4	PRI	0.456	9
$NDVI_{705}$	0.50	5			







Flowering and podding



Filling and maturity

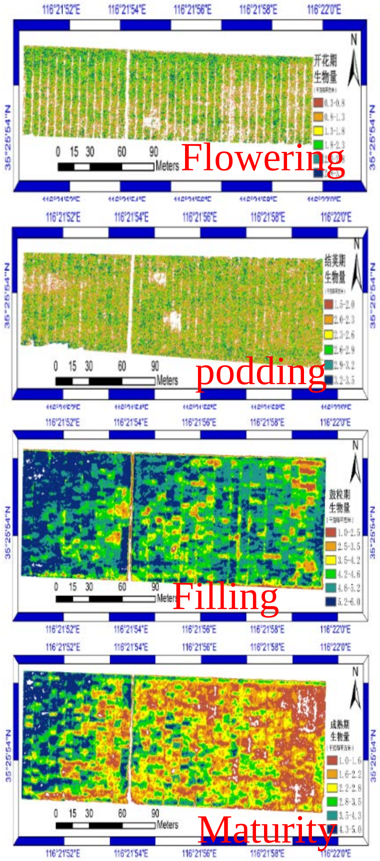


Fig. 1 Yield prediction based on NDVI of R5

Function type	Sensitive band combination 1 (nm)	Sensitive band combination 1 (nm)	Sensitive band combination 2 (nm)	Sensitive band combination 2 (nm)
	695-1350	503-713	1569-1793	577-696
Linear	0.000-0.692		0.455-0.604	
Power	0.520-0.709		0.471-0.625	
Exponential	0.515-0.711		0.466-0.627	

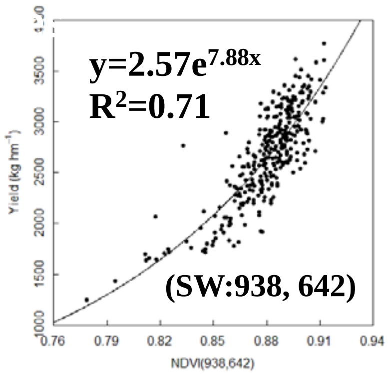


Fig. 2 Yield prediction based on NDVI of multi-growth stages

Growth stage	Regression equation	Model test	Model parametric test x_1	x_2	x_3	Intercept	R^2	RMSE
R2,R5	$y=e^{0.39+1.39x_1+7.17x_3}$	P<0.01	0.39**		1.39**	7.17**	0.728	249.47
R4,R5	$y=e^{-2.01+4.87x_2+6.20x_3}$	P<0.01		-2.01**	4.87**	6.20**	0.751	237.32
R2,R4,R5	$y=e^{-2.16+1.02x_1+4.44x_2+5.82x_3}$	P<0.01	1.02**	4.44**	5.82**	-2.16**	0.760	232.69

Note: R2: Flowering; R4: Podding; R5: Pod filling

$y=e^{-2.16+1.02x1+4.44x2+5.82x3}$

UAV-based crop phenotyping in breeding

What can we measure now?

- Canopy height
- Leaf color
- Chlorophyll
- Lodging area
- N content
- Canopy temperature
- powdery mildew
- Biomass
- LAI
- Yield

What are we working on?

- Increasing the precision and replication of retrieving models

- Fusion of spectrum and thermal data to predict yield

- Determining the strategies for phenotyping different crops

- Ready for providing service to breeders for field phenotyping

Published Journal Papers

No	Title	Journal	
1	Retrieving Soybean Leaf Area Index from UnmannedAerial Vehicle Hyperspectral Remote Sensing:Analysis of RF, ANN, and SVM Regression Models	Remote Sensing,2017	SCI
2	Geometric Correction Method of Rotary Scanning Hyperspectral Image in Agriculture Application	Remote Sensing,2017	SCI
3	Comparison of three regression methods for the winter wheat biomass estimation using hyperspectral data	Remote Sensing,2017	SCI
4	Unmanned aerial vehicle remote sensing for field-based crop phenotyping: Current status and perspectives	Frontiers in Plant Science ,2017	SCI
5	The DOM Generation and Precise Radiometric Calibration of A UAV-mounted Miniature Snapshot Hyperspectral Imager	Remote Sensing,2017	SCI
6	农用无人机多传感器遥感辅助小麦育种信息获取	农业工程学报,2014	EI
7	无人机多光谱影像辐射一致性自动校正	农业工程学报,2013	EI
8	无人机遥感解析田间作物表型信息研究进展	农业工程学报,2016	EI
9	基于无人机高光谱遥感的冬小麦叶面积指数反演	农业工程学报,2017	EI
10	基于无人机载高光谱空间尺度优化的大豆育种产量估算	农业工程学报,2016	EI
11	基于无人机数码影像的冬小麦叶面积指数探测研究	中国生态农业学报,2016	核心
12	基于无 人机搭载数码相机的小麦育种表型信息解析	中国种业,2016	核心
13	基于成像高光谱仪的大豆叶面积指数反演研究	大豆科学,2016	核心
14	基于无人机载LIDAR数据的玉米涝灾灾情评估	中国农业科学,2016	核心

Conclusion and Summary

1. UAV remote sensing technology is a good supplement for airborne, satellite remote sensing and ground observations.

2. UAV remote sensing has a huge potential values for large scale crop breeding to improve breeding efficiency.

3. It is also important that we should speed up data analysis and keep high estimation accuracy. Developing real time acquirement and processing system is needed in the future.

4. Determining the optimal methods, parameters and growth stages is very important for the crop phenotyping.

Acknowledgement

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Ruyang Zhang

MC

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