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2024.10.29
THE 17TH INTERNATIONAL WORKSHOP ON NONDESTRUCTIVE QUALITY EVALUATION OF AGRICULTURAL, LIVESTOCK AND FISHERY PRODUCTS

Advancing sustainable food production through user-centric AI-based phenotyping

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The University of Tokyo
東京大学大学院農学生命科学研究科

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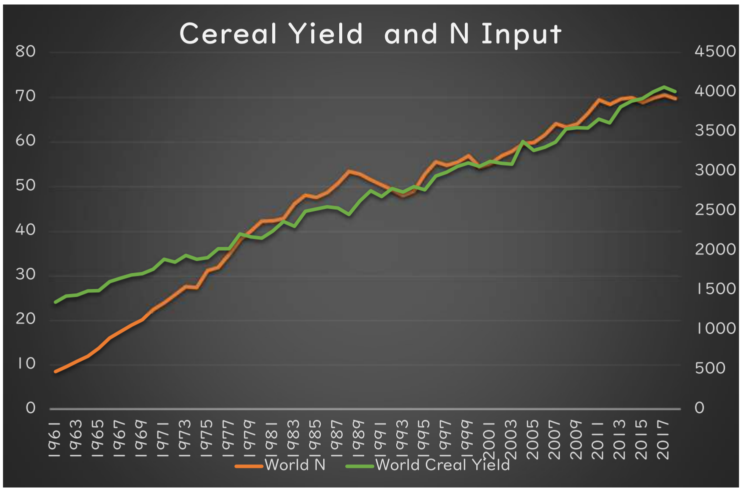
Agriculture of the 20th century was quite successful in terms of productivity



Productivity has been supported by

- Chemicals
  - Fertilizers
  - Pesticides
  - Herbicides
  - Plastics
- Water usage
  - Irrigations
- Energy
  - Machineries
  - Green houses
- Genetics
  - Breeding

Made based on FAOSTAT 2020, Credit: Prof. Ninomiya, UTokyo

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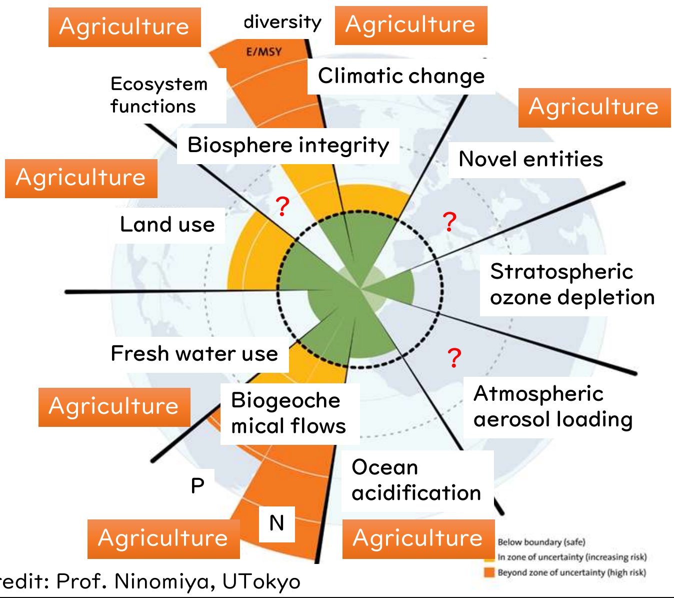
Planetary Boundaries



- To categorize earth system risks and quantify the irreversibility of earth system
- Many categories are at risk. And many of the risks are due to agricultural activities
- We need to achieve productive and sustainable crop production

Increasing risk | High risk | Safe

Stockholm Resilience Centre — Sustainability Science for Biosphere Stewardship | Stockholm University

Credit: Prof. Ninomiya, UTokyo

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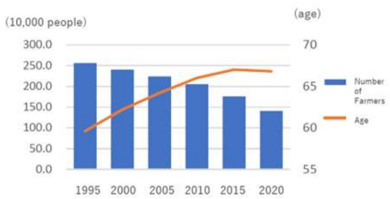
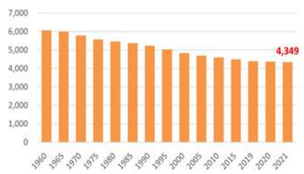
In addition, Japanese agriculture is facing several serious issues

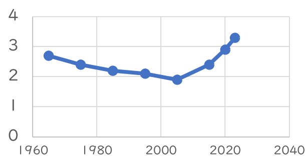
Aging and number of farmers



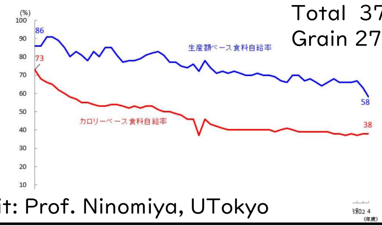
Total cultivation area (10^3 ha)



Cultivation area/farm household (ha)

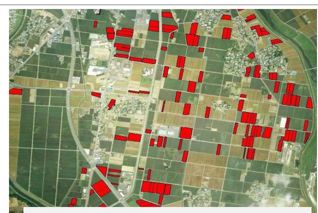


Calorie-based Food self-sufficiency



40% of farmland is in mountainous areas of Japan

A farm with 150 ha of 300 plots



(provided by Dr. Yoshida. NARO, Japan)

Credit: Prof. Ninomiya, UTokyo

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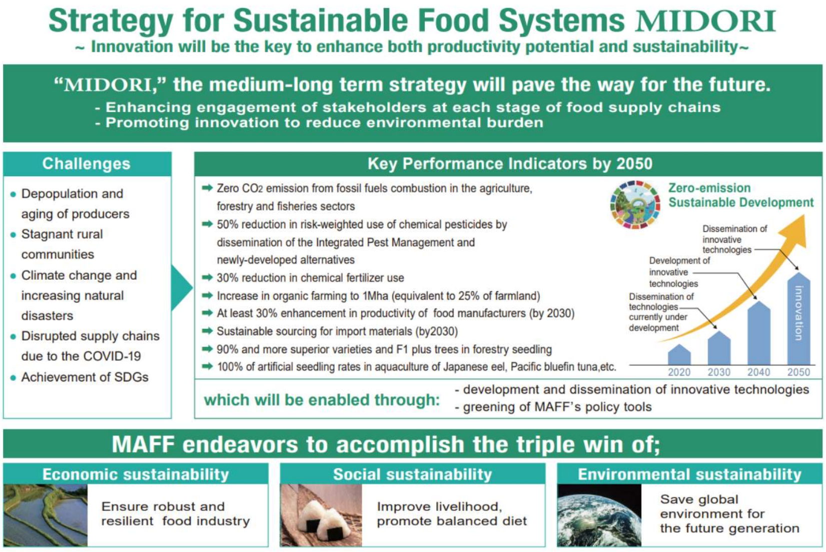
Medium-long term strategy in Japan



Source: MAFF

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Policies for co-existence of productive and sustainable agriculture

- Farm to Fork Strategy (May 2020)
  - EU food system as a global standard
  - 50% reduction in pesticide use and risk by 2030
  - 20% reduction in chemical fertilizer use by 2030
  - 50% reduction in sales of antimicrobials used for livestock and aquaculture

- Super innovation is necessary to achieve the goals
- Smart farming takes an important role

  - The new president announced a stronger policy (Jan, 2021)
- Sustainable Food System Strategy (May 2021)
  - みどりの食料システム戦略（绿色食品系统战略）
  - 50% reduction in pesticide use and risk by 2050
  - 30% reduction in chemical fertilizer use by 2050
  - Reaching 25% of the farmland used for organic farming by 2050

Super innovation？

• By ChatGPT: Agriculture in 2050

<—Japan

World—>

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Key techniques of Smart agriculture

• Data-driven farming

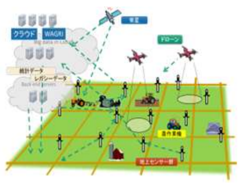
Farm field monitoring
- Crop status
- Environments: weather, soil, water, pests, etc.
- Past, current, future

Decision making for farm field management

Farm field management

Data Platform

Difficult technology transfer	Easy technology transfer
Conventional F.	Smart F.
Visual and manual • Inconvenient, subjective • Low frequency	IoT sensors • Automatic, objective • High-frequency & high accuracy
Empirical decisions • Subjective • Qualitative	Decisions by AI • Objective • Quantitative
Empirical operations • Laborious, inefficient	Robots & navigation • Automatic, accurate, efficient,
Paper based • Inefficient • Dead stock	Cloud database • Automatic, big-data • Reusable



Credit:
Prof. Seishi Ninomiya, University of Tokyo

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Plant Phenomics ?

- Plant Phenomics:

The study of plant growth, performance and composition by high-dimensional phenotypic data on an organism-wide scale

- Phenotype:

Affected by Genotype and Environment

- Phenotyping:

Measuring plant phenotype to

Understand the growth of plants

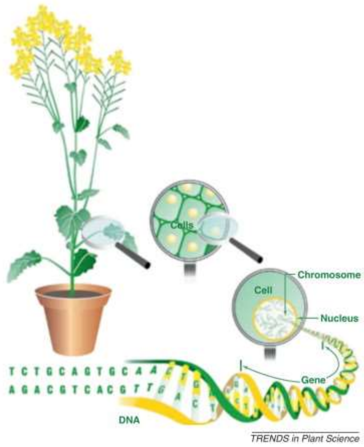

Figure:
Furbank, R. T., & Tester, M.
Trends in Plant Science, 2011

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Monitoring the crops (phenotyping)

Source: Nature 541, 445 – 446; 544, S21 – S23 (2017)

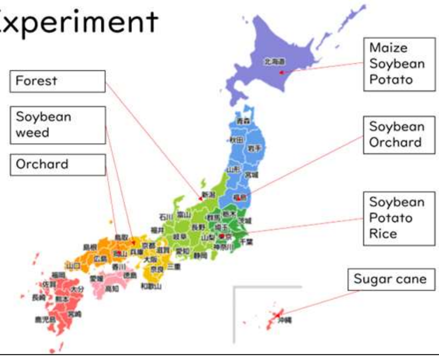
About US

- 2017: Preparation of Laboratory of Field Phenomics
- 2021: Endowed Chair for Field Phenomics, funded by Sarabetsu Village , Hokkaido
- 2023: Trans-disciplinary team (Breeding Science, Crop Science, Informatics, Engineering)

Research topics

- Development of field Sensing techniques and facilities (Applied research)
  - IOT
  - Robotics
  - UAVs
- Development of phenotyping algorithms and applications (Basic + Applied research)
  - Crop growth monitoring
  - Crop organ detection
  - Crop/tree 3D reconstruction and analyzing
- Development of phenotyping Pipeline, System, protype (Experimental development)
  - Collaboration with Private Company
  - Startup projects

Field Experiment



https://lab.fieldphenomics.com/

Field sensing

Data collection for Plant phenotyping

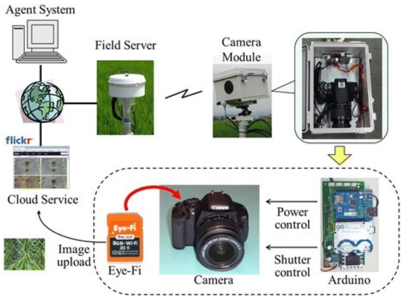
Field IoT

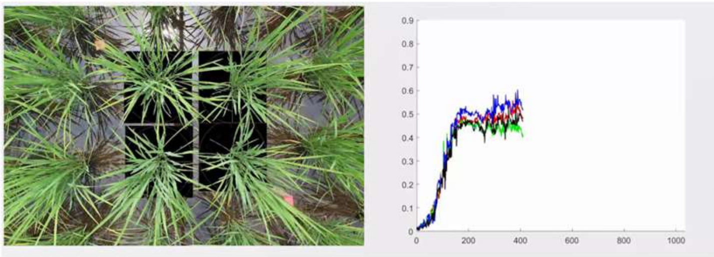
Field Scanners

Field Robots

UAVs

Field IOT





Field scanner

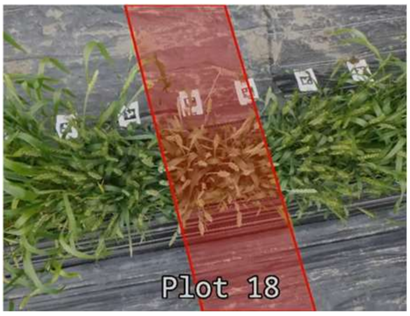
Lidar

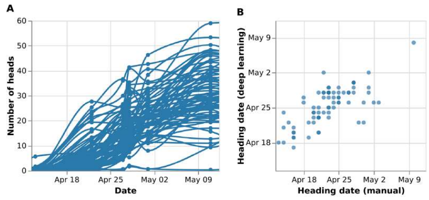
RGB

Kodama et al., Zhang et al., unpublished

Lab of Field Phenomics, University of Tokyo & Quantomics Co. , Ltd.

Ground Robot





For small plots (25cm) x 1000+ phenotyping tasks

Kuroki et al., 2022, Breeding Science

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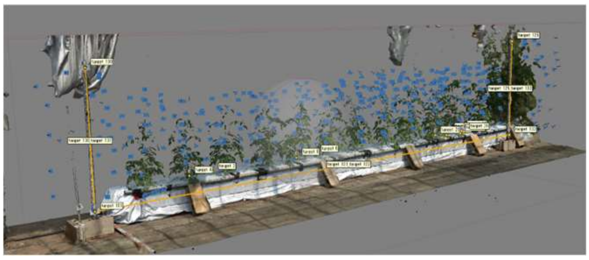
UAVs in door



Kodama, K., Tanabata, T.,
With Kazusa DNA Institute & KAZUSA Lab & HIGH LANDER

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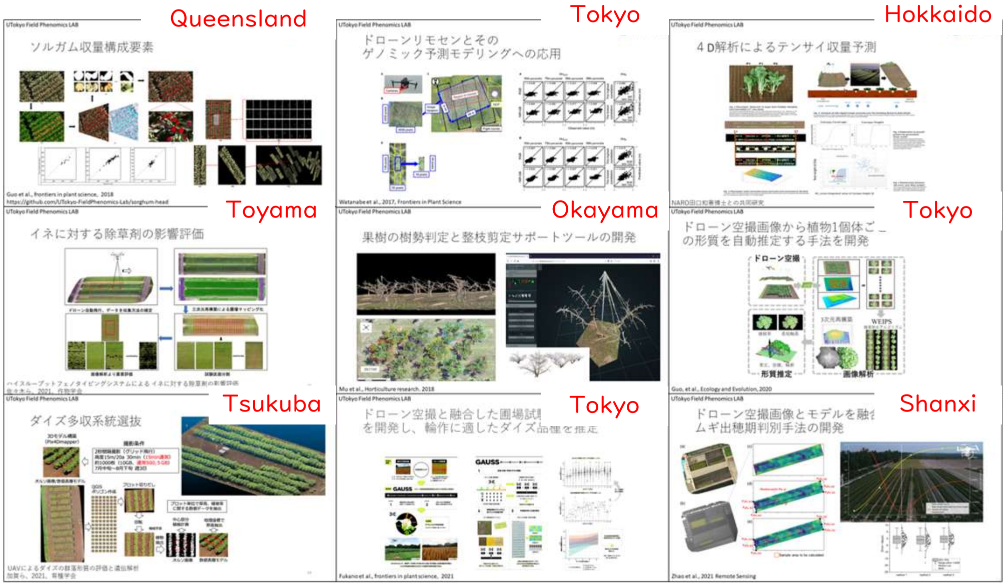
UAVs outdoor



Patented in Japan, China, U.S.A

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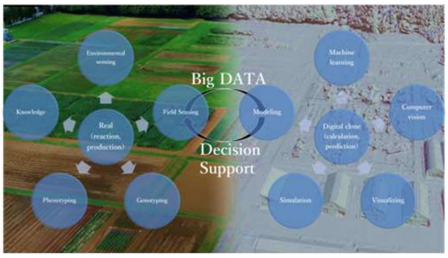
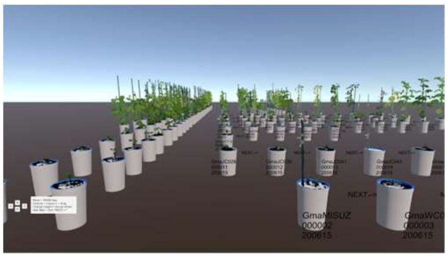
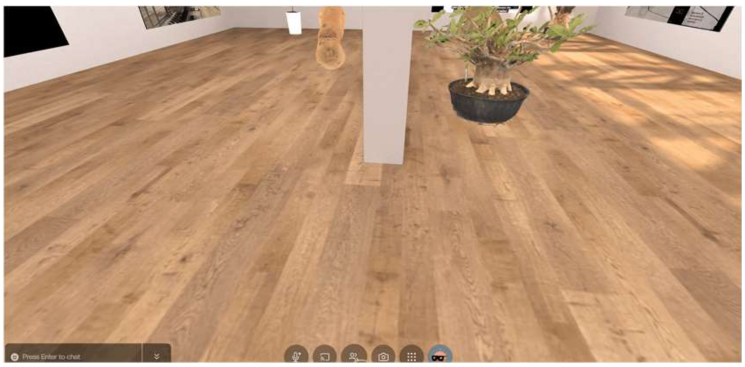
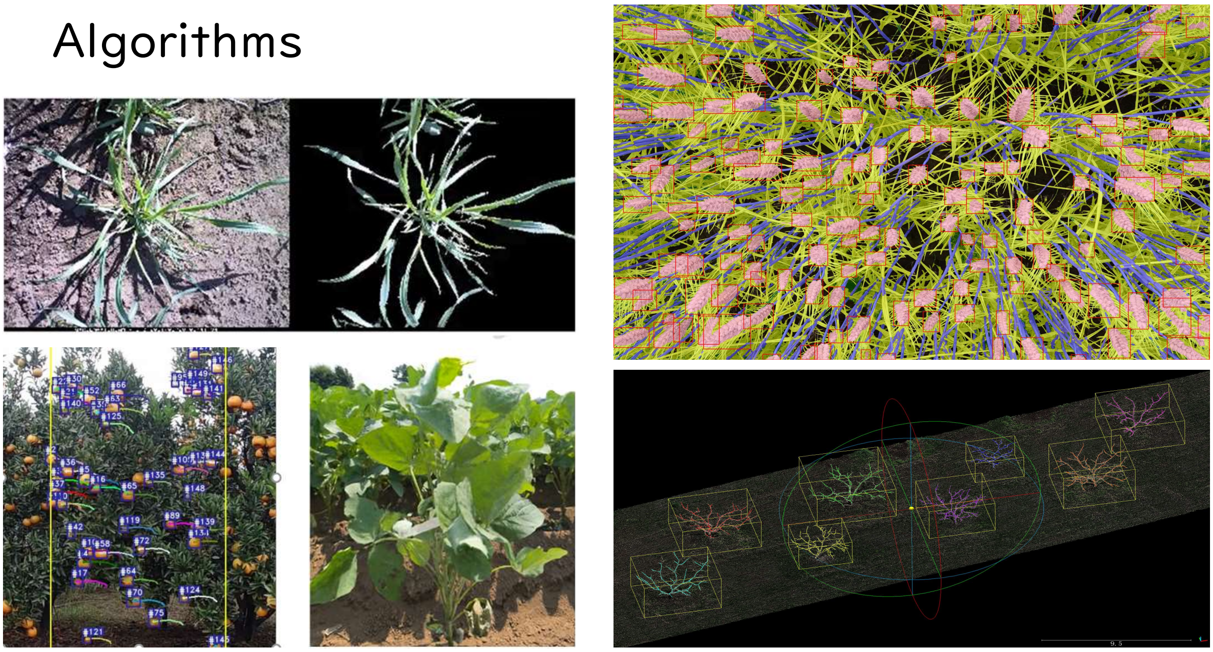
Phenotyping Beyond Reality







Algorithms



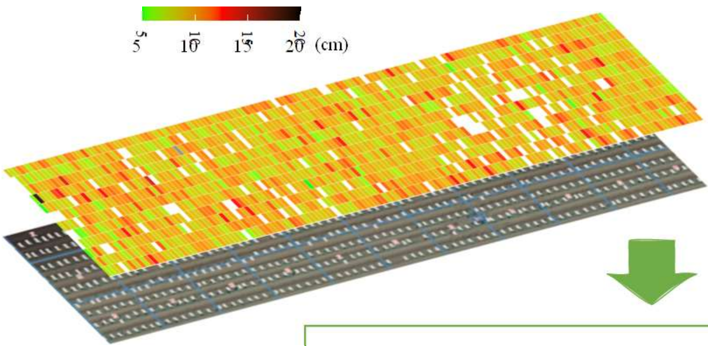
User-centric AI-based phenotyping?

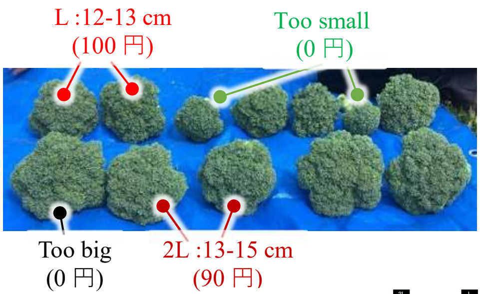
~Case study 1~

Vegetables around us

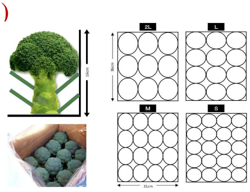
Problems of vegetable farmers

- Broccoli as an example

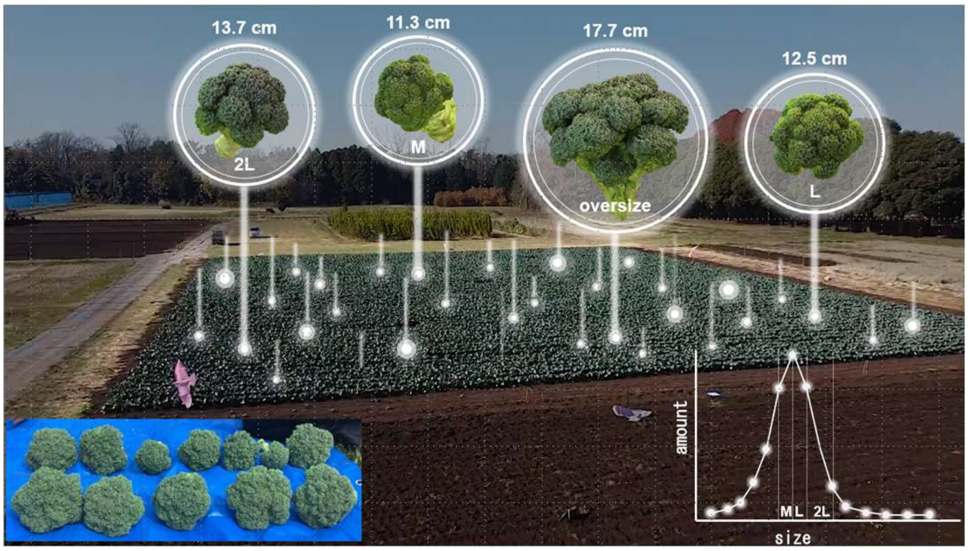




Multi-time harvest: labor cost
One-time harvest: on-farm food loss
Farmer Income Decrease

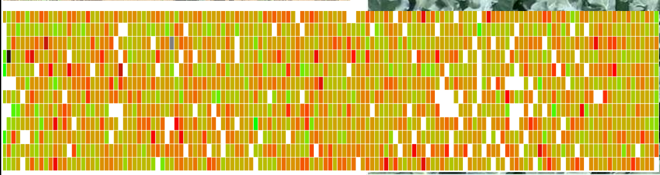


Solution: Growth dynamics of individuals



Conventional farming:

- Check the field, selective harvest / set the optimal harvest date



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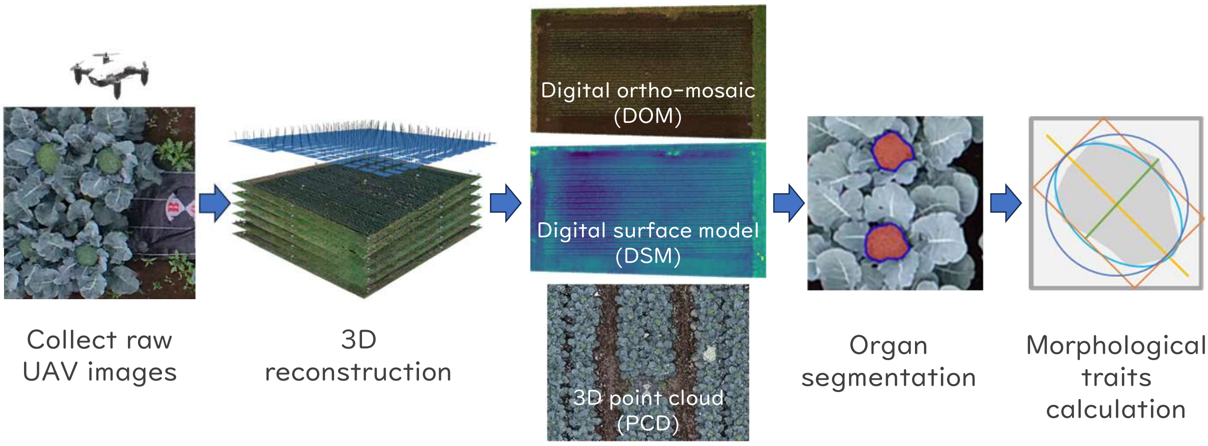
Smart farming:



Collect raw UAV images → 3D reconstruction → Organ segmentation → Morphological traits calculation

Wang et al., Plant Phenomics 2023

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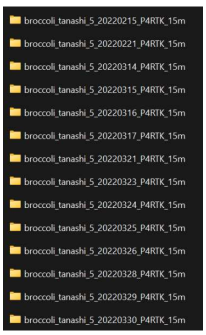
Challenges: Big image data

1 ha = cost of data storage



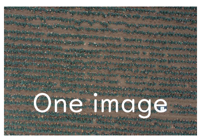
Large amount of time-series data
(38 flights in 2022)

One flight →

200+

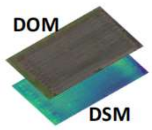
raw images
(2.7GB+)

→



5742 x 3648 pixels

200 x 20 billion = 4 trillion pixels per flight



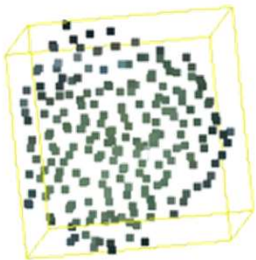
(1GB+)

→

19572 x 17664 pixels

0.3 trillion pixels per flight

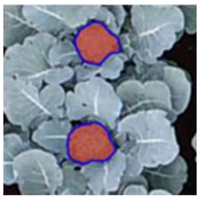
Challenges: low image quality



3D canopy model
(PCD)

2D field map
(DOM)

Challenges: Complex conditions



Huge differences between time, sunlight, soil condition, growing stage, cultivars
Make deep learning model training difficult

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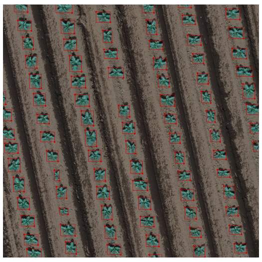
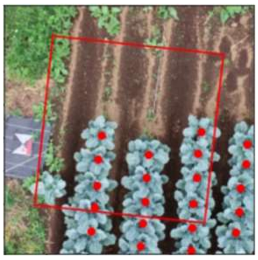
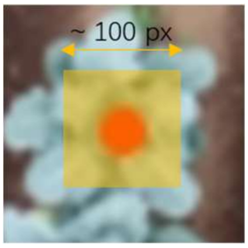
Solutions

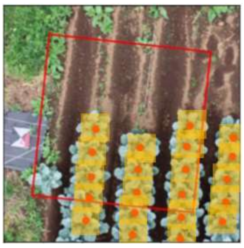
Temporal data fusion

narrow the processing regions by using prior knowledge of agriculture

Broccoli head position is almost the same as its seedling position





Narrow the processing area around the seedling area

(100 x 100) pixels x 3000 count = 30 billion pixels per flight

per crop

one raw image

5742 x 3648 ~ 20 billon pixels

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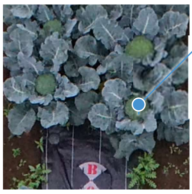
Solutions

Spatial data fusion

combine raw images (pixel coordinates) with field maps (geo coordinates)



(2341,1492)

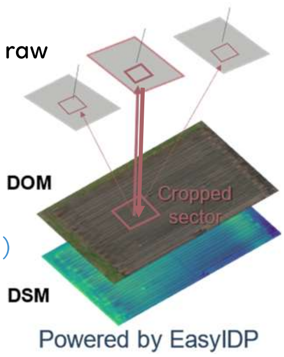
Pixel coordinates

Better quality

Lacks spatial context

(35.7393N, 139.5414E, 96.34m)

Geo coordinates



pixel-coordinates

Spatial fusing

geo-coordinates

Wang et al., Plant Phenomics 2023

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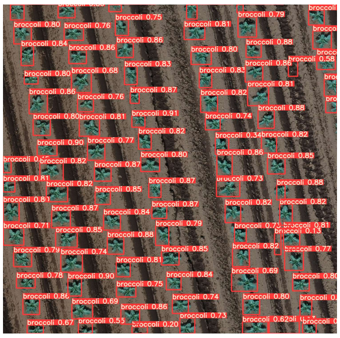
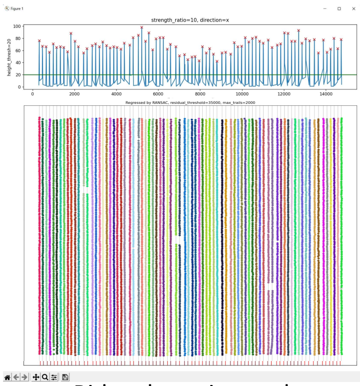
Results

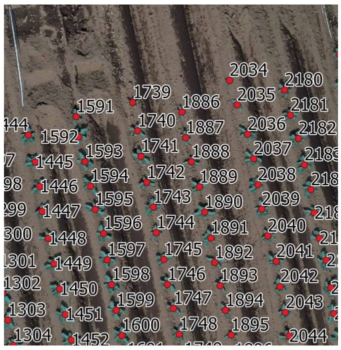
Seedling position detection



Seeding detection by pre-trained Yolo v5
(With only 2 annotation images)



Ridge detection and broccoli clustering



Get ID and geo-location of each broccoli

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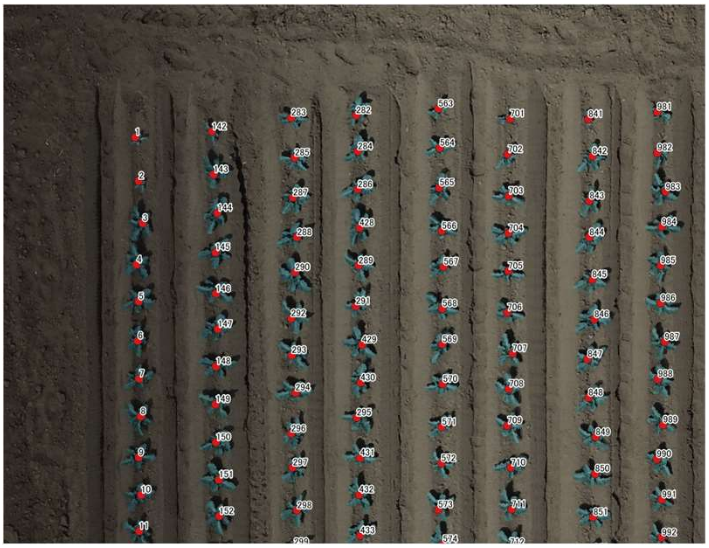
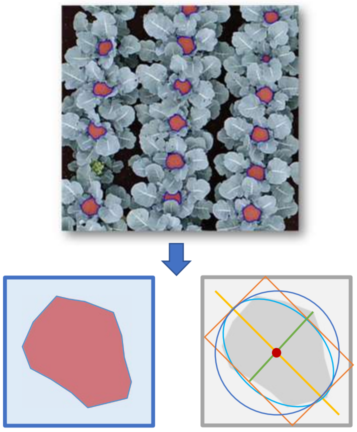
Results



Seedling position on flowering stage on field map (geo-coordinate)

Results

For each broccoli head



Minimum area rectangle max/min side-length

Equivalent diameter

broccoli center points

Eccentricity, circularity

Major axis length
Minor axis length

Area, perimeter

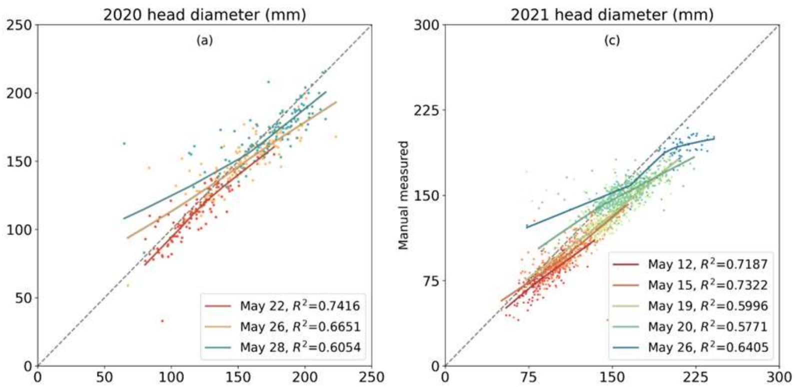
Convex area

Wang et al., Plant Phenomics 2023

Accuracy of head size estimation

Has acceptable correlation with manual measured head size

Y: Manual field measured



X: Aerial measured

Wang et al., Plant Phenomics 2023

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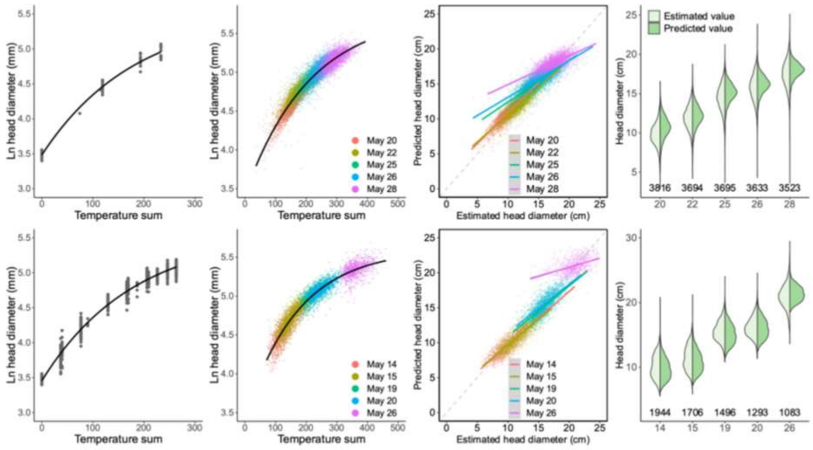
Growth prediction



Wang et al., Plant Phenomics 2023

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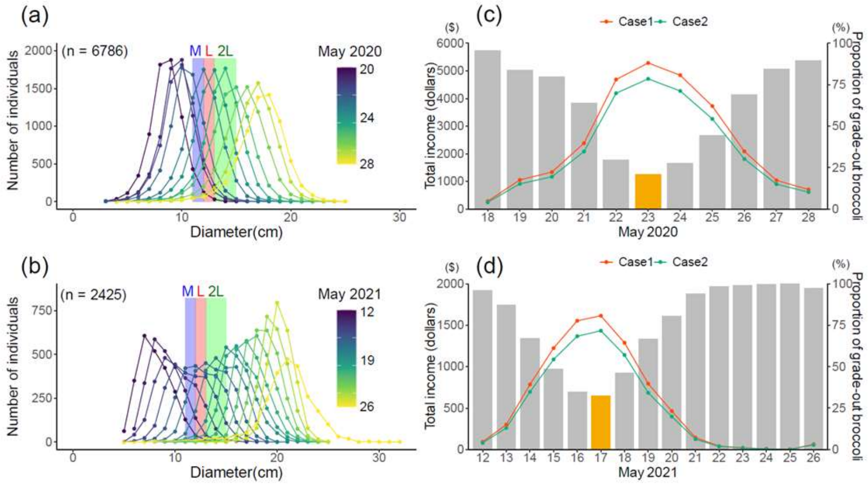
Harvest date prediction

One day shift in harvest from the optimal date could lead to considerable income loss (3.7% to 20.4% reduction)



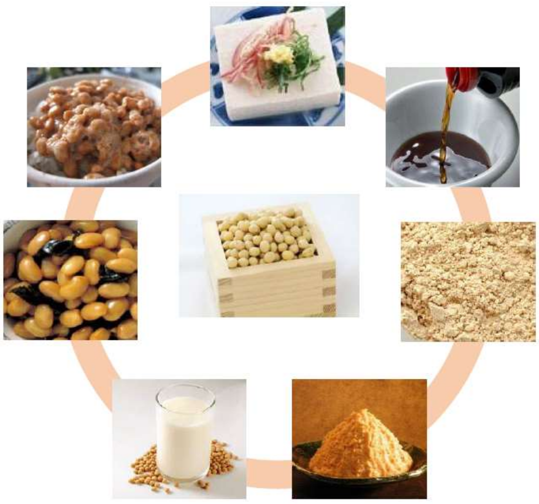
Wang et al., Plant Phenomics 2023

User-centric AI-based phenotyping?

~Case study 2~

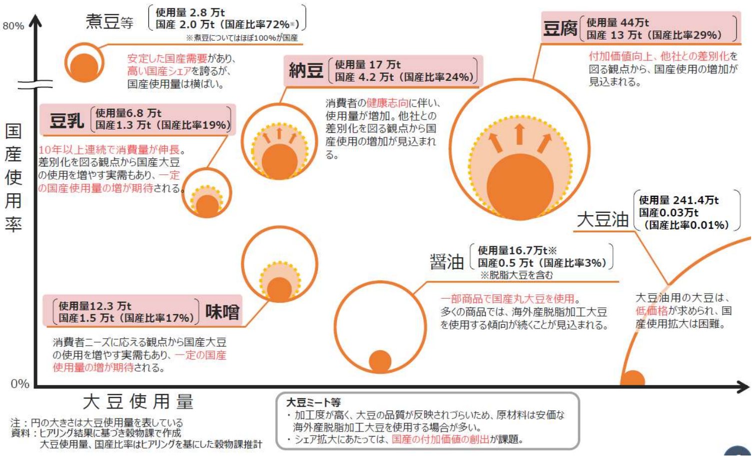
Soybean in Japan

- 2022 self-sufficiency rate : 6%
  - Needs: 3,895,000 ton
  - Food use: 1,000,000 ton
  - Domestic production: 234,000 ton



https://www.maff.go.jp/j/seisan/ryutu/daizu/
大豆をめぐる事情2024

Soybean Demand Trends
~by Application~



https://www.maff.go.jp/j/seisan/ryutu/daizu/
大豆をめぐる事情2024

Polices in Japan
~Increase domestic production~

小麦・大豆の国産化の推進

【令和６年度予算額　50（90）百万円】
（令和５年度補正予算額　13,000百万円）

＜対策のポイント＞
産地と実需が連携して行う**麦・大豆の国産化を推進**するため、ブロックローテーションや営農技術・機械の導入等による**生産性向上**や**増産**を支援するとともに、国産麦・大豆の安定供給に向けた**ストックセンターの整備**や民間主体の**一定期間の保管、新たな流通モデルづくり**、更なる利用拡大に向けた**新商品開発**等を支援します。

＜事業目標＞［平成30年度→令和12年度まで］
○ 小麦生産量の増加（76万t→108万t）　○ 大麦・はだか麦生産量の増加（17万t→23万t）　○ 大豆生産量の増加（21万t→34万t）

＜事業の内容＞

1．国産小麦・大豆供給力強化総合対策
① 生産対策（麦・大豆生産技術向上事業）　47（90）百万円
【令和５年度補正予算】4,500百万円
麦・大豆の増産を目指す産地に対し、水田・畑地を問わず、**作付けの団地化、ブロックローテーション、営農技術の導入**等を支援します。
② 流通対策　3（－）百万円
【令和５年度補正予算】430百万円
ア 麦・大豆供給円滑化推進事業
国産麦・大豆を**一定期間保管**することで、安定供給を図る取組を支援します。
イ 新たな麦・大豆流通モデルづくり事業
麦・大豆の流通構造の転換に向けた**新たな流通モデルづくり**を支援します。
③ 消費対策（麦・大豆利用拡大事業）　【令和５年度補正予算】70百万円
国産麦・大豆の利用拡大に取り組む食品製造事業者等に対し、**新商品開発**や**マッチング**等を支援します。

2．産地生産基盤パワーアップ事業のうち国産シェア拡大対策（麦・大豆）
【令和５年度補正予算】8,000百万円
国産麦・大豆の取扱数量を増加させる取組を推進するため、増産に資する**農業機械や乾燥調製施設の導入、**不作時にも安定供給するための**ストックセンターの整備**、国産麦・大豆の利用拡大に向けた**食品加工施設の整備**等を支援します。

＜事業の流れ＞
国 →（交付、1/2）都道府県 →（定額、1/2）生産者団体等（都道府県、市町村を含む）（1①、1②ア（大豆）の事業）（2の事業）
国 →（定額、1/2）民間団体等（1②ア（麦）の事業）
国 →（定額）民間団体等（1②イの事業）
国 →（定額）民間団体 →（定額、1/2）民間団体等（コンソーシアム及び民間企業を含む）（1③の事業）

＜事業イメージ＞
1．生産対策
営農技術の導入（定額）
農業機械の導入（1/2以内）
乾燥調製施設の整備（1/2以内）
2．流通対策
・ストックセンターの整備（1/2以内）
・一定期間の保管（定額、1/2以内）
3．消費対策
国産むぎ
豆腐 国産
・新商品の開発（定額、1/2以内）
・加工設備・施設の導入（1/2以内）
麦・大豆の国産化を一層推進

［お問い合わせ先］
（1①、1②ア（大豆）、1②イ、1③（大豆）、2の事業）農産局穀物課　（03-6744-2108）
（1②ア（麦）、1③（麦）の事業）　貿易業務課（03-6744-9531）

https://www.maff.go.jp/j/seisan/ryutu/daizu/
大豆をめぐる事情2024

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Phenotyping strategies for soybean






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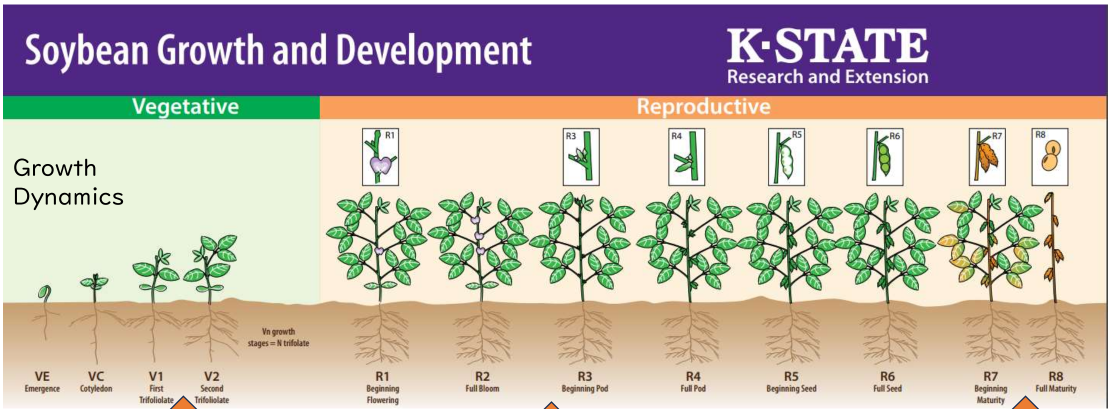
Phenotypic traits



1 Growth Dynamics

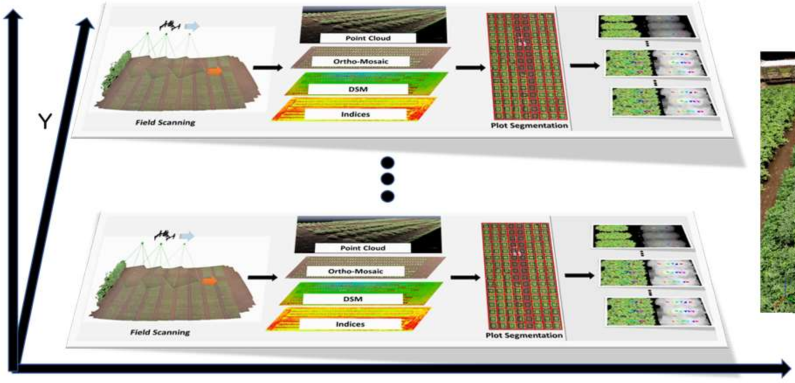
2 Weed

3 Canopy structure

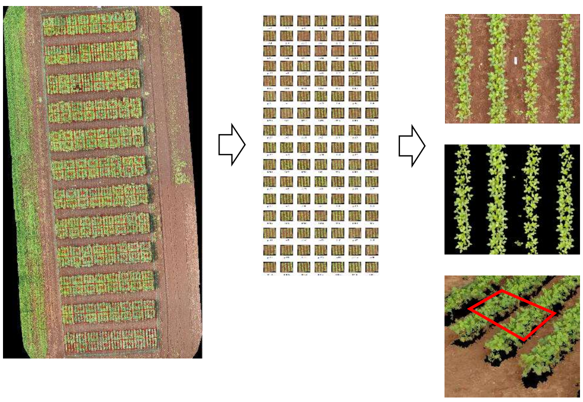
Seeds 4

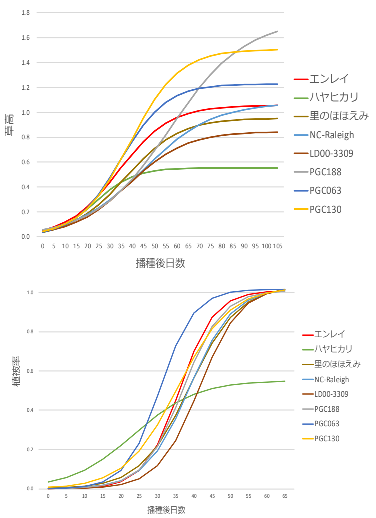
Phenotyping growth dynamics

- The benefit of UAV phenotyping



Growth dynamics in breeding field





Kaga & Guo, 2017, UAV pipeline for phenotyping soybean

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Weed mapping

- Weed control in the soybean field
  - hardly controllable weeds (e.g.: Ipomoea spp.)

大豆栽培における 難防除雑草の防除
https://www.naro.go.jp/project/research_activities/soybeanzassoumanual_full_202103.pdf

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Weed control

❑ Chemical-based field-scale weed management
- ✔ Easily achieved
- ✘ Evolution of weed resistance
- ✘ Biodiversity loss
- ✘ Environmental pressures
- ✘ Economic burden

❑ Deep learning-based site-specific weed management (SSWM)

Takes targeted measures only

DL-based mapping system → **Treatment decision** → **Treatment application**

- ★ DL depends on large-scale dataset
- ✔ Reduces financial burden
- ✔ Avoids environmental pollution
- ✔ Protects biodiversity

Natural Scenarios ?

- ❑Severe Overlaps, Similarities between weeds and plants
- ❑Uniform soil background
  Labor intensive &
  Knowledge dependence

To prepare a large dataset with correct annotations?

Requires:

Huge amount of works by specialists

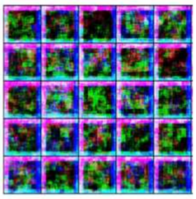
Images of different areas with different weed communities

Natural Scenarios Generation

Data collection under natural scenarios ✗ Data annotation by agronomy specialist

Automatic indoor cultivation

Automatic individual data collection



Synthetic Individual Data Generation

Natural Scenario Simulation

Natural Scenario Data

Li et al., IPPS2022 & IPPS2024; Plant Phenomics2024.

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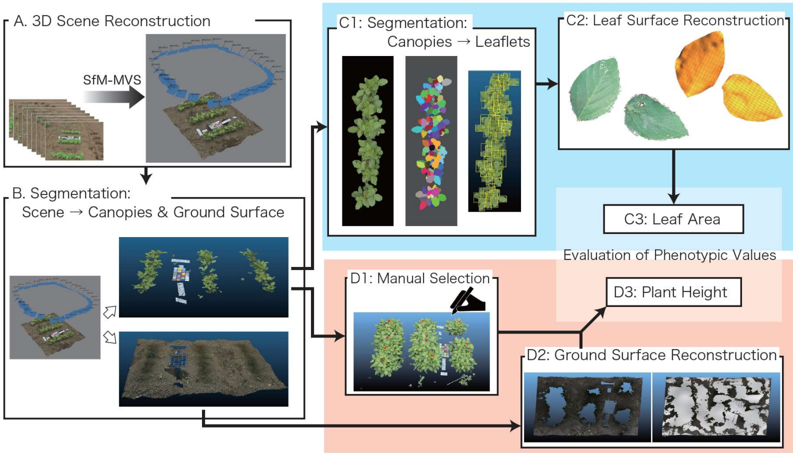
3D canopy structure



Noshita et al., unpublished.

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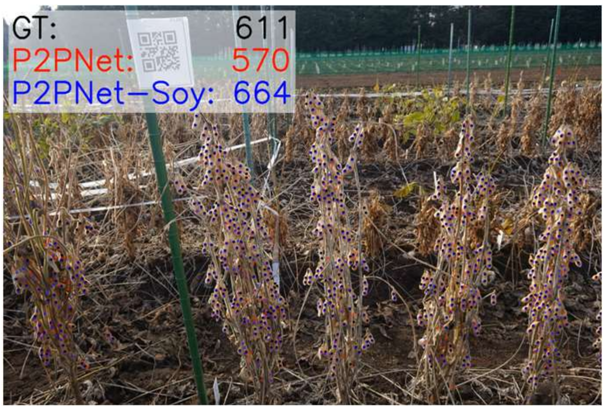
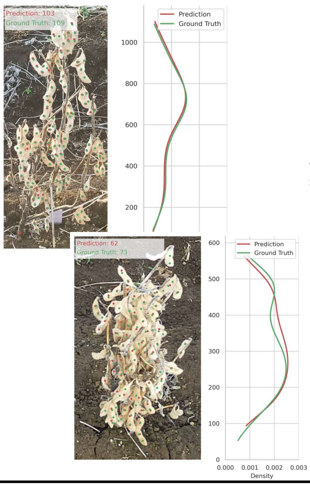
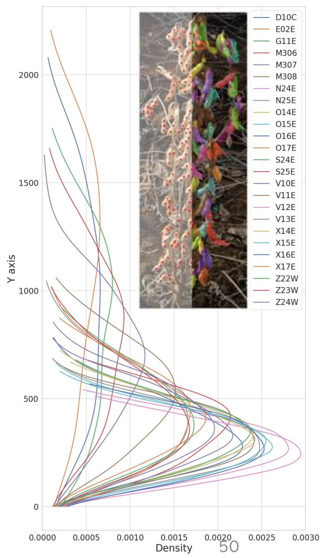
Vertical Seed Distribution

- Understand the vertical seed distribution







Zhao et al., Plant Phenomics 2023
Li et al., Plant Phenomics 2024

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What's next?

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The future of Sustainable Agro-ecosystems?

Picture Draw by ChatGPT 4o

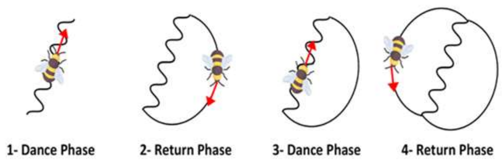
Phenotyping for Agro-ecosystems

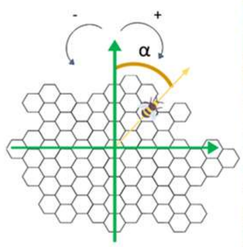
- Hive :
  - Bee waggle dance
- Plant :
  - Insects flower visiting behavior
- Field :
  - Land Use and Land Cover (LULC)

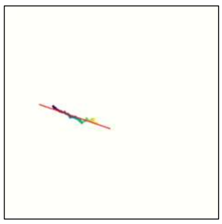
Picture Draw by ChatGPT 4o

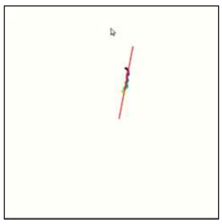
Grison et al., ongoing project.

Understand the waggle dance









Grison et al., ongoing project.

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Other topics

- Data labeling for AI
- Phenotyping for crop improvement
- Low cost high accurate 3D
- UAV and Cross-scale Data Fusion
- VR/Digital twin, metaverse
- Bioinformatics and social implementation
- Data farm and GAN
- Phenotyping for micro growth
- Phenotyping sensors and robots

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Conclusion

- Phenotyping techniques is **ready** (Partially ^^)
- Data driven agriculture has a bright future
- Bridging GAPs between **agriculture** and **computer science**
  - Need more Valuable Data
  - Domain knowledge
  - Stay with crops
  - Build the algorithms in the field
- Still looking for the innovation!
  - Smallholder farmers

- *Yield* $y = f_y(G, E, M)$

P:phenotype *G*: genotype *E*:Environment *M*: Management

$$y = f(G + E + M + G \times E + G \times M + E \times M)$$

………………

- *Quality* $q = f_q(G, E, M)$
- *Nitrogen uptake* $n = f_n(G, E, M)$
- *Water demand* $w = f_w(G, E, M)$

………………

- *Benefits* $b = f_b(G, E, M)$

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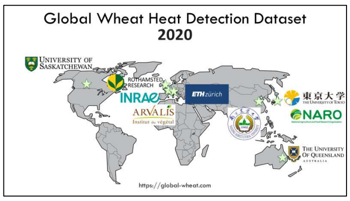
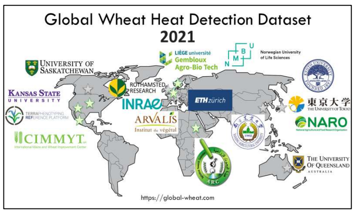
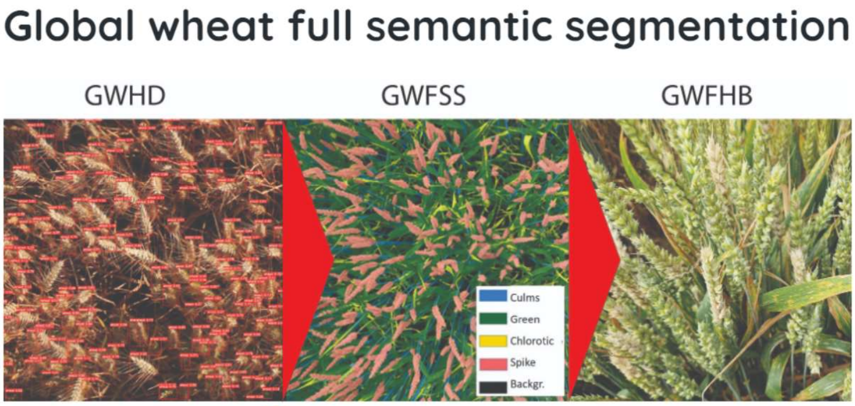
New Global Wheat (call for contributors)

- A Large and Diverse Dataset of High-Resolution RGB-Labelled Images







David, et al., Plant Phenomics, 2020 & 2021
http://www.global-wheat.com/

Global Wheat Datasets

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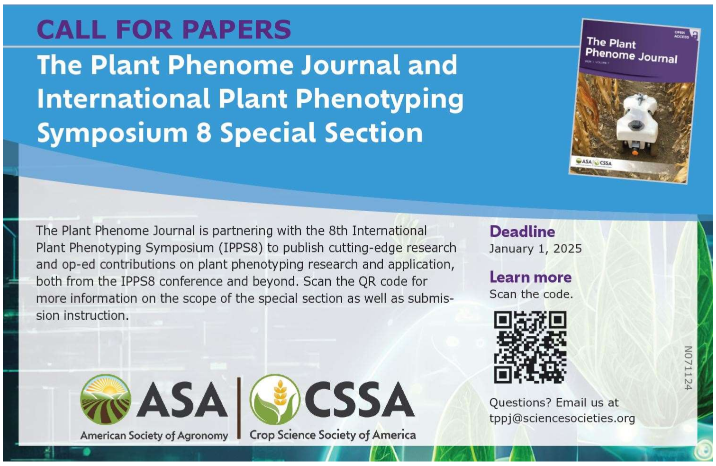
IPPS8 Special issue



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International Plant Phenotyping Network
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University of Nebraska – Lincoln
Kioumars Ghamkhar,
AgResearch
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University of Tokyo
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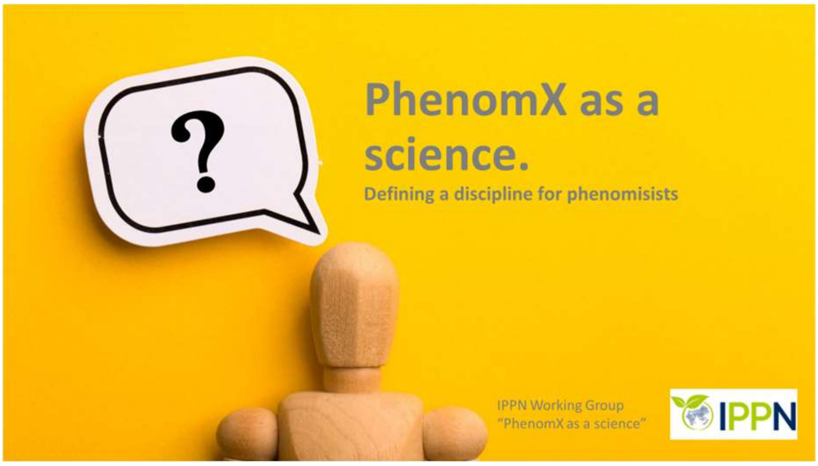
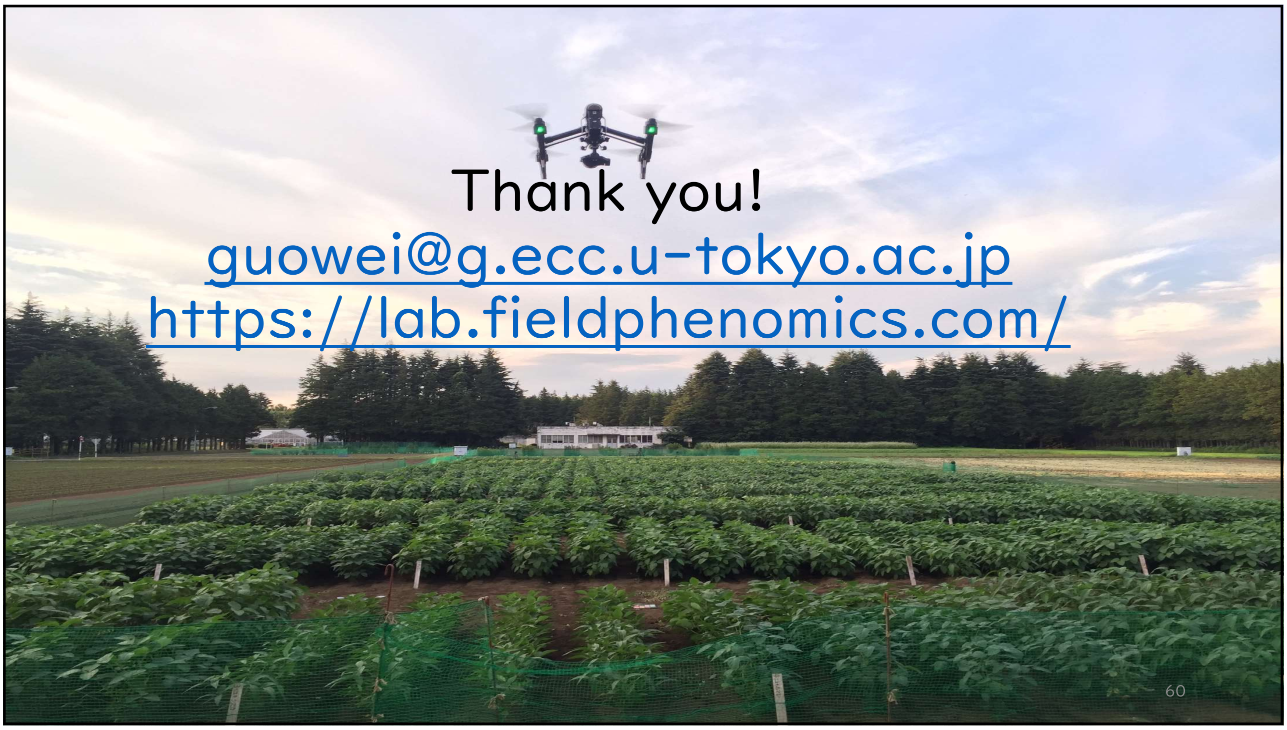
Michigan State University

https://acsess.onlinelibrary.wiley.com/journal/25782703

I am a phenomisist !



https://www.plant-phenotyping.org/IPPN_Working_Groups



Thank you!

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https://lab.fieldphenomics.com/