



**Development of robust Unmanned Aerial Vehicles (UAVs) -based
phenotyping solutions for field-growing rapeseed plants to
accelerate the yield improvement in rapeseed breeding**

Jiangwei Qiao

qiaojiangwei@caas.cn

Oil Crops Research Institute of the Chinese Academy of Agricultural Sciences
Wuhan, China

I. Brief introduction of rapeseed breeding in China

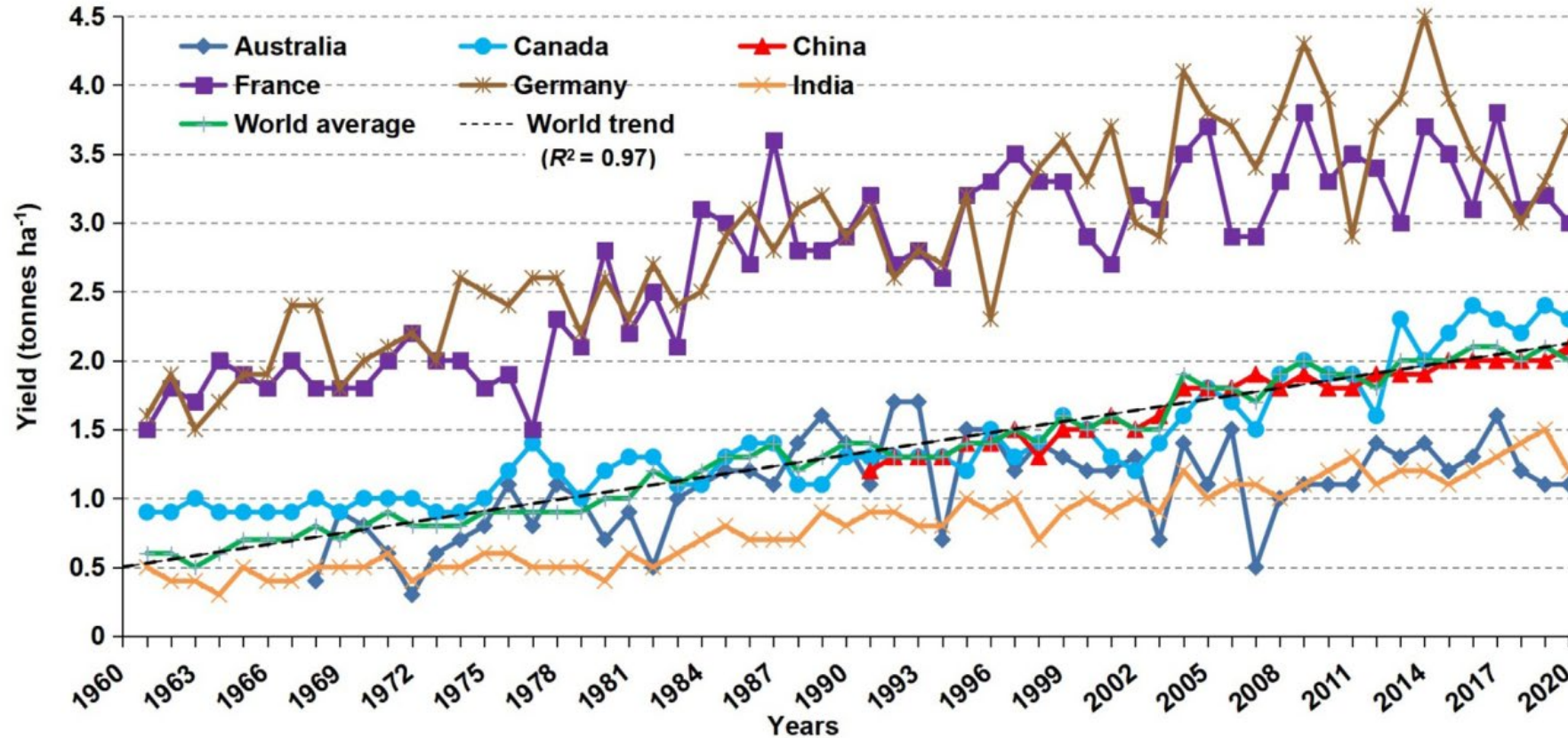
II. Introduction of Plant Phenotyping

III. Our explorative phenotyping solutions to high-yield rapeseed breeding

IV. Several case studies on field-growing rapeseed

V. Further studies/projects

I. Brief introduction of rapeseed breeding in China



Liu et al., 2022

- ✓ Seed yield per area stagnated or even decreased in the past ten years around the world;
- ✓ Rapeseed average yield level in China remains much lower.



I. Brief introduction of rapeseed breeding in China

- China import more than 65% edible oil materials in recent years.
- Rapeseed is the largest oil crop in China, produces approximately 50% of Chinese edible oil;

Major rapeseed breeding objectives to increase the total oilseed yield:

1. Improve the seed yield per area substantially:

Breeding elite varieties with much higher yield and stronger adaptability/resistance.

2. Enlarge the growing area:

e.g., Utilization of the winter-fallowed paddy fields, cold fields and barren fields.



To breed varieties with higher yield

Genotyping for
Genetic improvement

Phenotyping for growth monitoring
and yield estimation

Pyramiding of elite genes/qtls:

- ✓ Large silique (seed size, seed number);
- ✓ Plant architecture with high harvest-index;
- ✓ Abiotic resistance to lodging, ...;
- ✓ Biomass (photosynthesis);
- ✓ Nutrient utilization efficiency;
- ✓ Biotic resistance to sclerotiniose, ...;

Requirements of performance features:

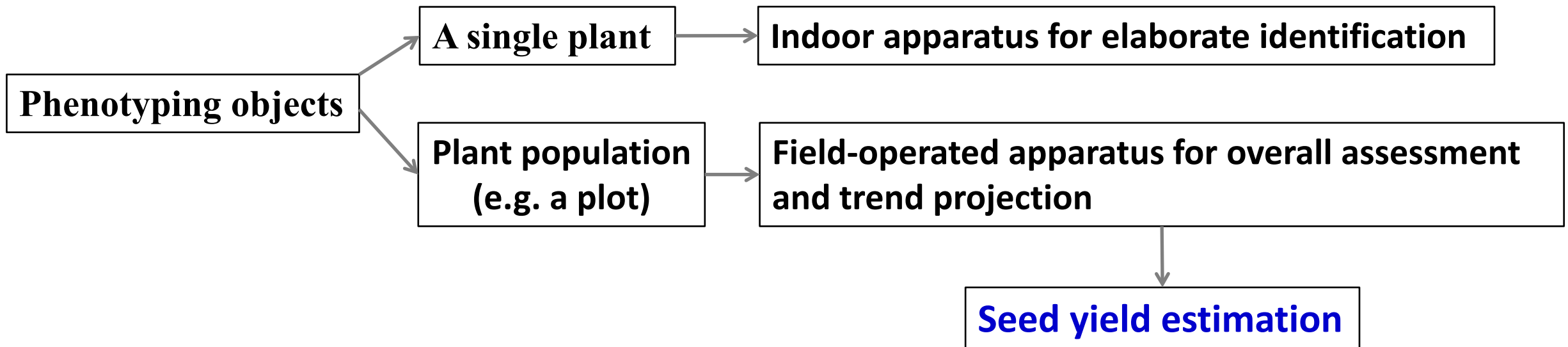
- ✓ high-throughput, accurate, robust and low-cost;
- ✓ Applicable to field-grown plants;
- ✓ Focus on seed yield, involve each key growth stages;
- ✓ Intelligentized (Deep Learning and integrated);

Germplasm studies and
Genetic dissection

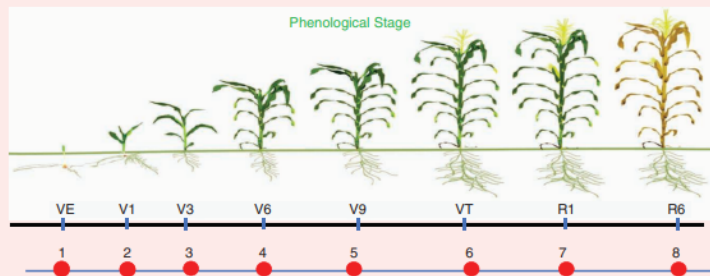
**Methods development based on
interdisciplinary cooperation**

II. Introduction of Plant Phenotyping

- Phenotype is expression of genotype, which is heavily influenced by the environmental factors;
- **Phenotype includes multiple aspects:** biomass, plant architecture, physiological status and resistance, ...;
- **Powerful high-throughput phenotyping depends on:** high-tech sensors, advanced robotics/flying platform, image processing systems, modeling analysis, ...;



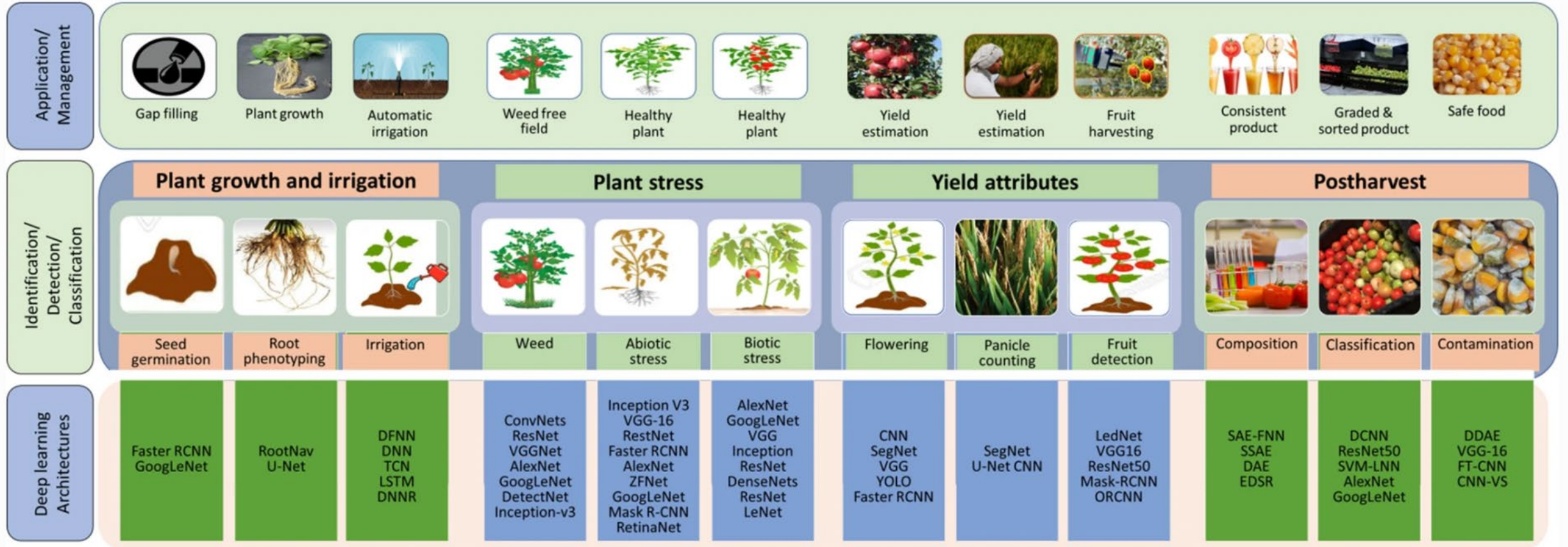
Ground and aerial phenotyping platforms carrying different sensors



	Counting 1 Plants	6 Tassel	8 Yield Components
Dynamic Monitoring	2 ← Crop Growth/Disease/Stress/Senescence/Structure/Phenology ... → 8		
Key Traits: GAI, FAPAR, Height, Anthesis, Chlorophyll and Nitrogen Content, Leaf Rolling and Angle, Canopy Coverage and Structure, Yield, Lodging			
	Dynamic Monitoring	2 ← Crop Growth/Disease/Stress/Senescence/Structure/Phenology ... → 8	
Key Traits: GAI, FAPAR, Chlorophyll and Nitrogen Content, Biomass, Water Content, Yield, Grain Quality, Lodging			
	Dynamic Monitoring	3 ← Crop Growth/Disease/Stress/Temperature ... → 8	
Key Traits: Canopy Temperature, Leaf Wilting, Water Content, Lodging, Leaf Rolling, Water Use Efficiency			
	Dynamic Monitoring	3 ← Crop Growth/Disease/Stress ... → 8	
Key Traits: Photosynthetic Status, Biomass, Water Use Efficiency, Light Use Efficiency, Nitrogen Use Efficiency, Yield			
	Dynamic Monitoring	3 ← Crop Growth/Disease/Stress ... → 8	
Key Traits: Chlorophyll Fluorescence, Biomass, Water Use Efficiency, Light Use Efficiency, Nitrogen Use Efficiency, Yield			
	Dynamic Monitoring	3 ← Crop Growth/Structure ... → 7	
Key Traits: Height, Leaf Angle, Lodging, Leaf Rolling, Biomass, Canopy Coverage and Structure, Yield			
	Dynamic Monitoring	2 ← Crop Growth/Structure ... → 7	
Key Traits: Height, Leaf Angle, Lodging, Leaf Rolling, Biomass, Canopy Coverage and Structure, Yield			

Aerial Phenotyping Platforms	Micro/ Nanosatellites	100–1,000 km	
	MAVs	100–5,000 m	
	UAVs	5–200 m	
Ground Phenotyping Platforms	Stationary Platforms	Ground Level 3	
	Phenomobiles	Ground Level 2	
	Phenopoles	Ground Level 1	

Deep Learning is a subfield of machine learning, in which computer systems learn tasks and identify patterns on their own with only limited training data. **Deep Learning has been widely applied in plant phenotyping.**



III. Design of our phenotyping solutions for rapeseed high-yield breeding



- Our research team (led by Prof. Hanzhong Wang) mainly focus on the **breeding of rapeseed varieties**, which are ecologically adapted to Yangtze river basin. The variety Zhuangshuang11 with high oil content, strong lodging resistance and strong adaptability, has been sequenced as reference genome and widely used as parents of hybrid breeding in China.



Zhongshuang11 (conventional)

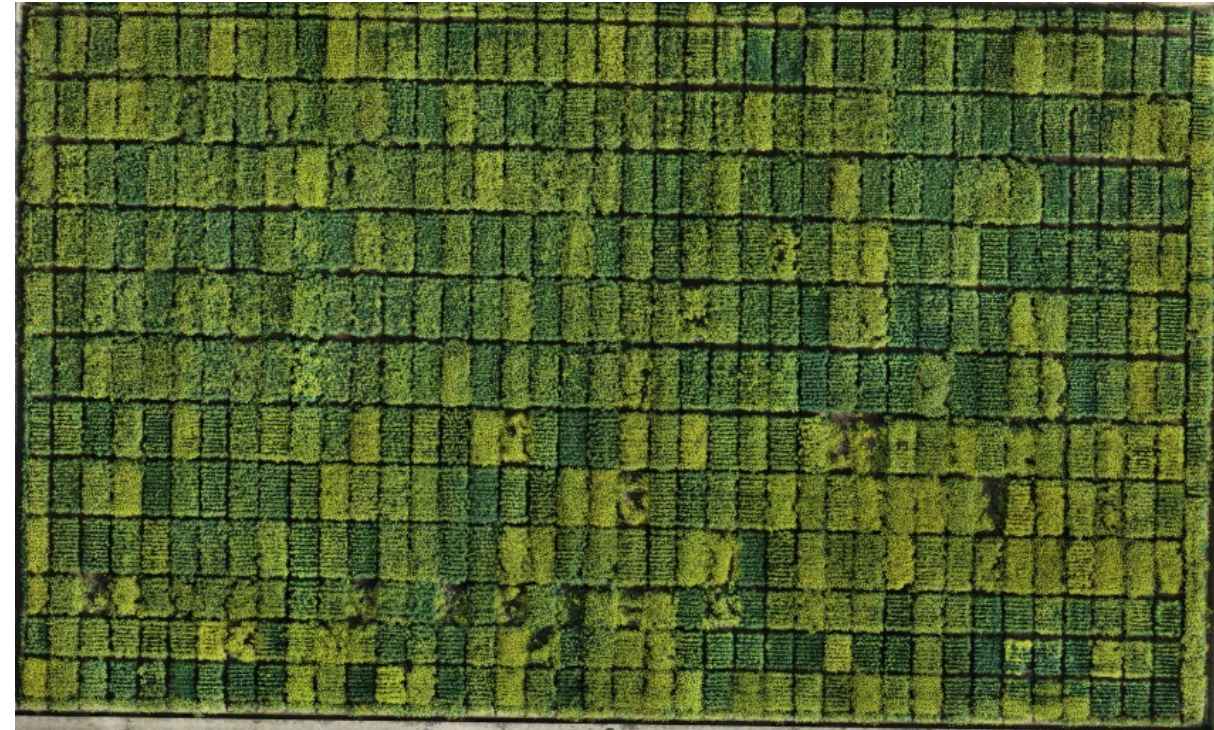
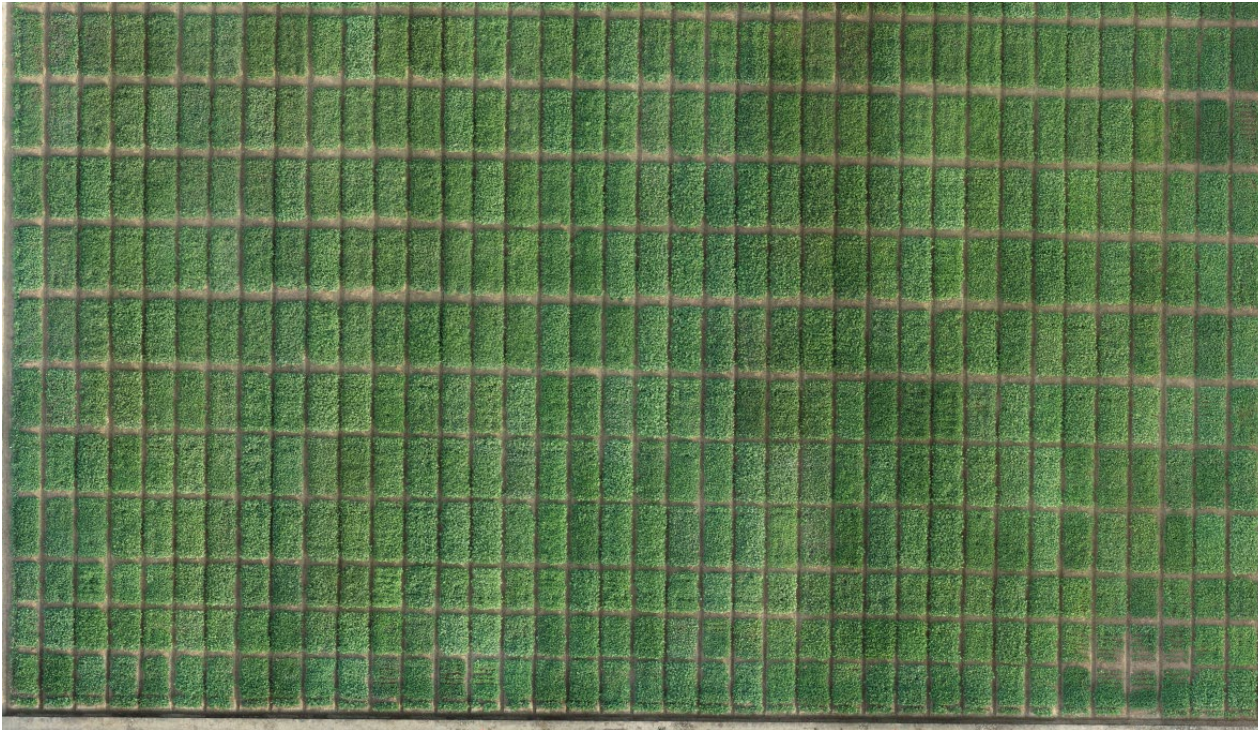


Zhongyouza19 (Hybrid)

III. Design of our phenotyping solutions for rapeseed high-yield breeding



- **Lack of accurate, convenient and high-throughput field-level phenotyping technologies** to monitor the growth status and predict the yield potential of a mass of breeding materials and hybridized combinations has become to be one of the biggest bottlenecks of crop breeding.



III. Design of our phenotyping solutions for rapeseed high-yield breeding



The seed yield shaping process of rapeseed:

Silique stage:

Seed yield:

- ✓ Total silique number/area
- ✓ seed number/silique
- ✓ seed weight

Flower stage:

Shoot branching:
inflorescence numbers and robustness

Seedling stage:

Total leaf photosynthesis

Corresponding phenotyping index:

Silique wall area index

flower richness:
Total inflorescence number/area

Leaf area index

III. Design of our phenotyping solutions for rapeseed high-yield breeding



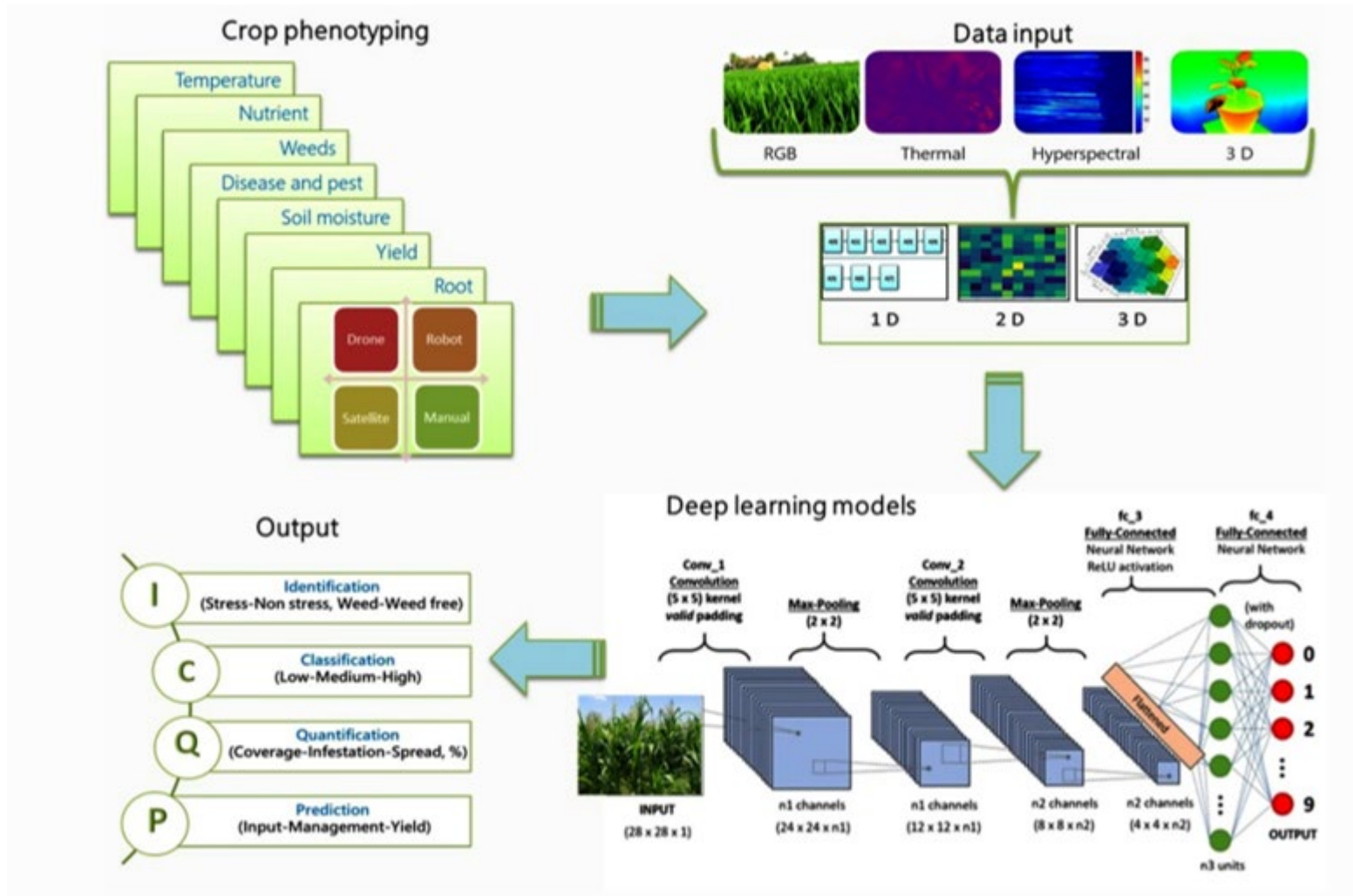
- The unmanned aerial vehicles (UAVs) aerial platforms with corresponding sensors were used to collect the digital image data;
- The airborne sensors mainly includes the following cameras: RGB, multispectral, hyperspectral, thermal and lidar system cameras;
- The ground manually-operated data collecting systems mainly include: Plant Canopy Analyzer (LAI-2200C), photosynthesis sensors (LI-COR 6800), Stereo Camera system (Artec Leo), general yield-related agronomy traits;



III. Design of our phenotyping solutions for rapeseed high-yield breeding

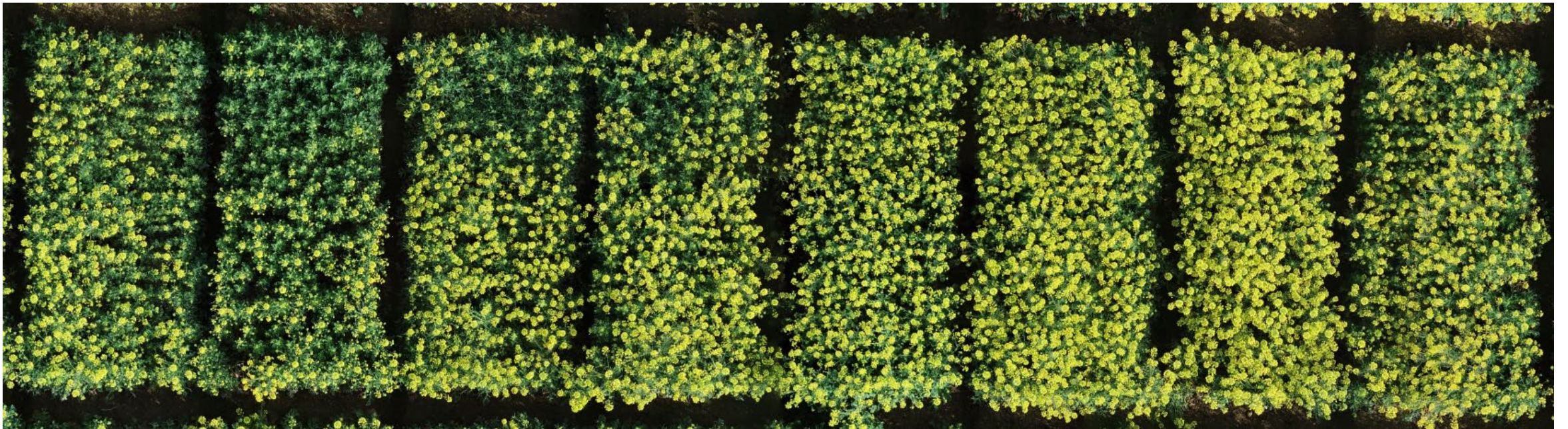


Flow chart representing image data processing and application:

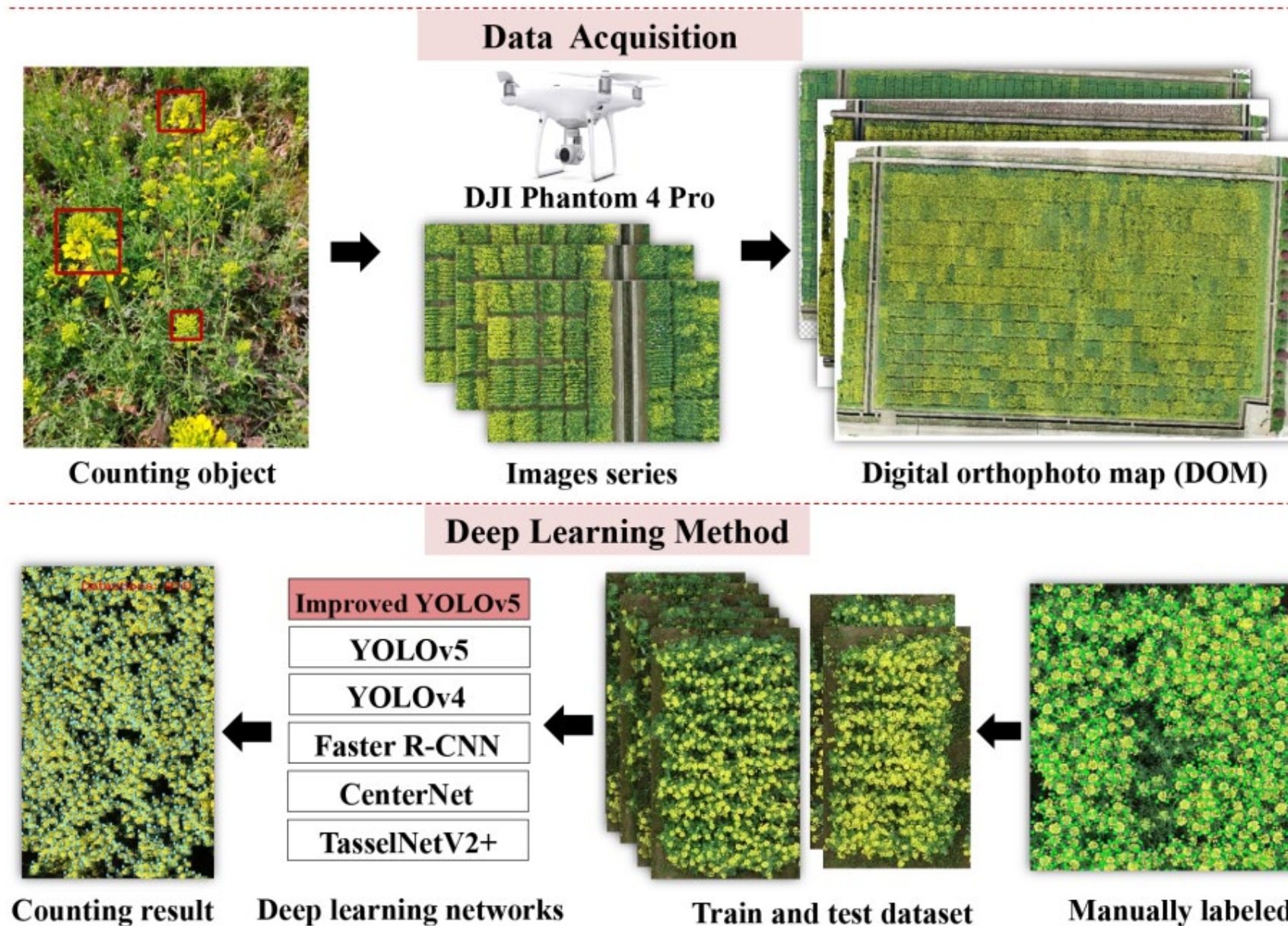


IV. A case study for Inflorescence richness estimation

- Flowering is a crucial developing stage for plants. Flowers develop on the main and branch inflorescences of rapeseed plants and then grow into siliques.
- **The seed yield of rapeseed heavily depends on the total flower numbers per area throughout the whole flowering period.**
- **The number of rapeseed inflorescences can reflect the richness of rapeseed flowers and provide useful information for yield prediction.**

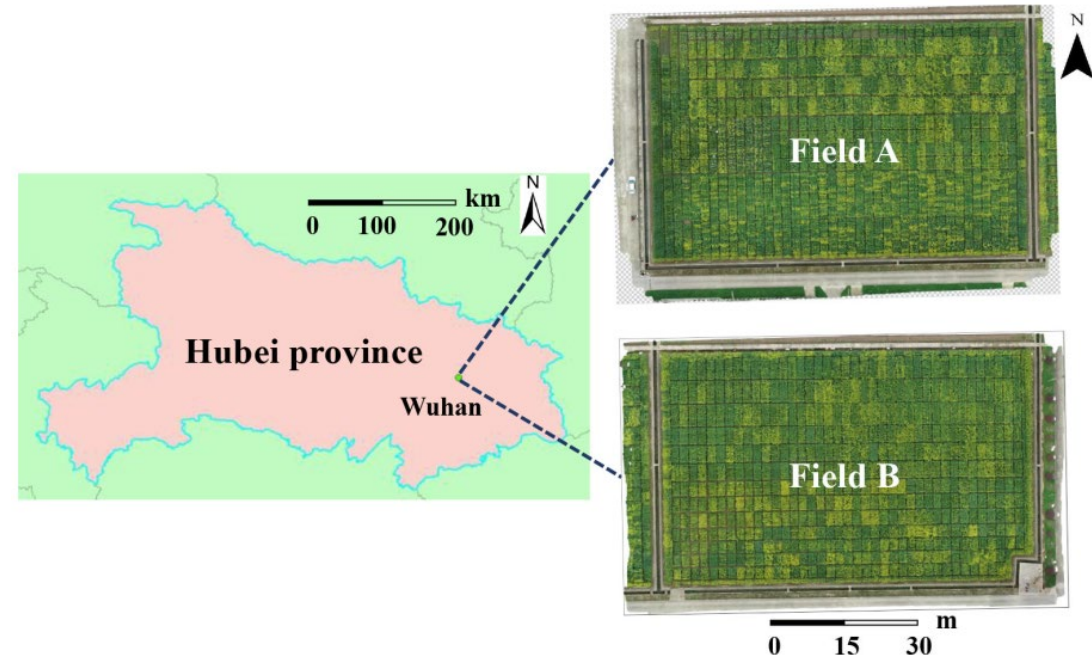


Data acquisition and processing:



Data acquisition:

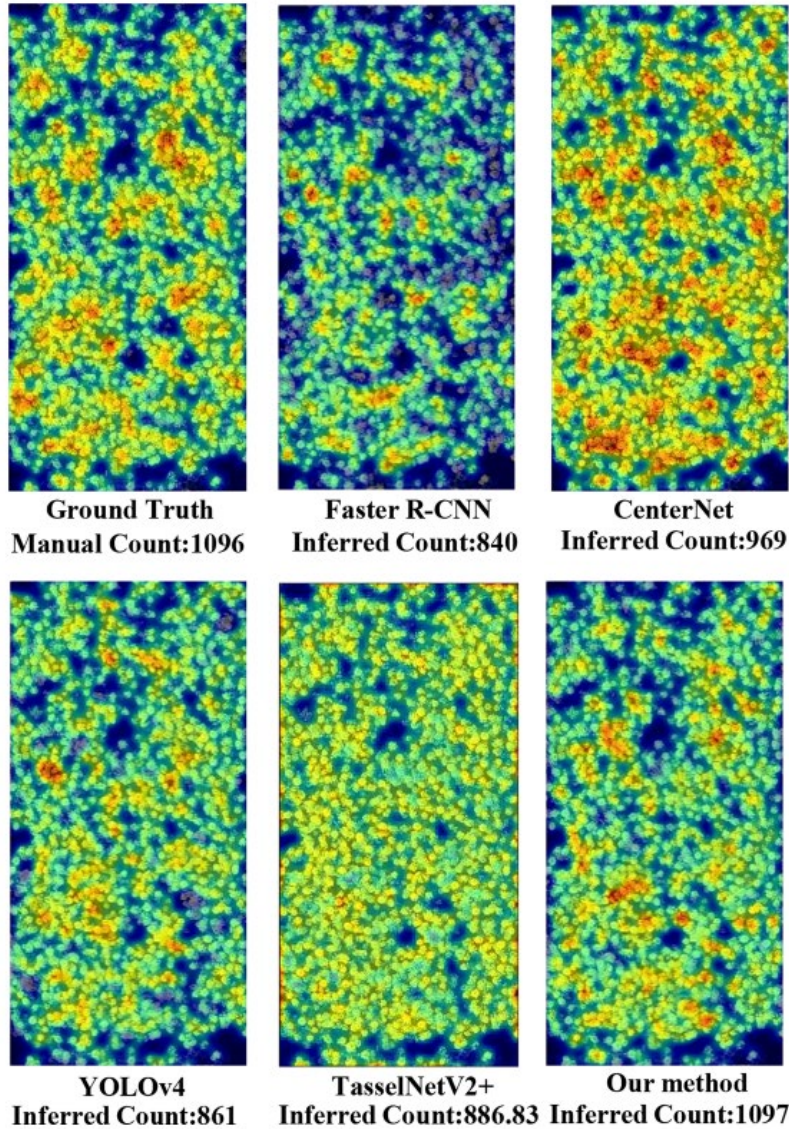
- ✓ DJI Phantom 4 Pro V2.0;
- ✓ **10-15 m flying height;**
- ✓ From February to April (across the whole flowering stage);



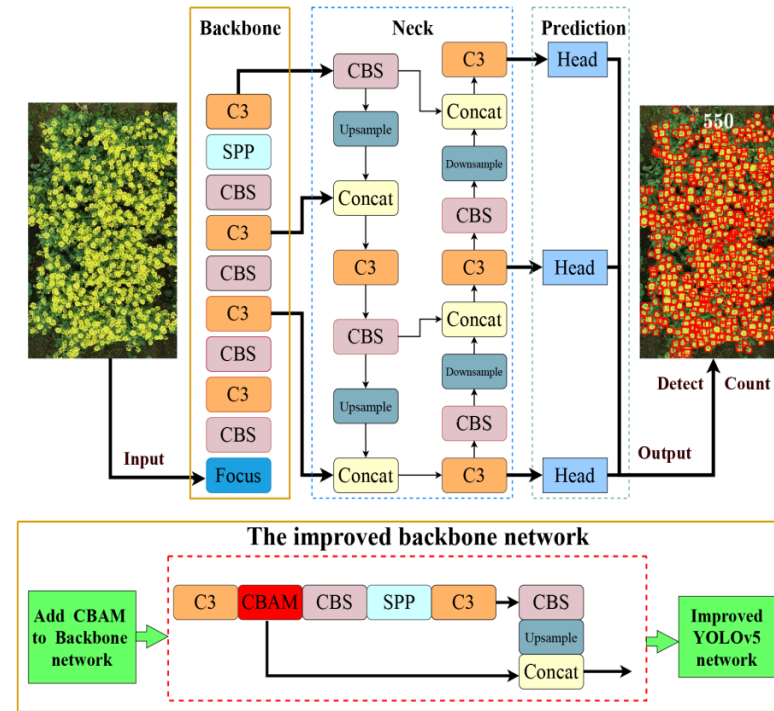
- ✓ **2021 spring: 6** flowering time points
- ✓ **2022 and 2023 spring: more than 12** flowering time points (every 3-5 days one time point)

Year	Acquisition dates	Flight altitude	Field	Temperature
	February 19	15m	Field A	12°C
	February 26	15m	Fields A and B	14°C
2021	March 3	10m	Fields A and B	21°C
	March 14	10m	Fields A and B	23°C
	March 22	10m	Fields A and B	24°C
	April 5	10m	Field A	15°C
2022	March 1	13m	Field B	20°C

Using the deep learning method to automatically count the inflorescence number :



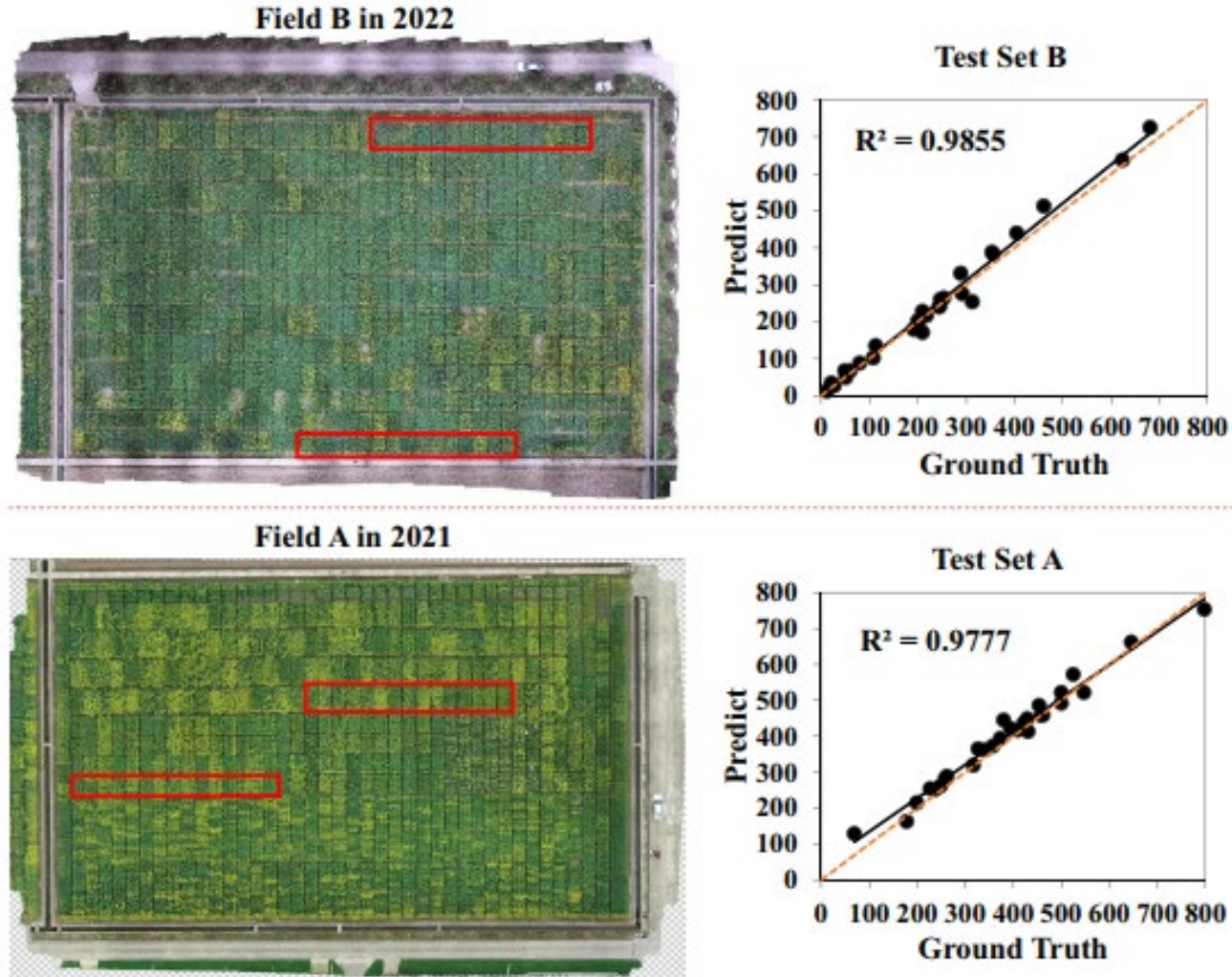
YOLOv5 win!



YOLOv5 model and its composition

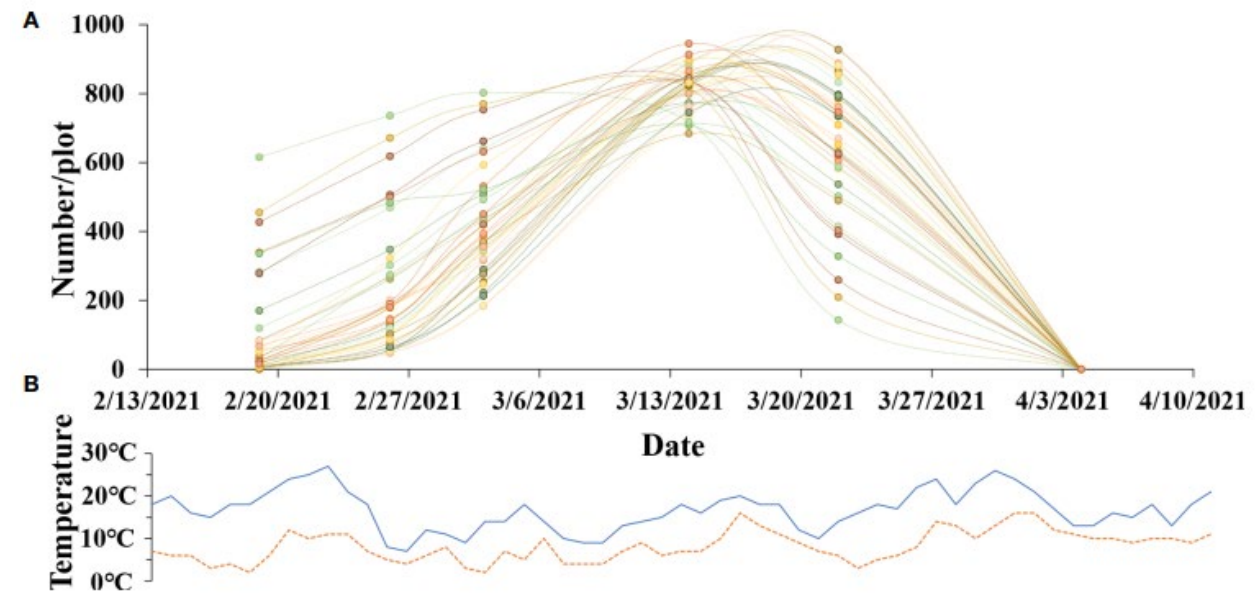
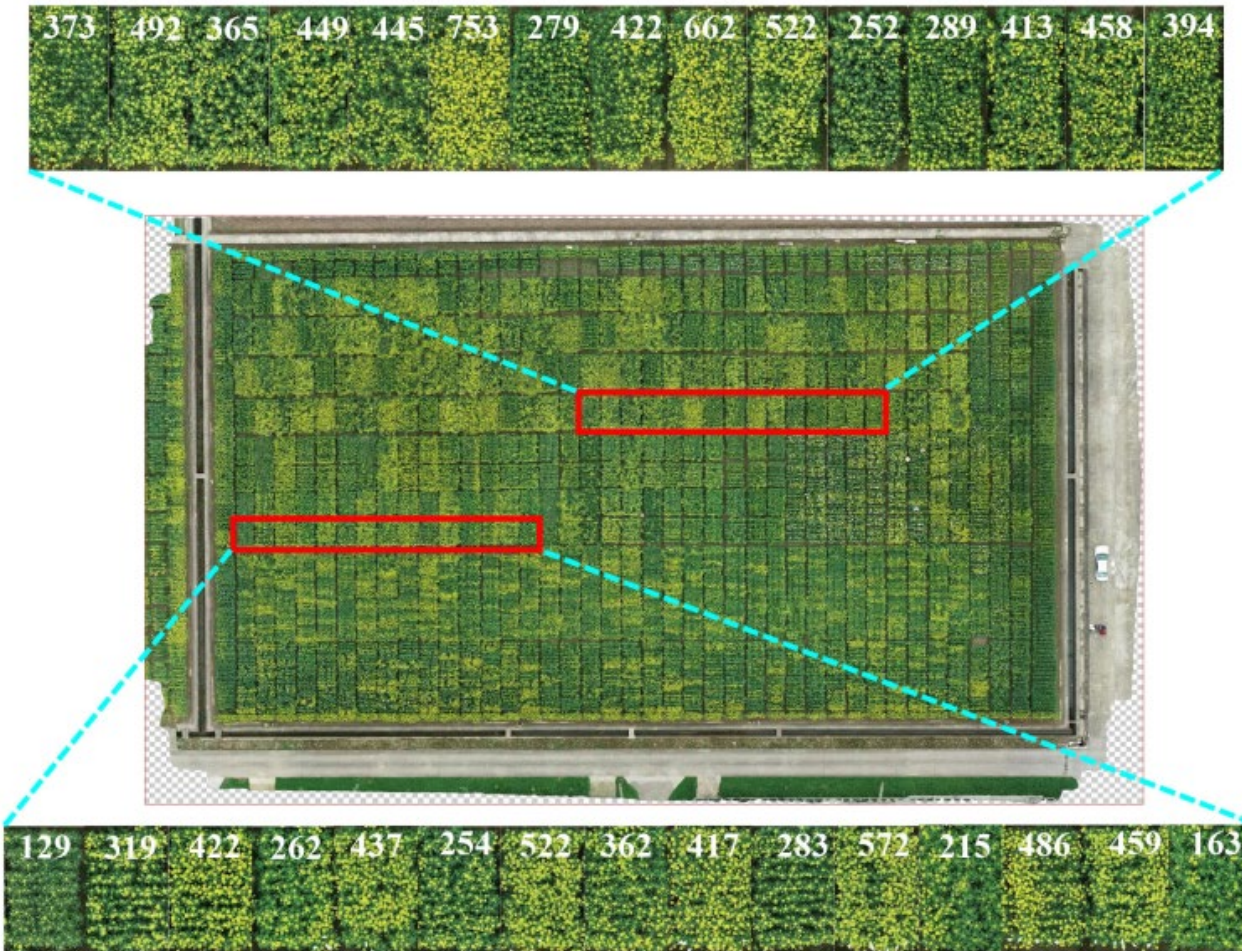
Methods	Precision(%)	Recall(%)	F1-score(%)	mAP(%)	R ²	RMSE	FPS(f/s)
Faster R-CNN	68.9	53.5	60.0	62.3	0.821	120.2	21.6
YOLOv4	94.0	74.2	83.0	91.4	0.926	180.9	40.5
CenterNet	95.1	61.3	75.0	86.3	0.964	53.9	77.9
TasselNetV2+	-	-	-	-	0.951	63.3	22.0
YOLOv5x+CBAM	90.1	87.4	88.7	93.6	0.966	52.1	44.8

Comparison between inferred counts and manual counts on two novel test sets:



Can complete the inflorescence number counting tasks of one field (about 1 hectare) within **20 minutes**.

Application of the UAV-RGB based inflorescence counting system:

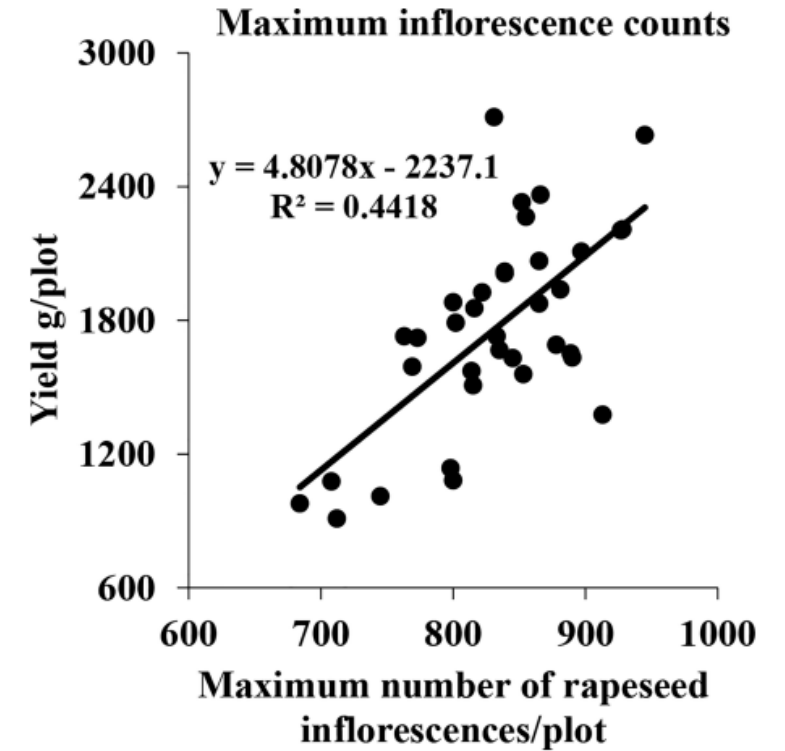
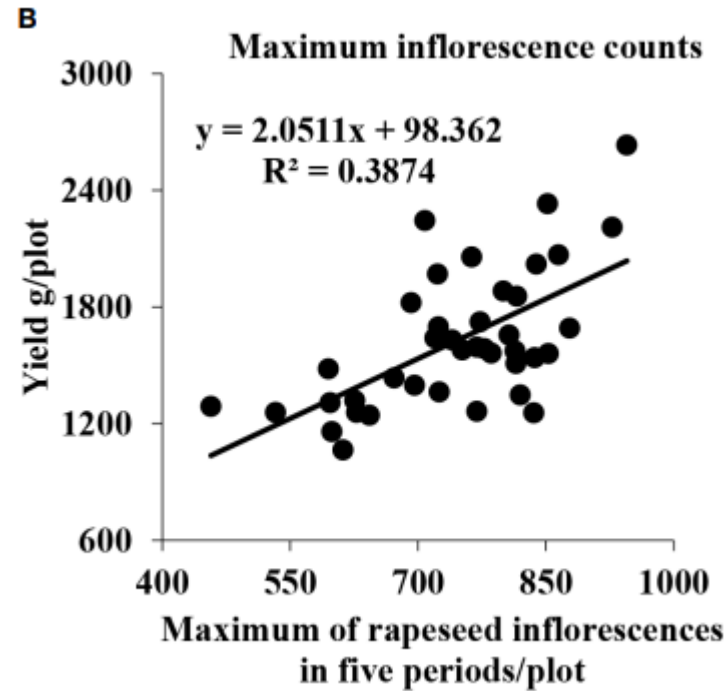
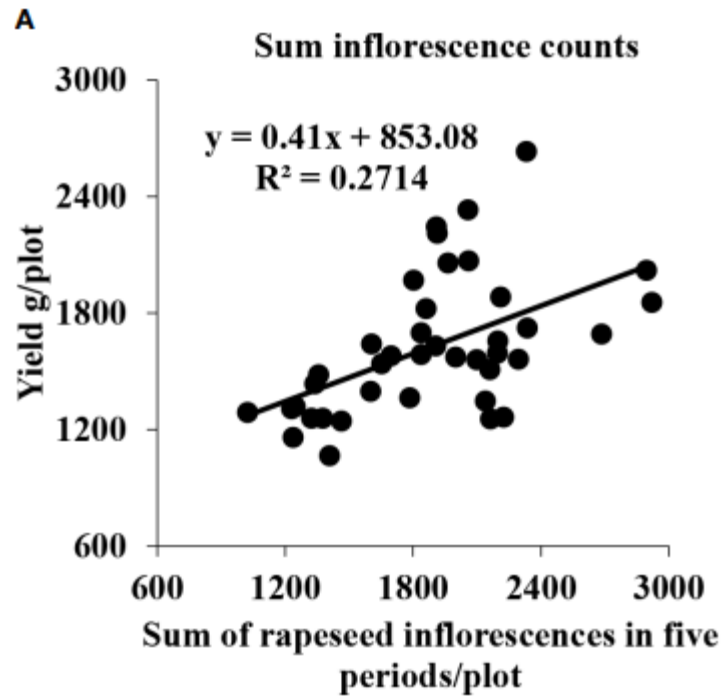


Quantitative dynamic change of the number of rapeseed inflorescences in time dimension

Demonstration of flower richness during the whole flowering stage

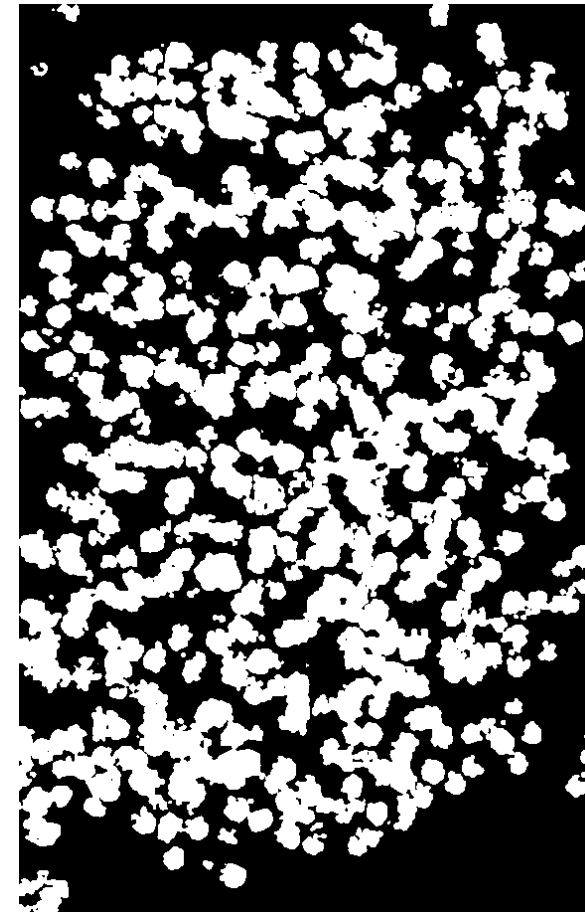
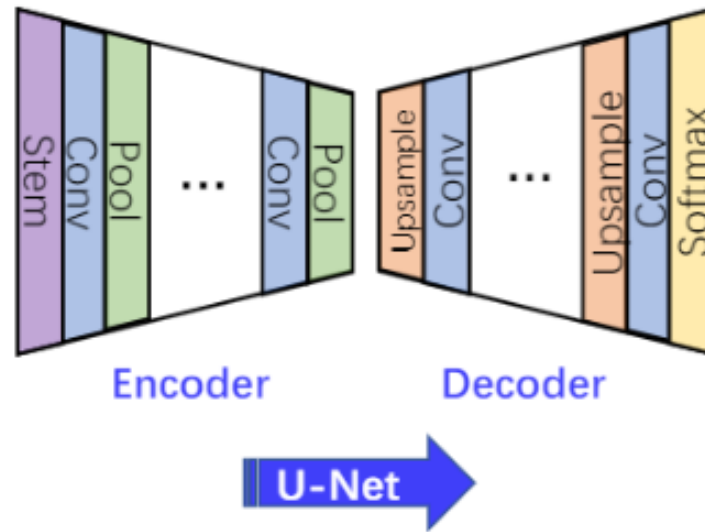
Li *et al.*, Automatic counting of rapeseed inflorescences using deep learning method and UAV RGB imagery. *Front. Plant Sci.*, 2023.

Application of the UAV-RGB based inflorescence counting system:



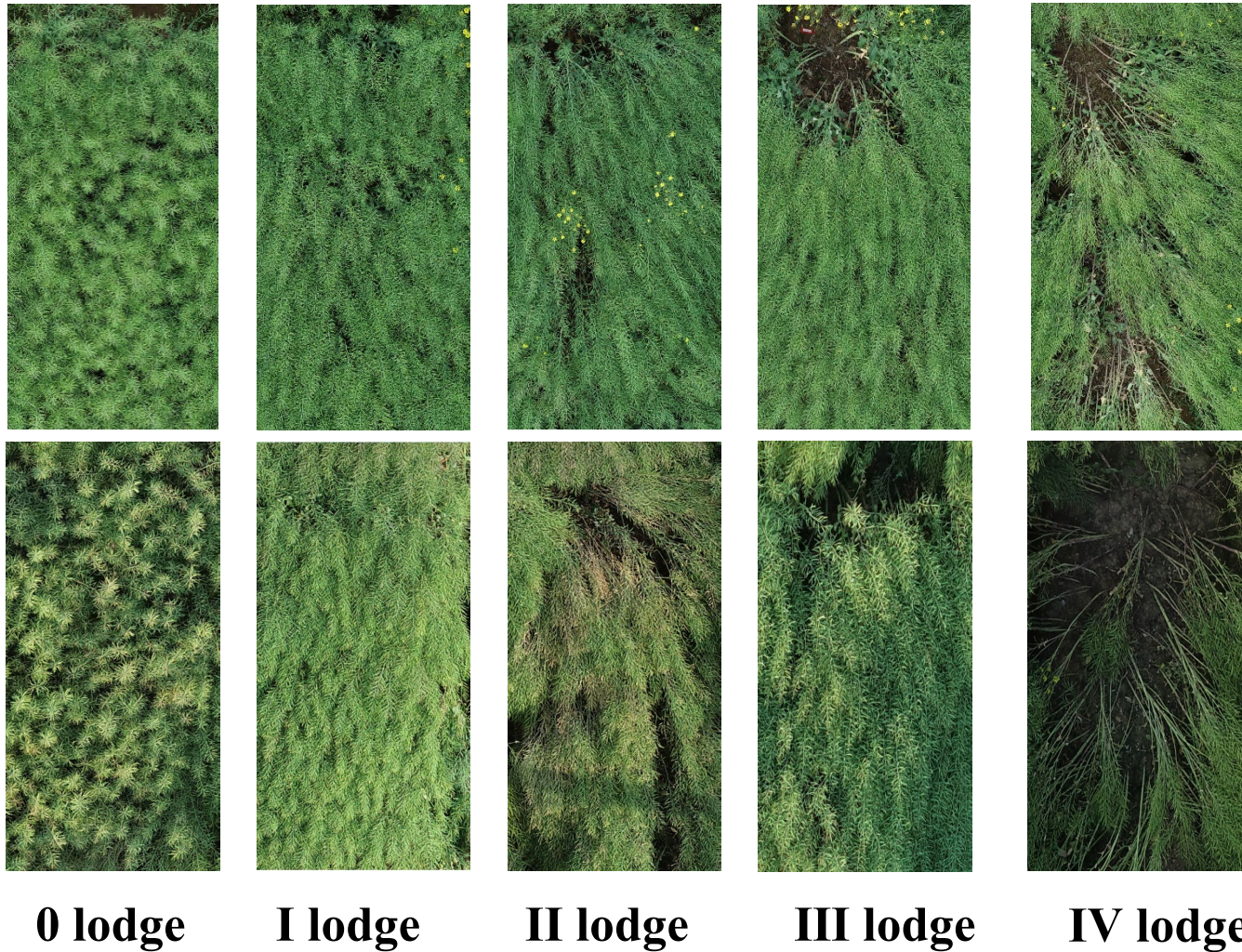
Rather high correlation between the counted Number of the Rapeseed Inflorescences and the Seed Yield

Flower coverage using deep learning (U-Net)

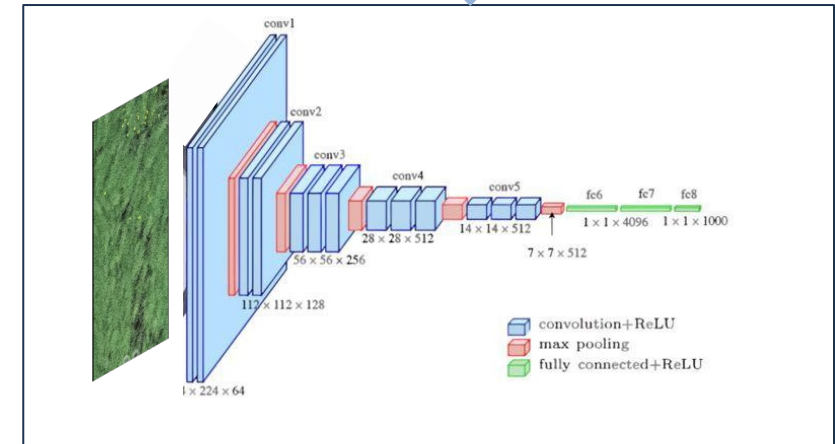


V. Ongoing studies: Lodging classification

Lodging classification using deep learning



Input



Output

I lodge

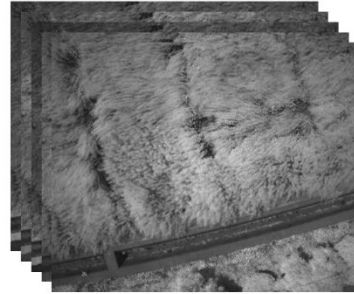
Unpublished data

V. Ongoing studies: monitoring of growth status during whole growth period

Data Acquisition



多光谱无人机

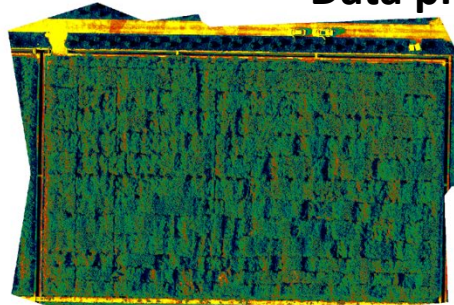


多光谱航拍影像

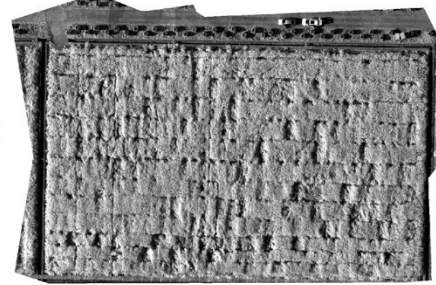
Multispectral synthesis image



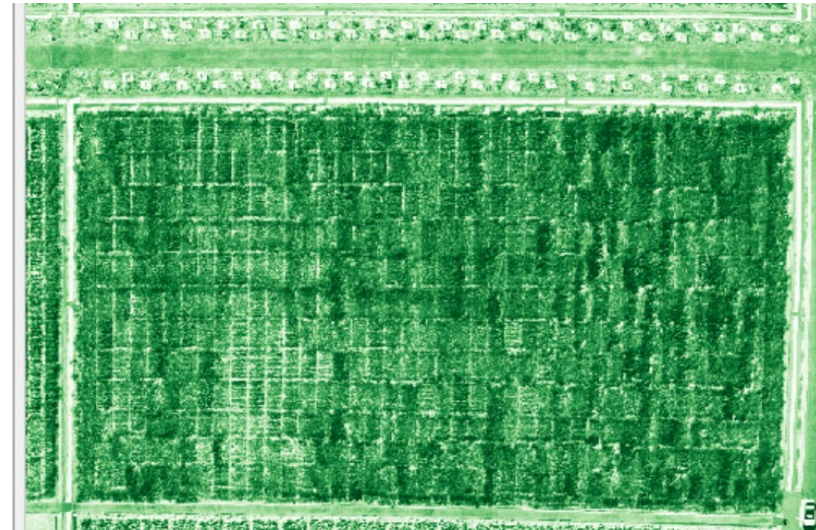
Data preprocessing



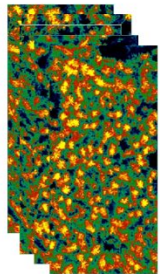
多光谱影像波段合成



多光谱影像拼接

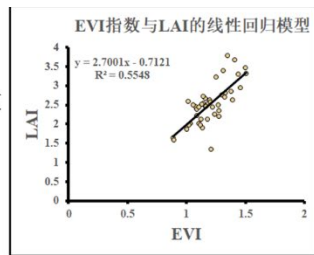


Application



多光谱影像分割裁剪

提取植被指数



植被指数与LAI相关性研究

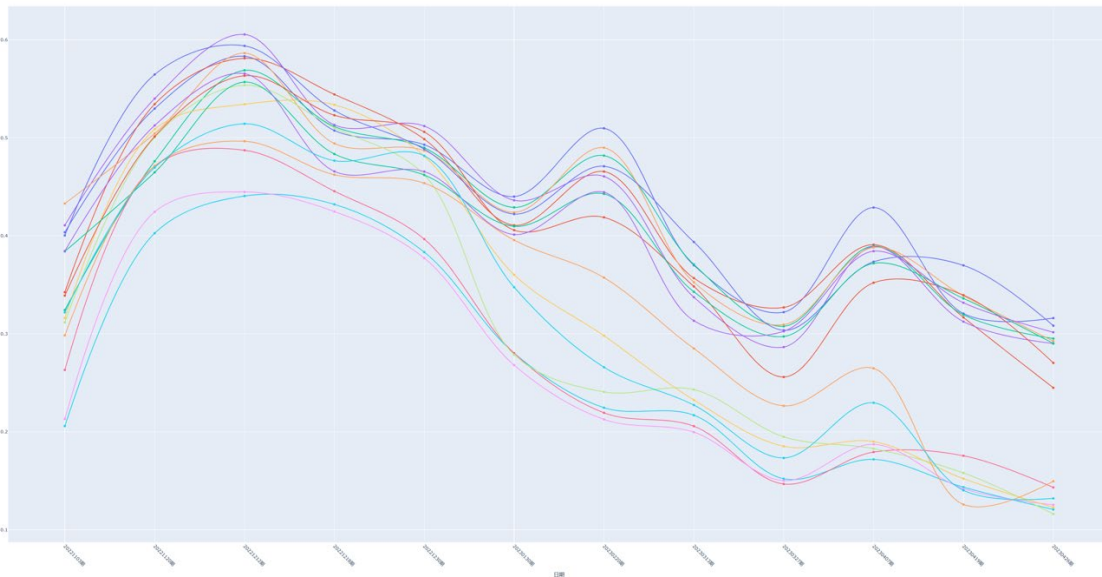
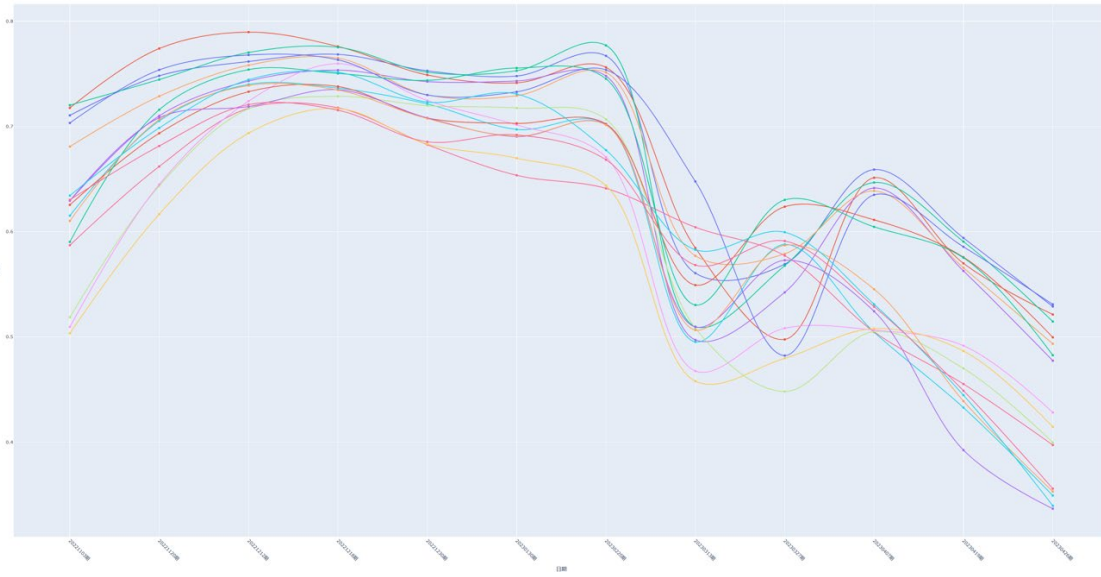
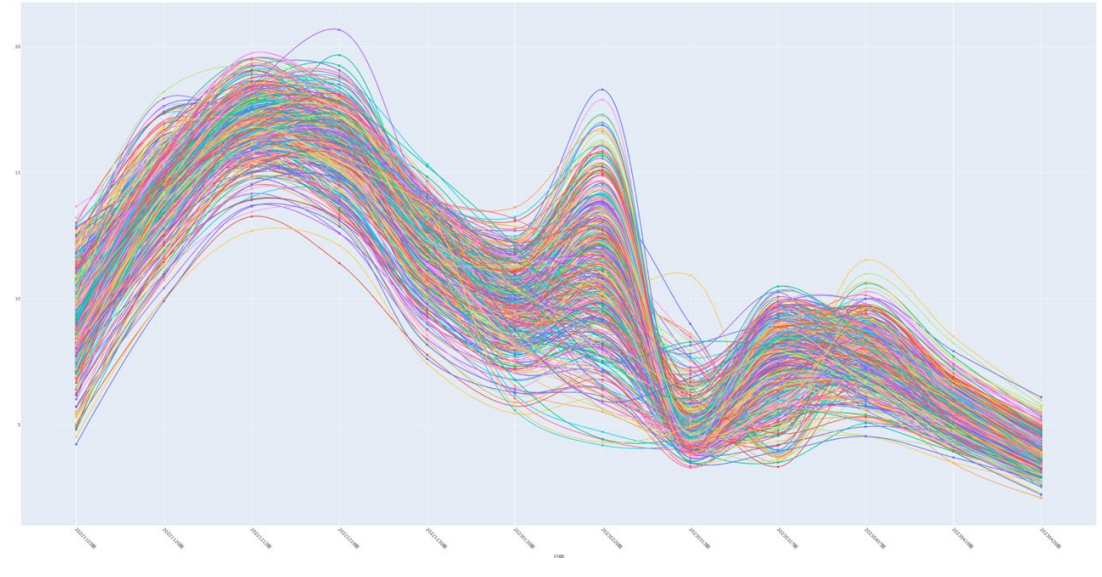
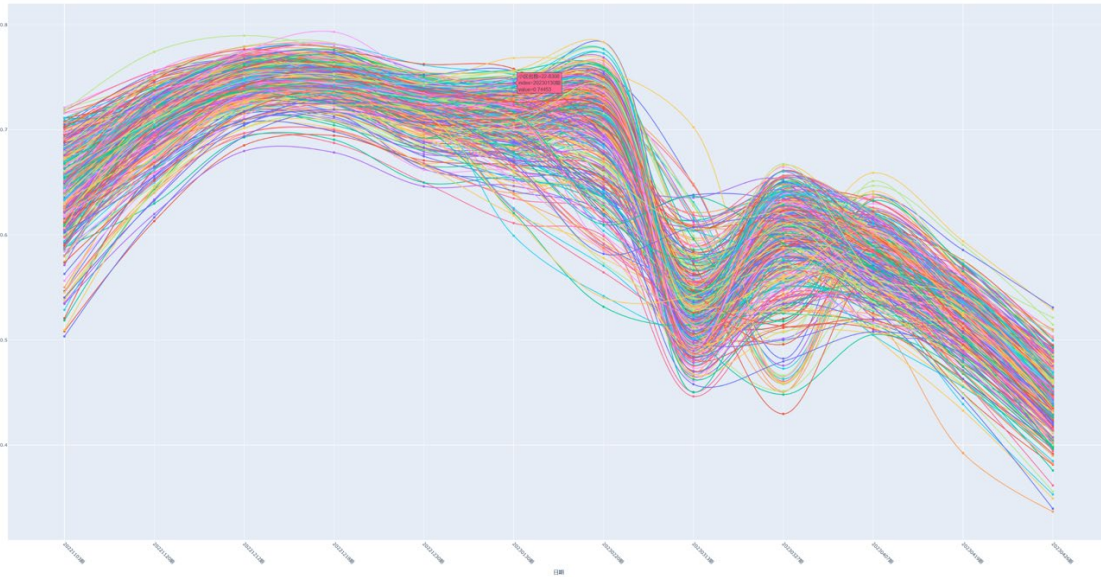
测量LAI



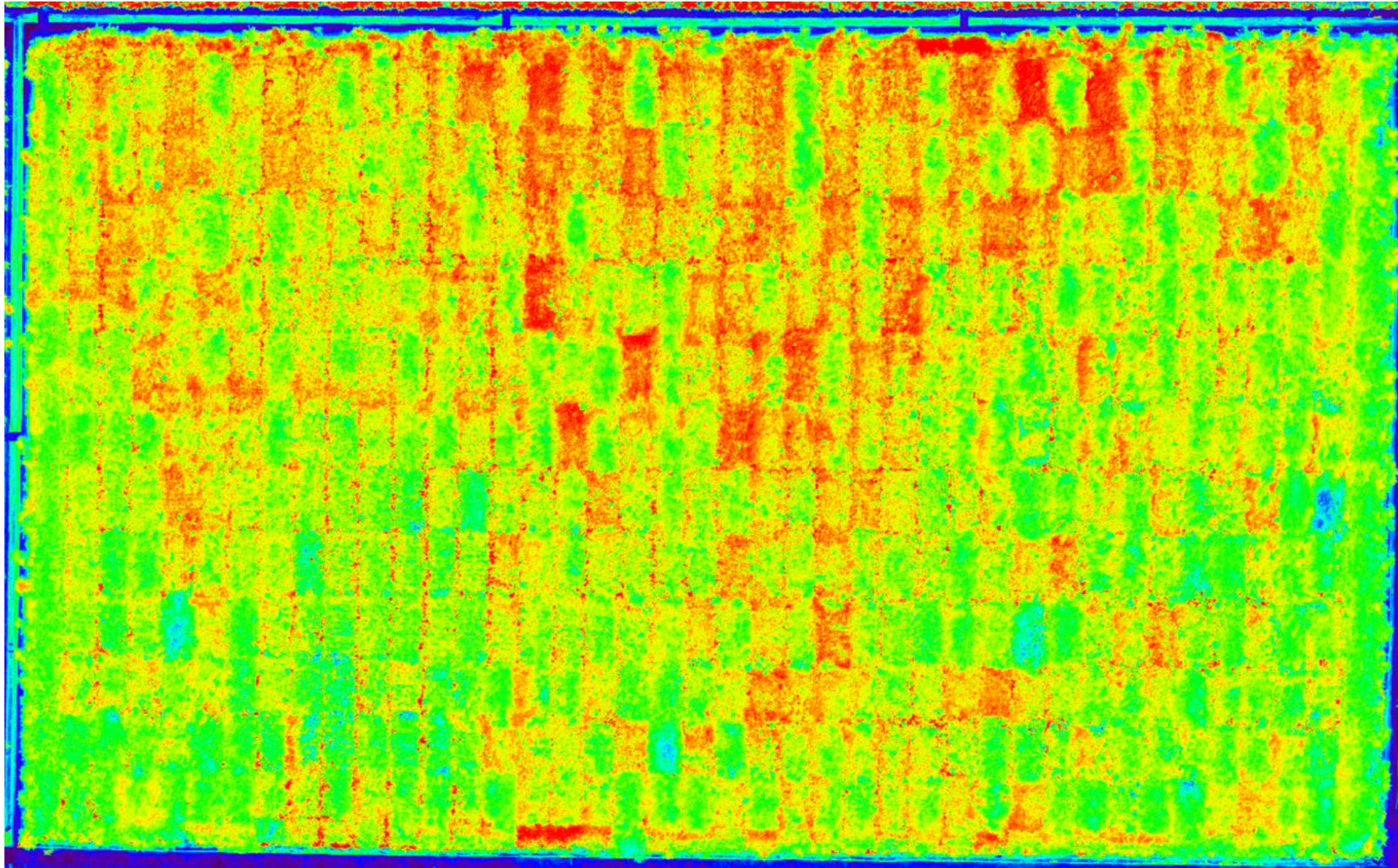
LAI测量

Unpublished data

V. Ongoing studies: monitoring of growth status during whole growth period



V. future studies: Potential seed yield prediction at plot level





Summary

- Providing means for the accurate identification and quantification of yield-related traits at the corresponding key developing periods can accelerate the dissection of yield shaping and extensively promote higher-yield rapeseed breeding.
- Based on our experimental understanding of yield shaping, three major elements: leaf area index, flower richness and silique pod area index are chosen to monitor and evaluate the growth performances and yield potential at vegetative, reproductive, and fruiting stages, respectively.
- A low-cost inflorescence counting approach using Convolutional Neural Networks (CNN) based on Unmanned Aerial Vehicle (UAV) Red-Green-Blue (RGB) imagery of consecutive rapeseed plots at flowering period were developed.
- By systematically combining and integrating the high-through phenotyping information of stress (abiotic and biotic) tolerance, lodging index, leaf area (vegetative vigor), flower richness (branch state) and canopy index (pod area index), the dissection of rapeseed yield shaping can be extensively promoted. All the developed methods can be used to substantively support the breeding of higher-yield rapeseed varieties.



irc 2023 SYDNEY

16th INTERNATIONAL RAPESEED CONGRESS
24 - 27 September 2023

GLOBAL CROP - GOLDEN OPPORTUNITY

Acknowledgements:

Agronomy part

OCRI of CAAS:

Prof. Hanzhong Wang

Prof. Xinfa Wang

Dr. Sheng Liu

Remote Sensing and computer part

Wuhan University:

Prof. Jiang Yao

Dr. Li Li

Hubei University of Technology:

Dr. Jie Li

Yi Li

Supported by:

- ✓ Projects from CAAS
- ✓ The National Natural Science Foundation of China