

# Artificial Intelligence in Plant Phenomics



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Artificial Intelligence Applications to Agriculture  
Texas A&M  
16 July 2020



Crop Development Center, Saskatoon, Canada



# P<sup>2</sup>IRC

Plant Phenotyping  
and Imaging  
Research Centre

Crop imaging



Roots/Soil



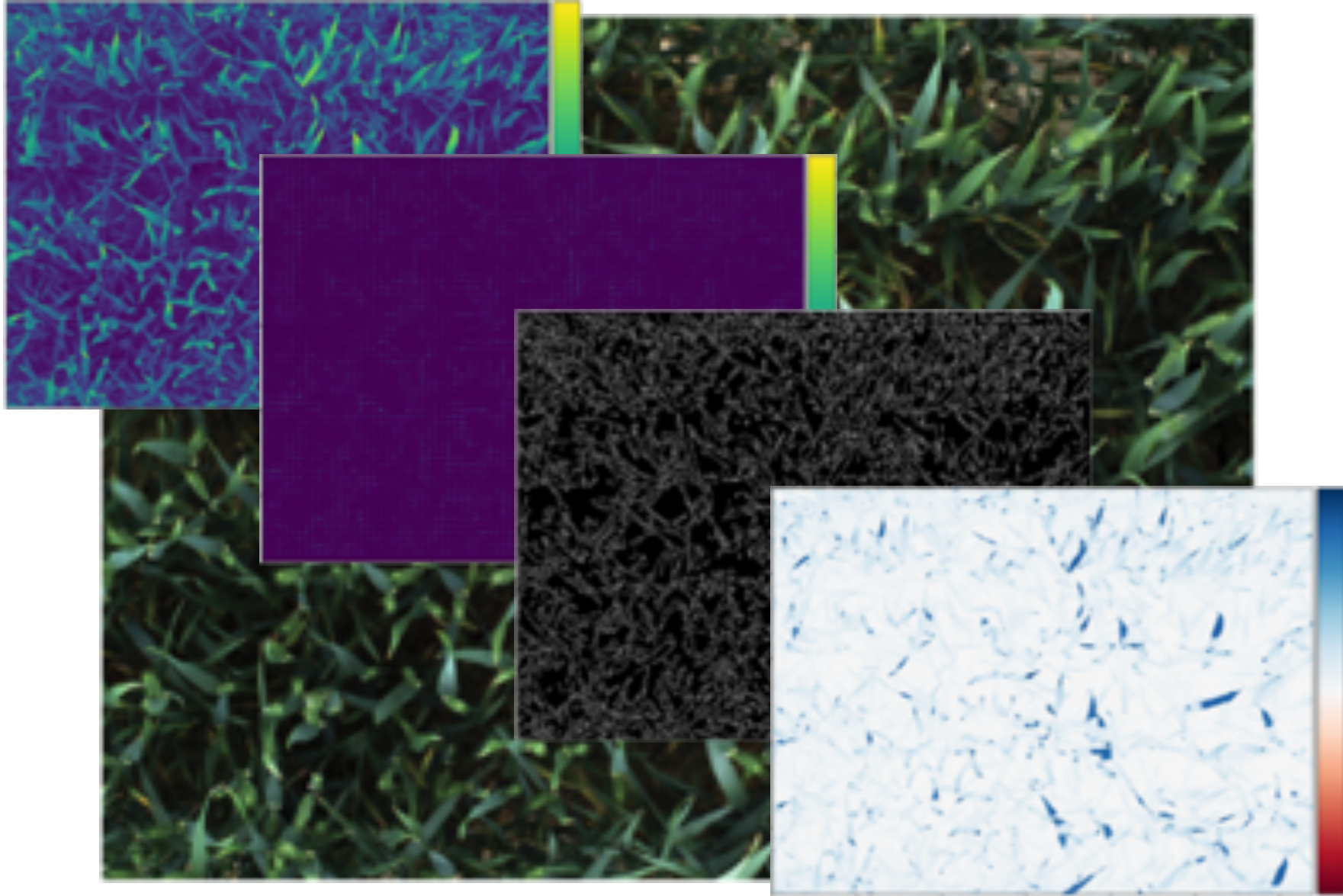
Deep learning



Plant breeding



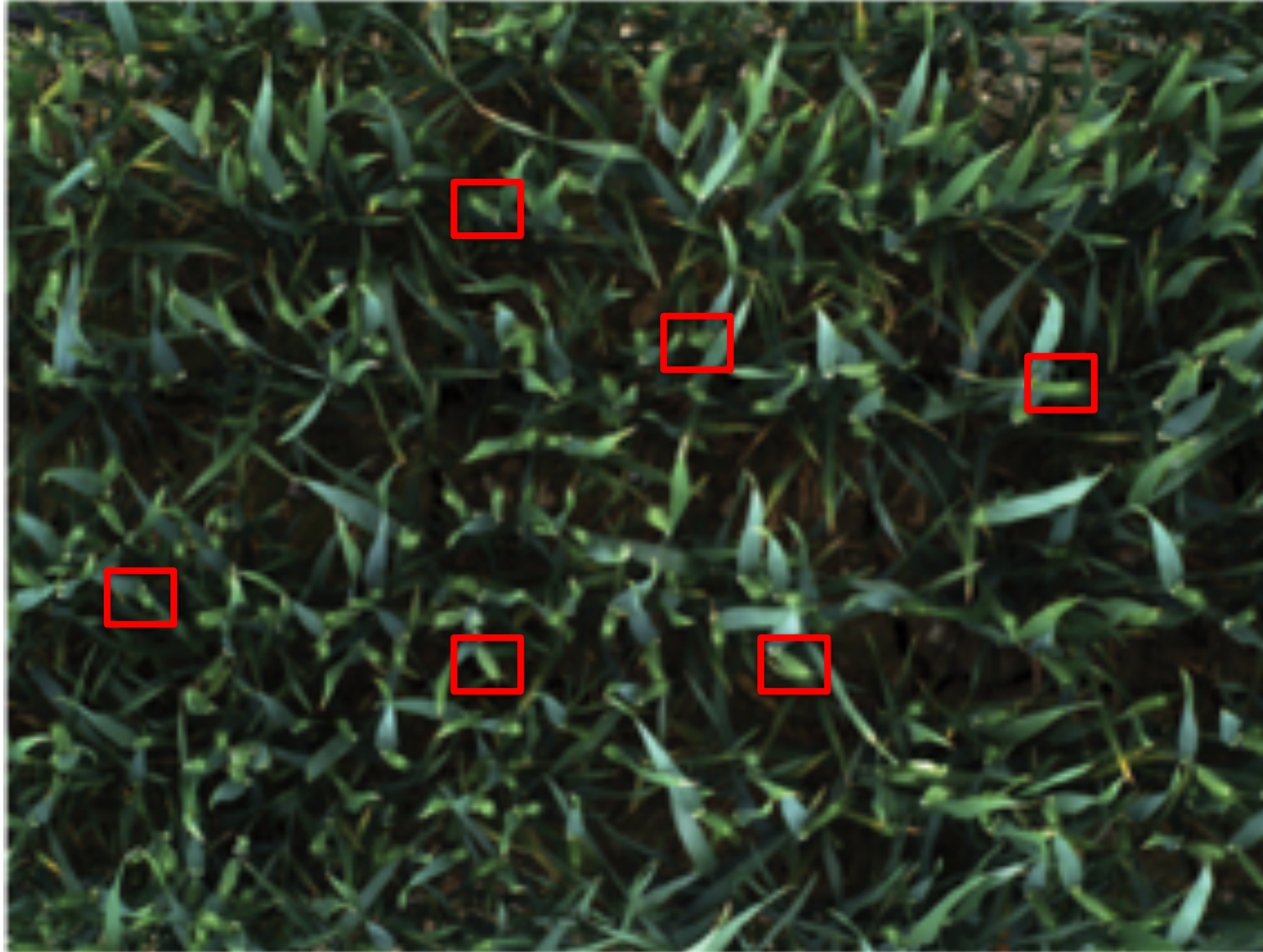
# Selecting features is hard



Sadeghi-Tehran et al. (2017). Automated Method to Determine Two Critical Growth Stages of Wheat: Heading and Flowering. *Front. in Plant Sci.*, 8(February), 1–14.



# Deep learning is representation learning

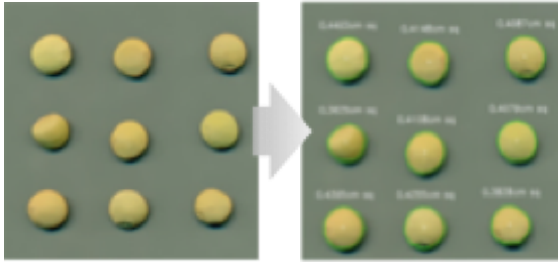


Sadeghi-Tehran et al. (2017). Automated Method to Determine Two Critical Growth Stages of Wheat: Heading and Flowering. *Front. in Plant Sci.*, 8(February), 1–14.

# Imaging & Deep Learning for Agriculture

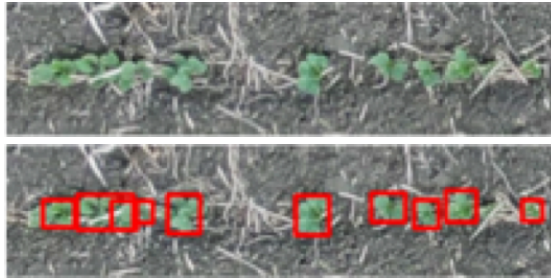
## Seed scale

*seed phenotyping,  
provenance*



## Plant scale

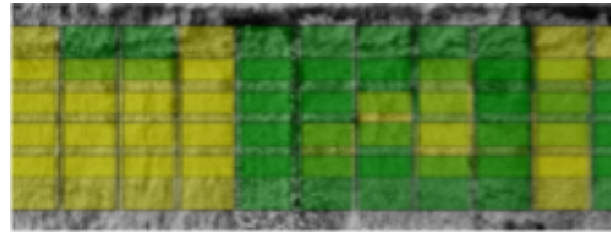
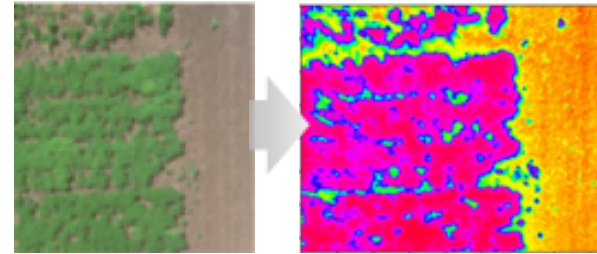
*identifying plants,  
estimating traits*



*early disease  
detection*

## Field scale

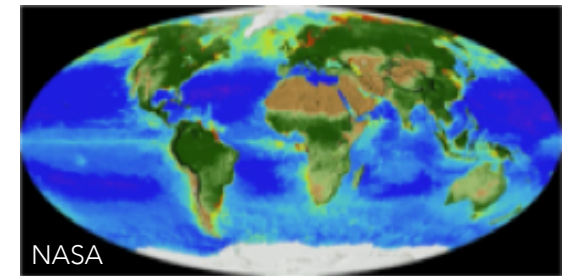
*crop health,  
precision management*



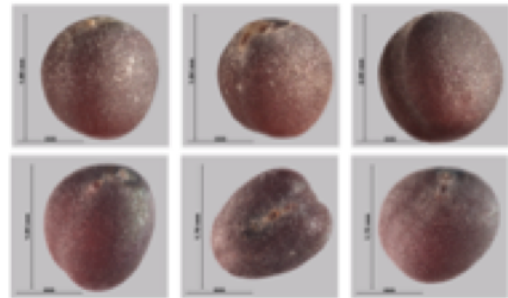
*crop damage,  
crop insurance*

## Global scale

*yield prediction,  
price forecasting*



*weather prediction,  
logistics*

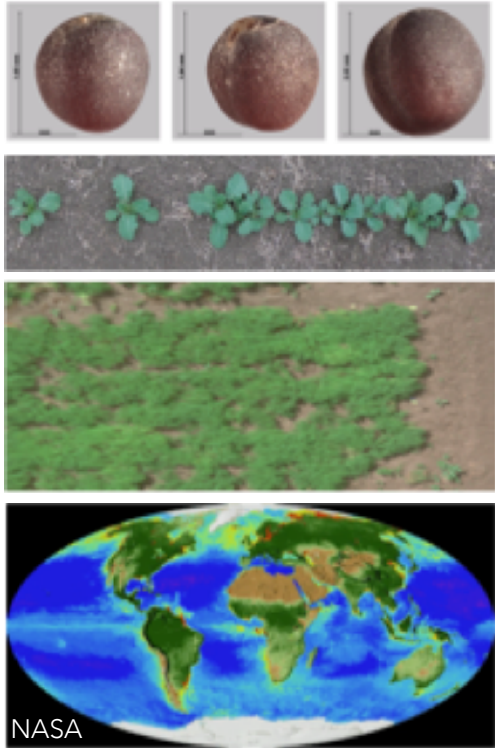


*automated seed  
inspection*

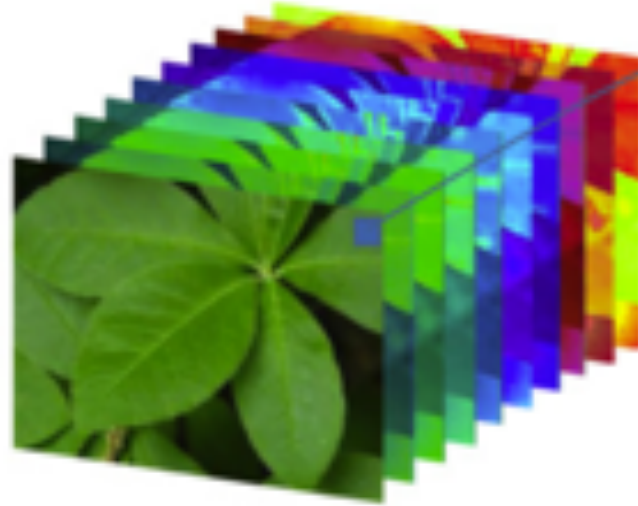


# Learned Features across Scales

## Spatial



## Spectral



(Mishra et al. 2017)

## Temporal



"Camera On A Stick"

# Image-based Phenotyping



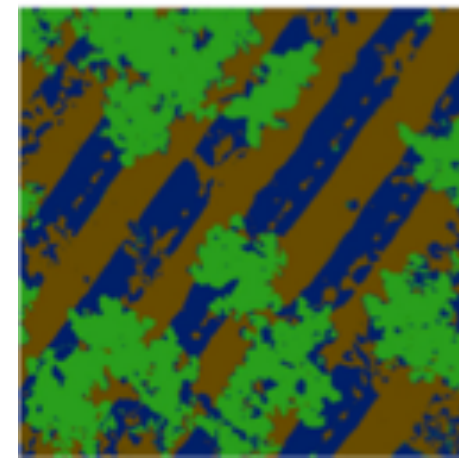
Classification  
/ Regression



Local  
Regression



Object  
Detection



Semantic  
Segmentation



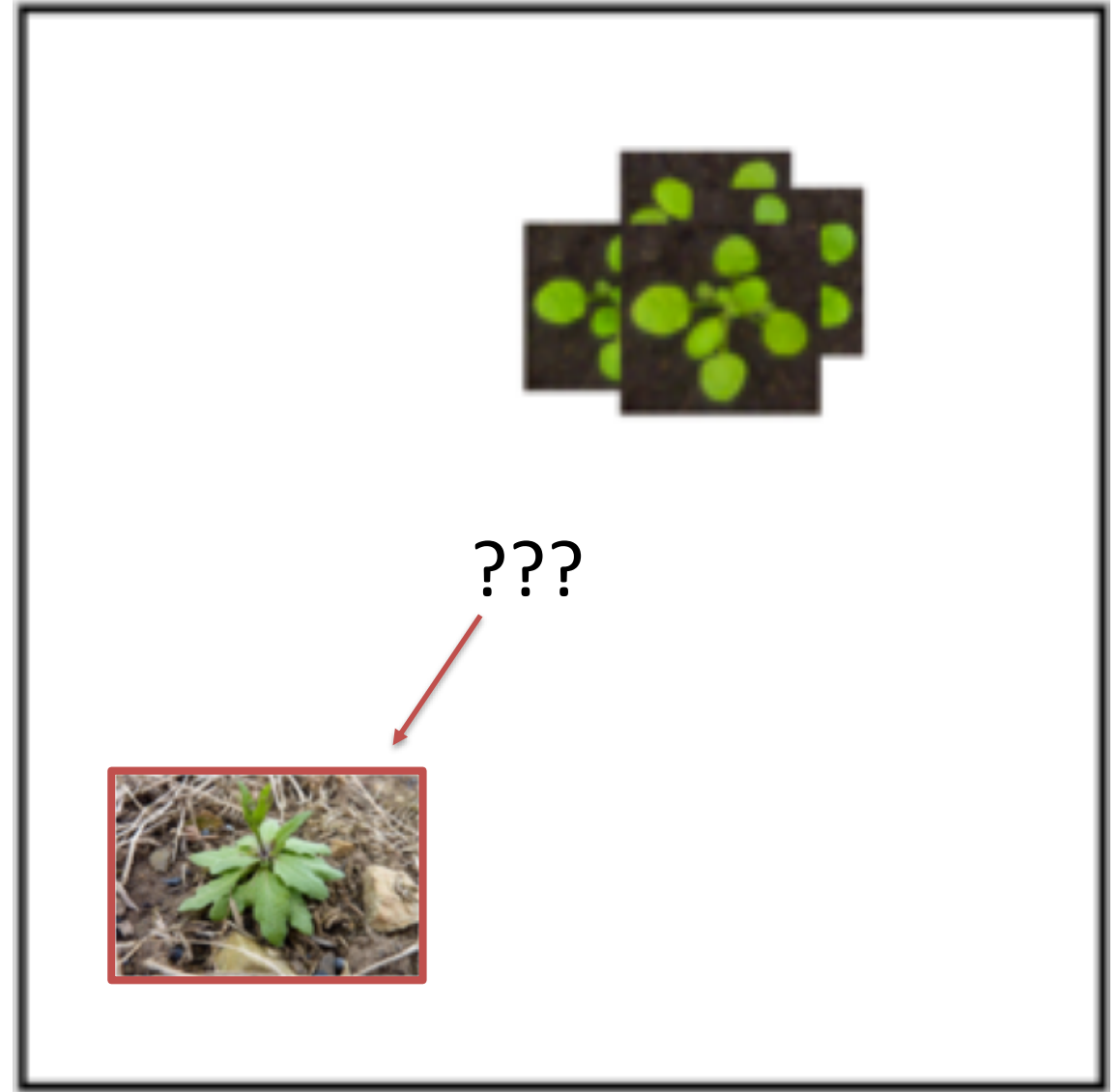
Instance  
Segmentation

## Deep Plant Phenomics

<https://github.com/p2irc/DeepPlantPhenomics>



# Challenge #1: Large diverse datasets



# New open datasets

## Global Wheat Head Dataset



<https://global-wheat.com>



# Global Wheat Head Detection Dataset



UTokyo\_1



UTokyo\_2



Arvalis\_1



Arvalis\_2



INRAE\_1



USask\_1



RRes\_1



ETHZ\_1



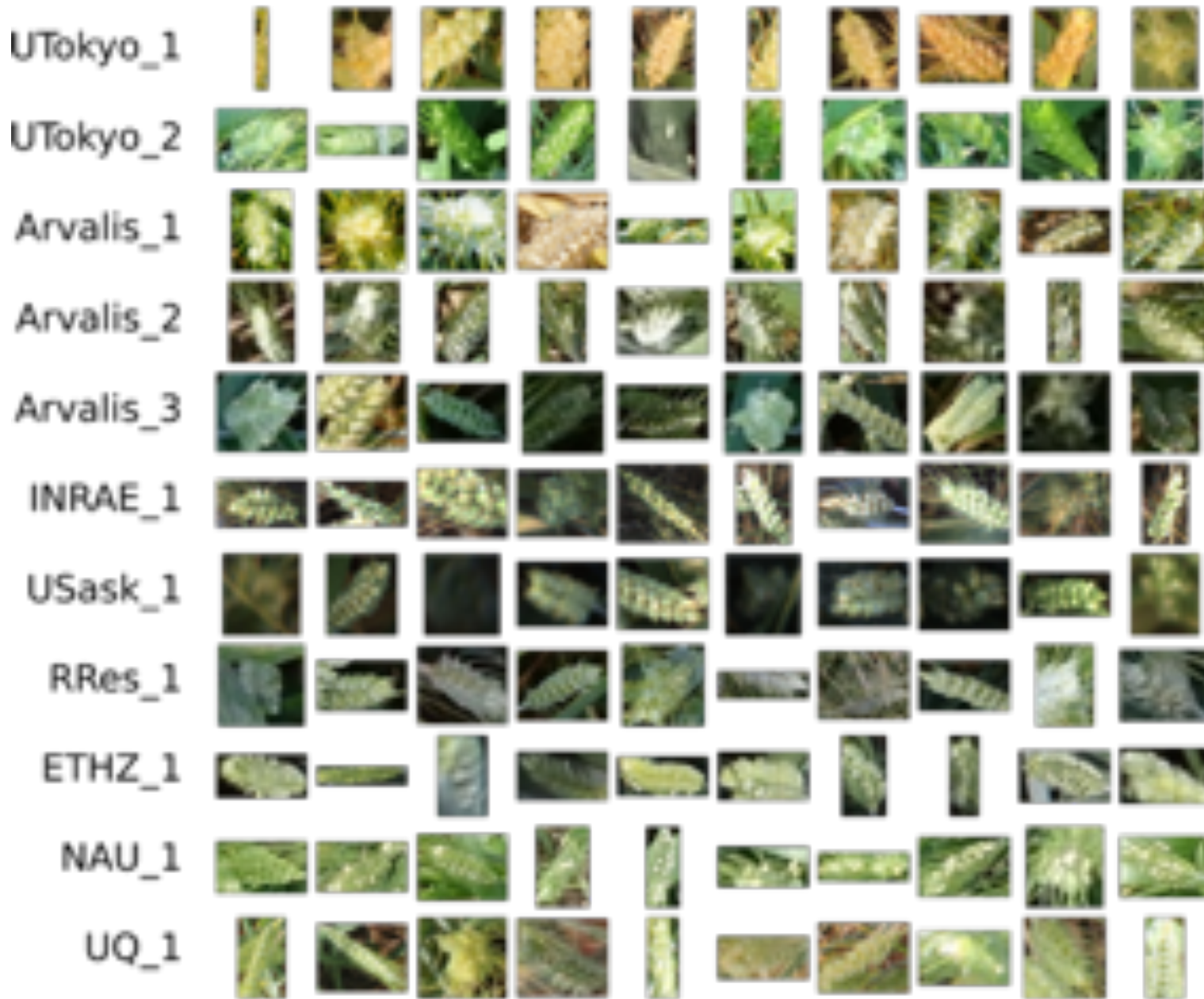
NAU\_1




UQ\_1

David, E., Madec, S., Sadeghi-Tehran, P., Aasen, H., Zheng, B., Liu, S., Pozniak, C., Stavness, I., Guo, W. (2020). Global Wheat Head Detection (GWHD) dataset. *Plant Phenomics*, *in press*.

# Global Wheat Head Detection Dataset





 Research Code Competition

## Global Wheat Detection

Can you help identify wheat heads using image analysis?

**\$15,000**

Prize Money



University of Saskatchewan · 1,799 teams · 19 days to go (12 days to go until merger deadline)

[Overview](#)[Data](#)[Notebooks](#)[Discussion](#)[Leaderboard](#)[Rules](#)[Host](#)[Join Competition](#)

Overview

Edit

Description

Evaluation

Timeline

Open up your pantry and you're likely to find several wheat products. Indeed, your morning toast or cereal may rely upon this common grain. Its popularity as a food and crop makes wheat widely studied. To get large and accurate data about wheat fields worldwide, plant



# *Global Wheat Data: Future Contributions*



<https://global-wheat.com>



# PlotVision



TRIAL

FIELD

YEAR

SOURCE

OKU1000

11

11

Search

RESET

TRIAL

**PHENOCANOLA**

FIELD

Llewellyn AAFC Farm

YEAR

2018

SOURCE

OKU1000

NETWORK

Trial Map

GCPs Uploaded

2018-06-20

2018-06-21

2018-06-22

2018-06-23

2018-06-24

2018-06-25

2018-06-26

2018-06-27

2018-06-28

2018-06-29

2018-06-30

2018-07-01

2018-07-02

2018-07-03

2018-07-04

2018-07-05

2018-07-06

2018-07-07

2018-07-08

2018-07-09

2018-07-10

2018-07-11

2018-07-12

SHOW

2018-07-30

SHOW BY STAGE

2018-07-30

ACTIONS

STATUS

NETWORK

GCPs Georeference

Camera Georeference

Drone Logs

TRIAL

**PHENOLENTIL**

FIELD

Nasser Kernen

YEAR

2018

SOURCE

OKU1000

NETWORK

Trial Map

GCPs Uploaded

2018-06-20

2018-06-21

2018-06-22

2018-06-23

2018-06-24

2018-06-25

2018-06-26

2018-06-27

2018-06-28

2018-06-29

2018-06-30

2018-07-01

2018-07-02

2018-07-03

2018-07-04

2018-07-05

2018-07-06

2018-07-07

2018-07-08

2018-07-09

2018-07-10

2018-07-11

2018-07-12

SHOW

2018-07-09

SHOW BY STAGE

2018-07-09

ACTIONS

STATUS

NETWORK

GCPs Georeference

Camera Georeference

Drone Logs

TRIAL

**PHENOWHEAT**

FIELD

Nasser Kernen

YEAR

2018

SOURCE

OKU1000

NETWORK

Trial Map

GCPs Uploaded

2018-06-20

2018-06-21

2018-06-22

2018-06-23

2018-06-24

2018-06-25

2018-06-26

2018-06-27

2018-06-28

2018-06-29

2018-06-30

2018-07-01

2018-07-02

2018-07-03

2018-07-04

2018-07-05

2018-07-06

2018-07-07

2018-07-08

2018-07-09

2018-07-10

2018-07-11

2018-07-12

SHOW

2018-07-12

SHOW BY STAGE

2018-07-12

ACTIONS

STATUS

NETWORK

GCPs Georeference

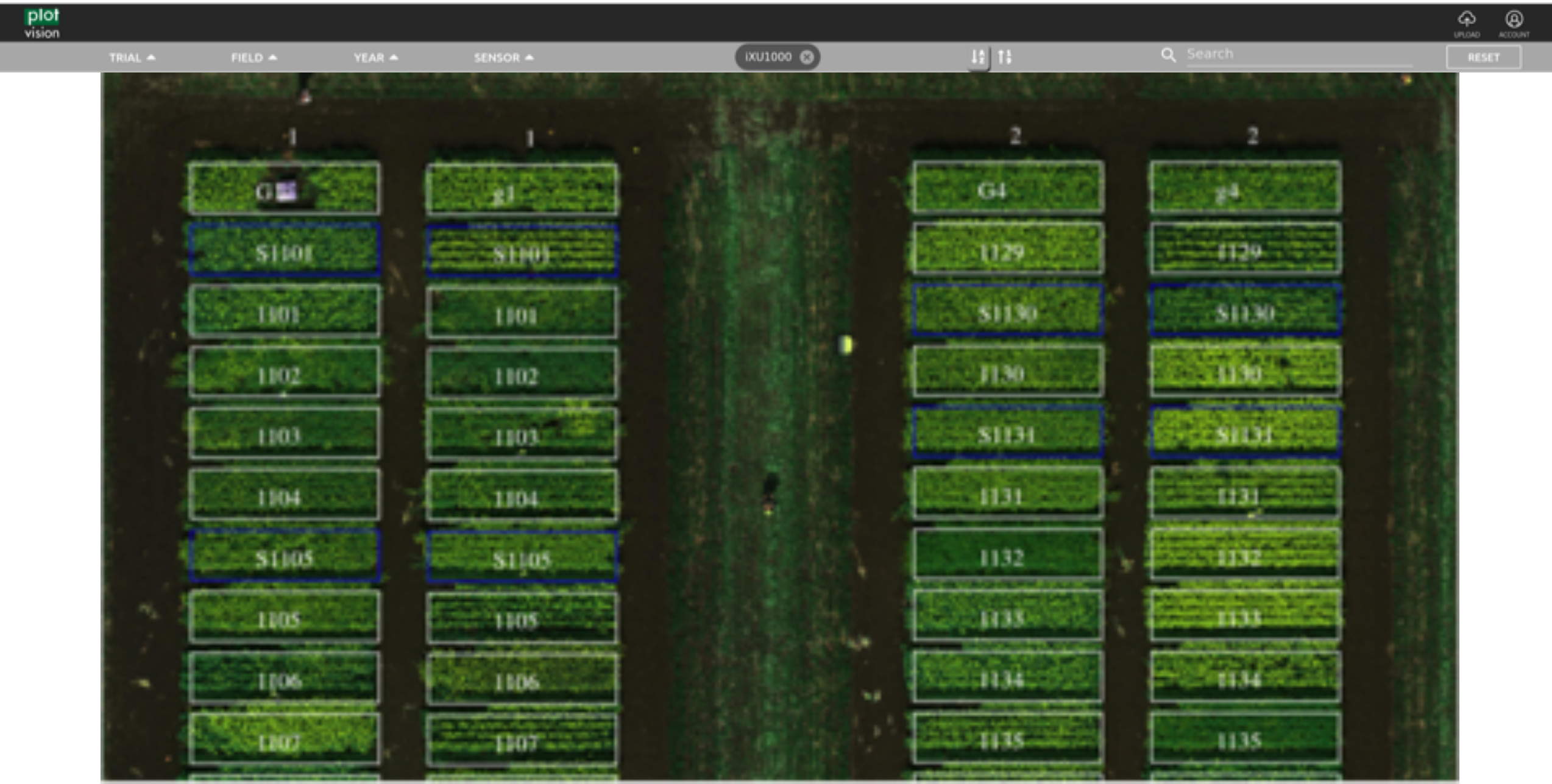
Camera Georeference

Drone Logs

DRONE UPLOADS

Report an issue

# PlotVision

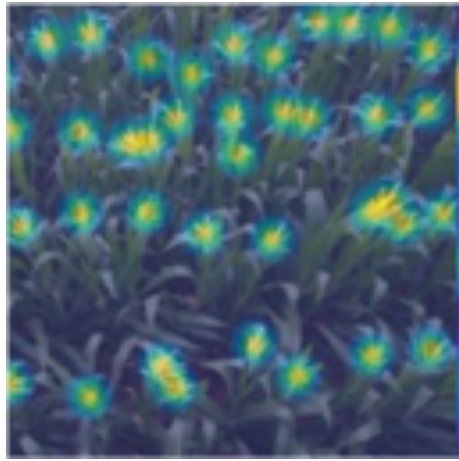




# Challenge #2: Image annotation



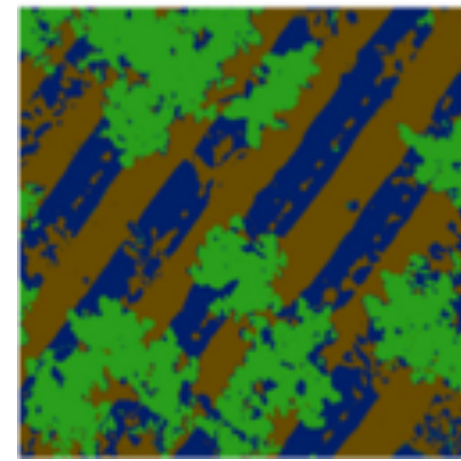
Label for  
whole image



Dot on each  
object



Box around  
each object



Draw outlines



Draw outlines  
for each object

Low cost

High cost

# Latent Space Phenotyping

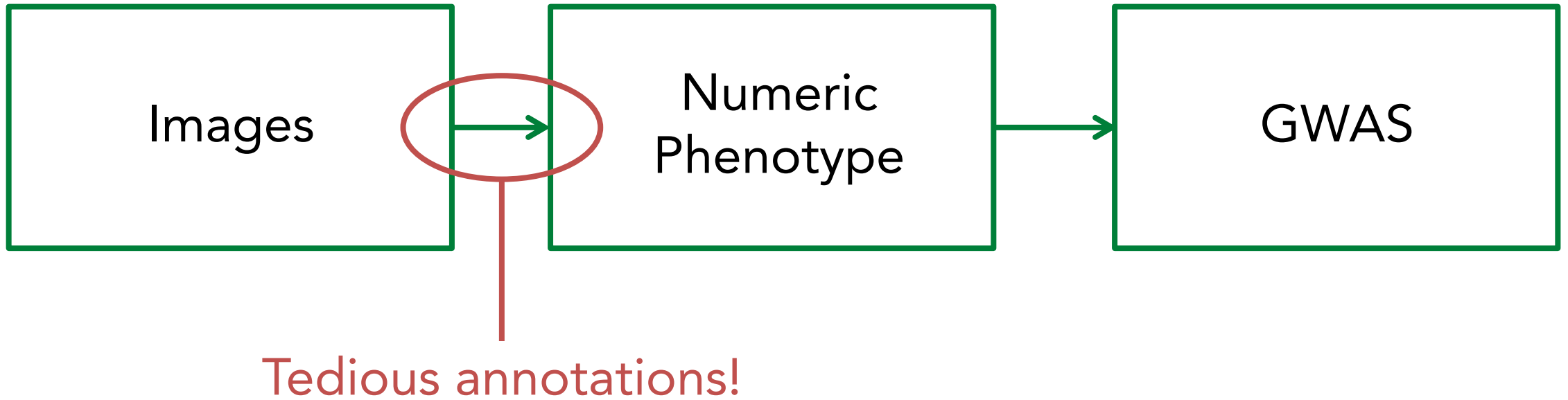
Phenotype-to-genotyping mapping for stress resistance

<https://github.com/p2irc/LSPlab>



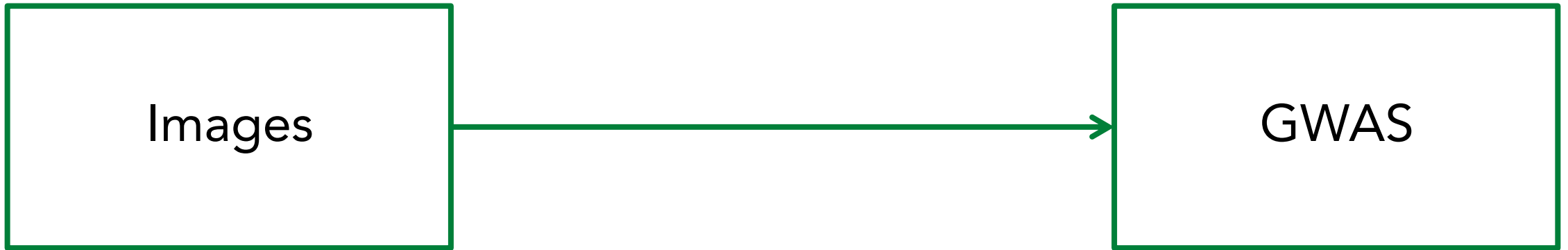
Ubbens, J., Cieslak, M., Prusinkiewicz, P., Parkin, I., Ebersbach, J., & Stavness, I. (2020). Latent space phenotyping: automatic image-based phenotyping for treatment studies. *Plant Phenomics*, 2020, 5801869

# Image-based Phenotyping

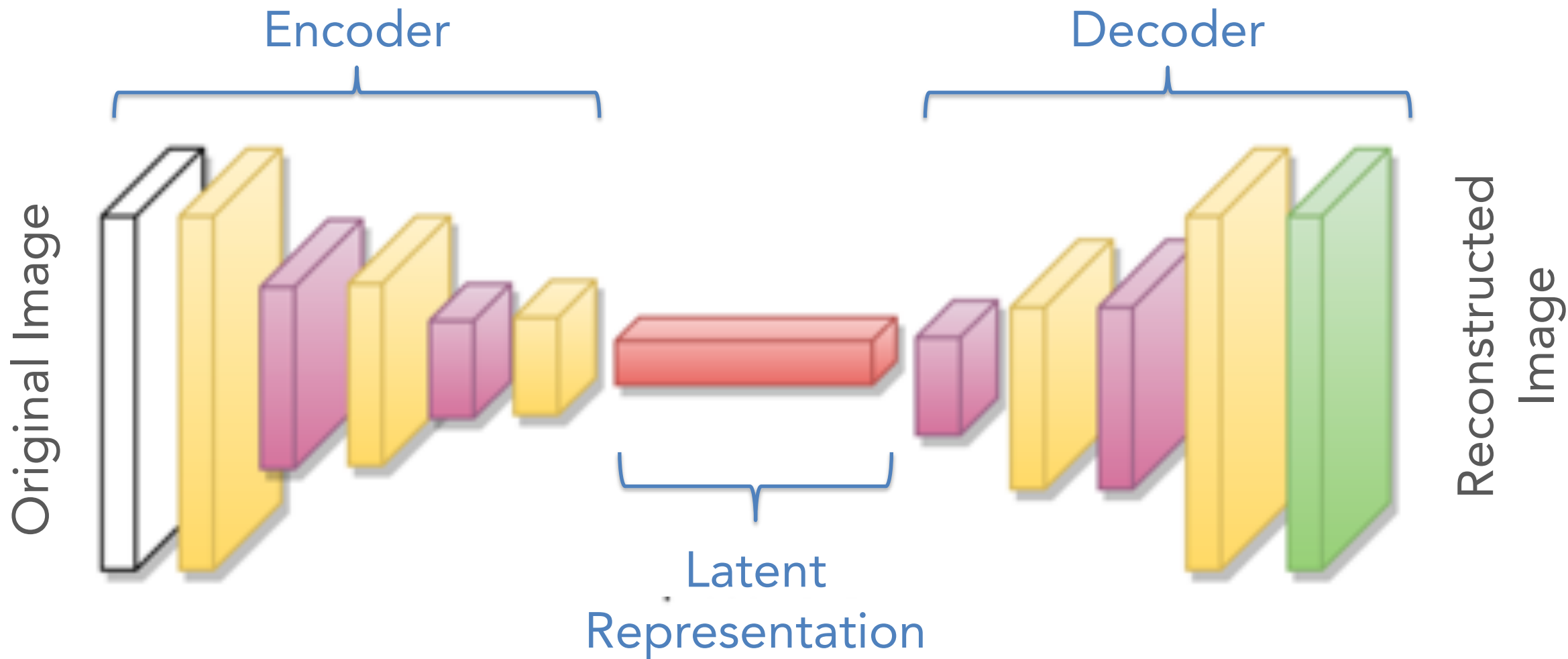




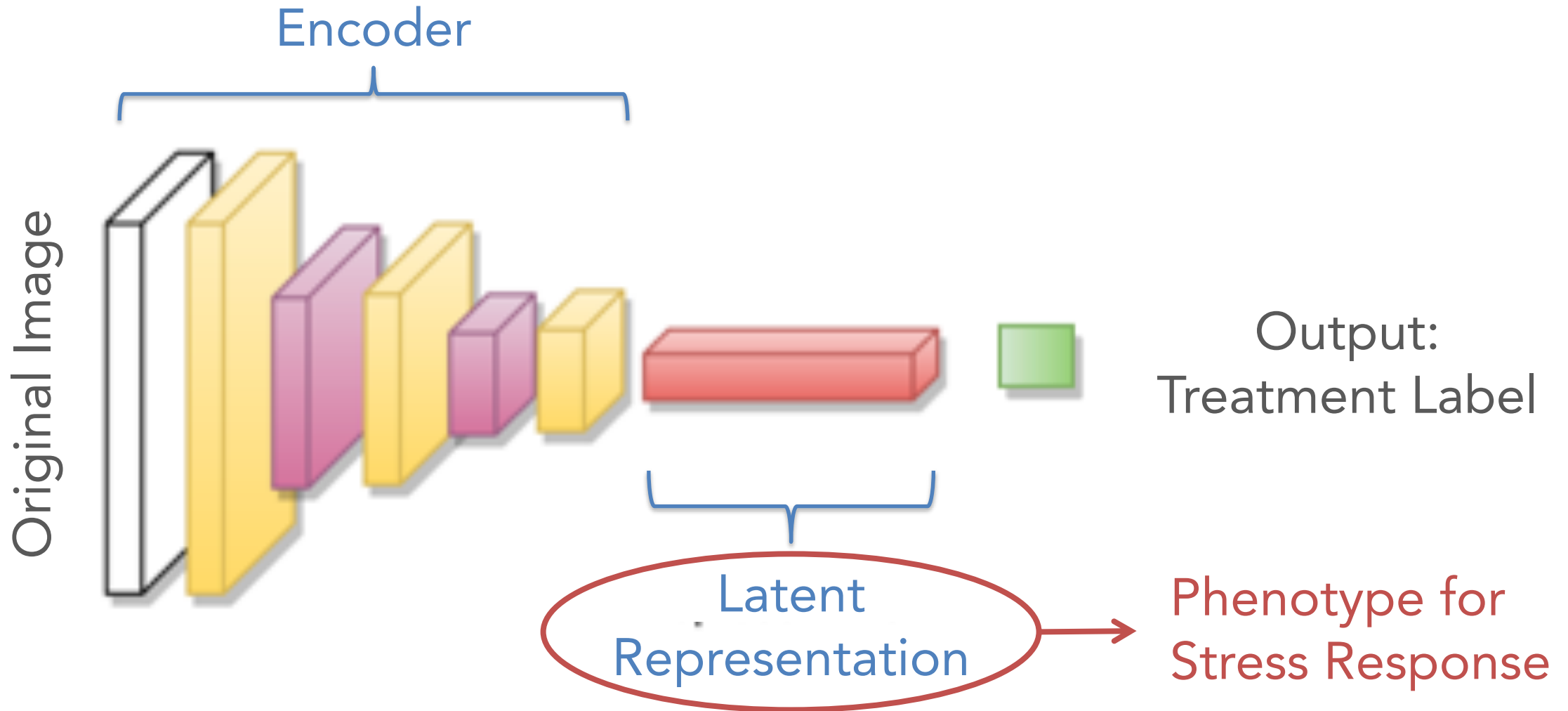
# Latent Space Phenotyping



# Latent variable models

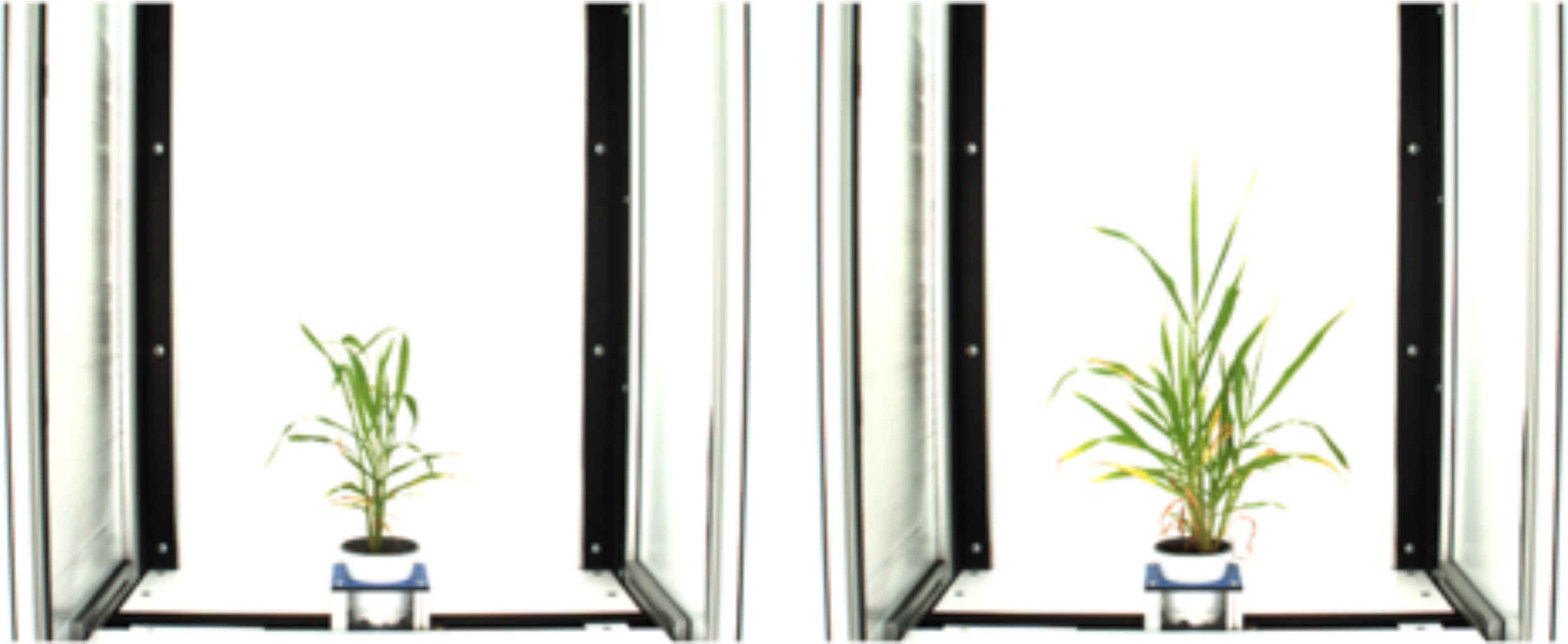


# Latent variable models



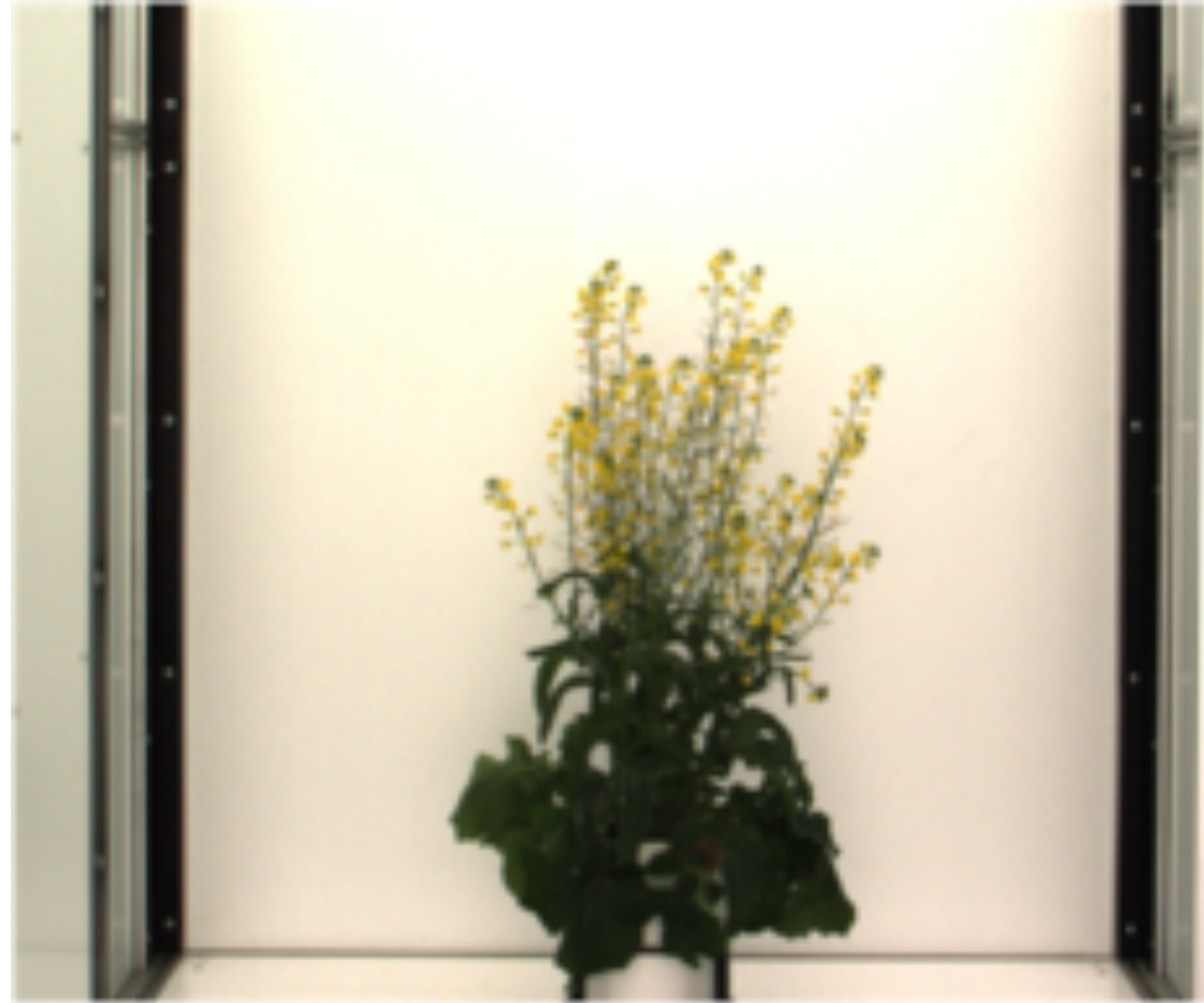
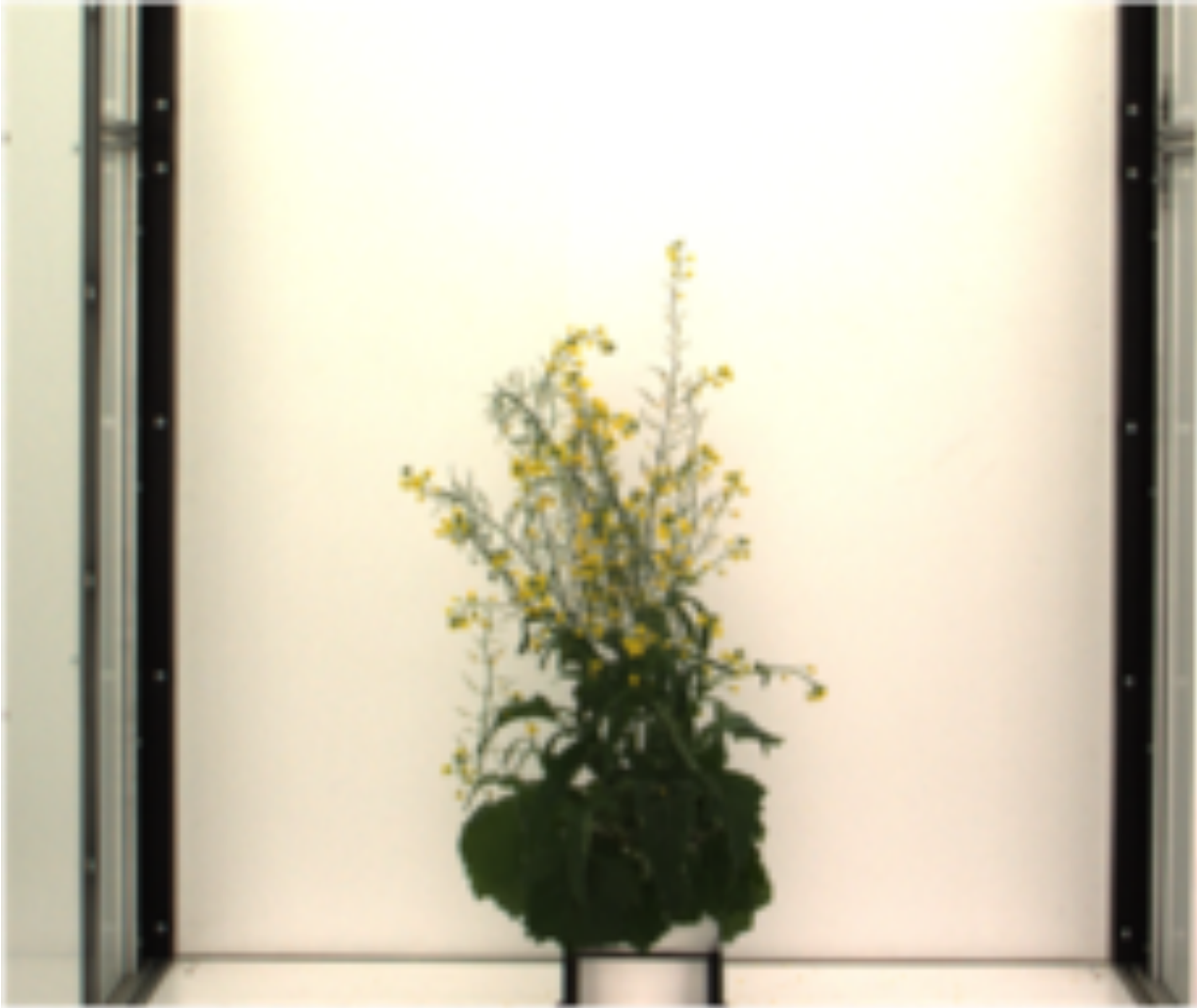


# Datasets: Setaria RIL

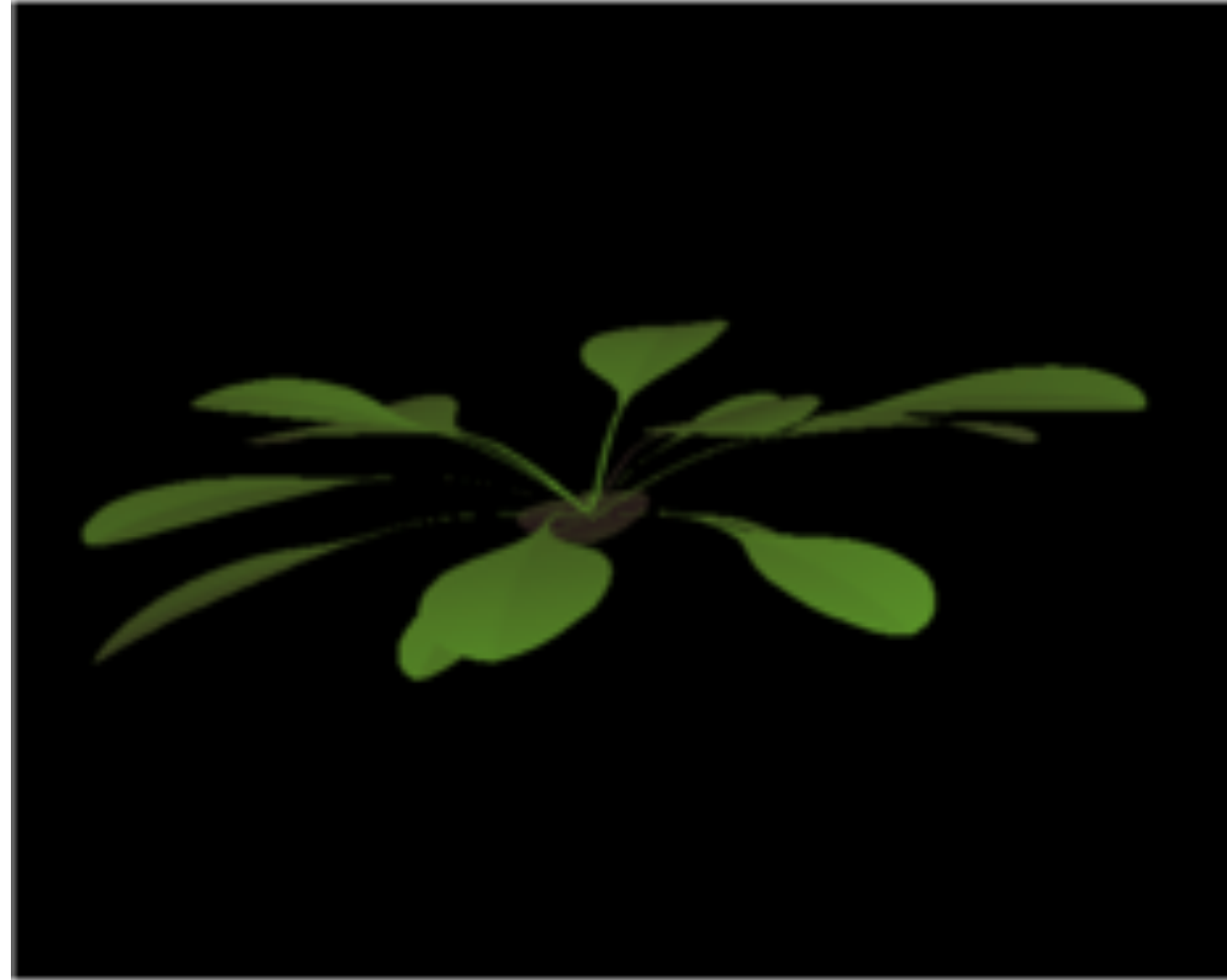


Feldman et al. (2018). Components of Water Use Efficiency Have Unique Genetic Signatures in the Model  $C_4$  Grass *Setaria*. *Plant Phys.*, 178(2), 699–715.

# Datasets: Canola NAM



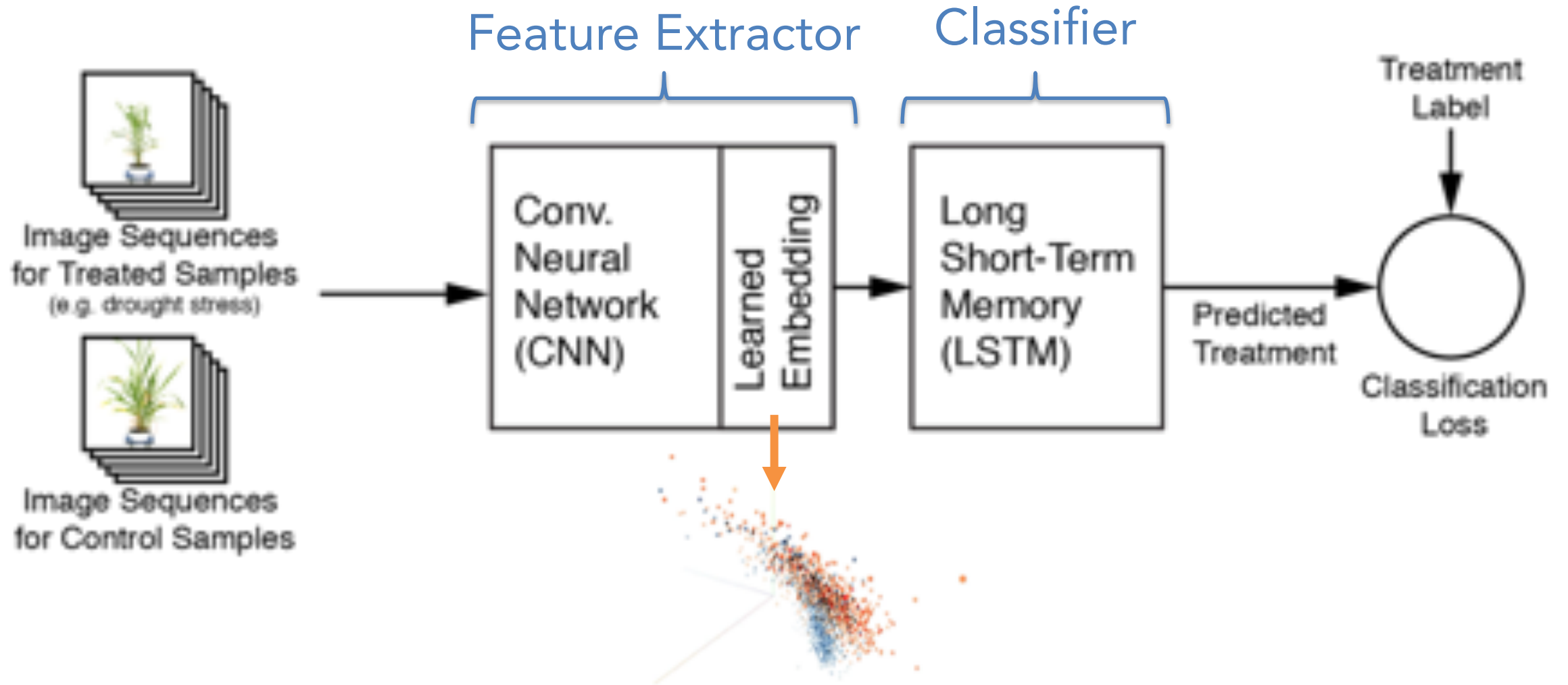
# Datasets: Synthetic Arabidopsis



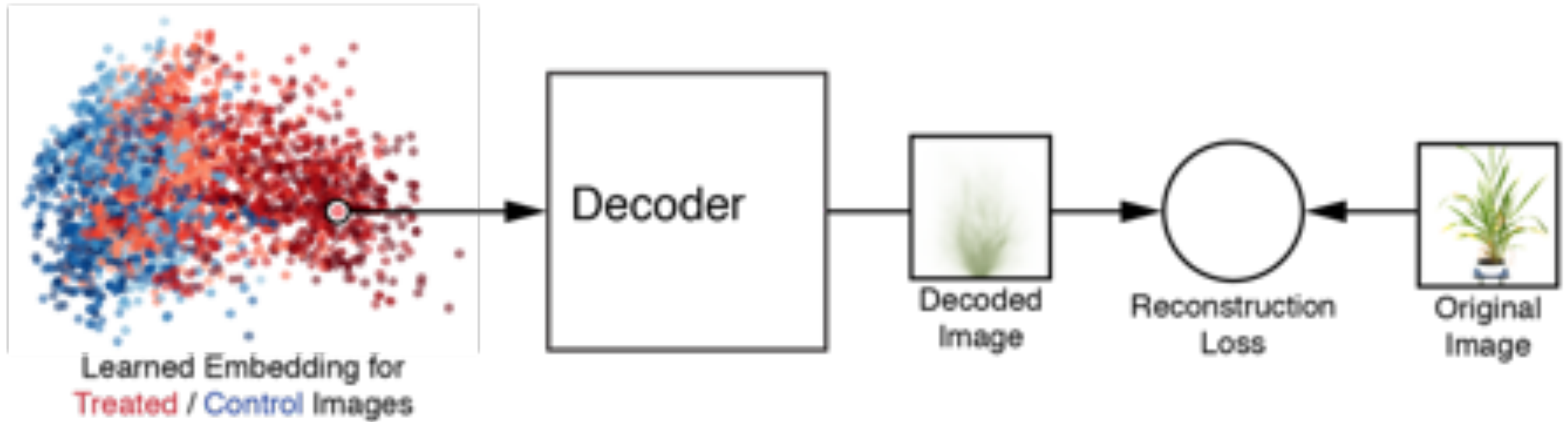
- Genomic data from the *A. thaliana* polymorphism database
- Images generated from a 3D L-system model



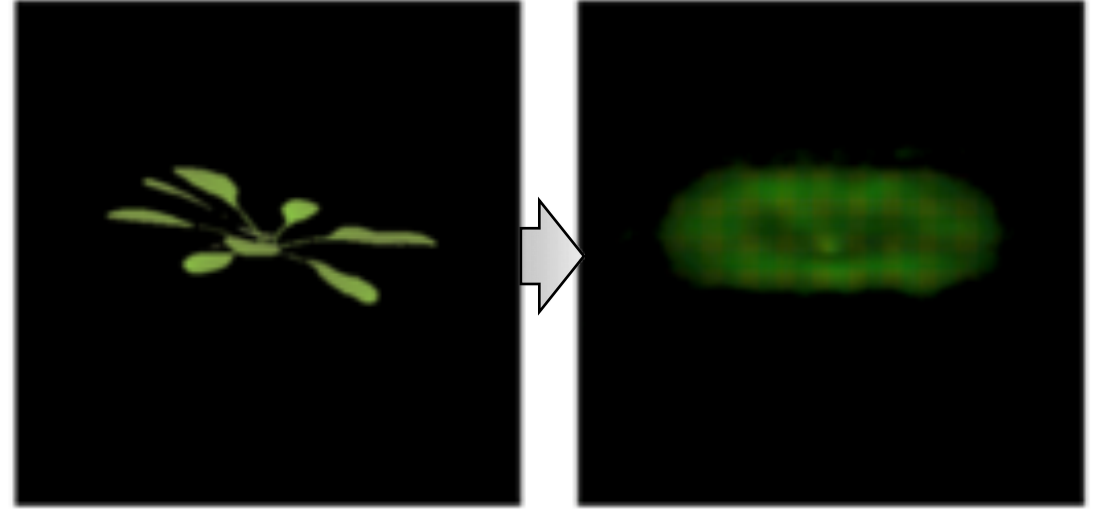
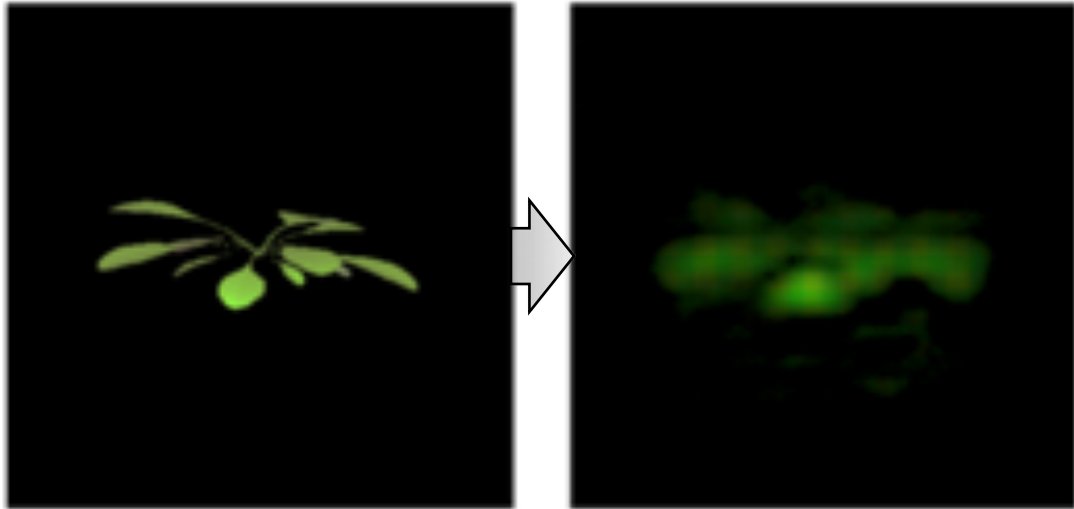
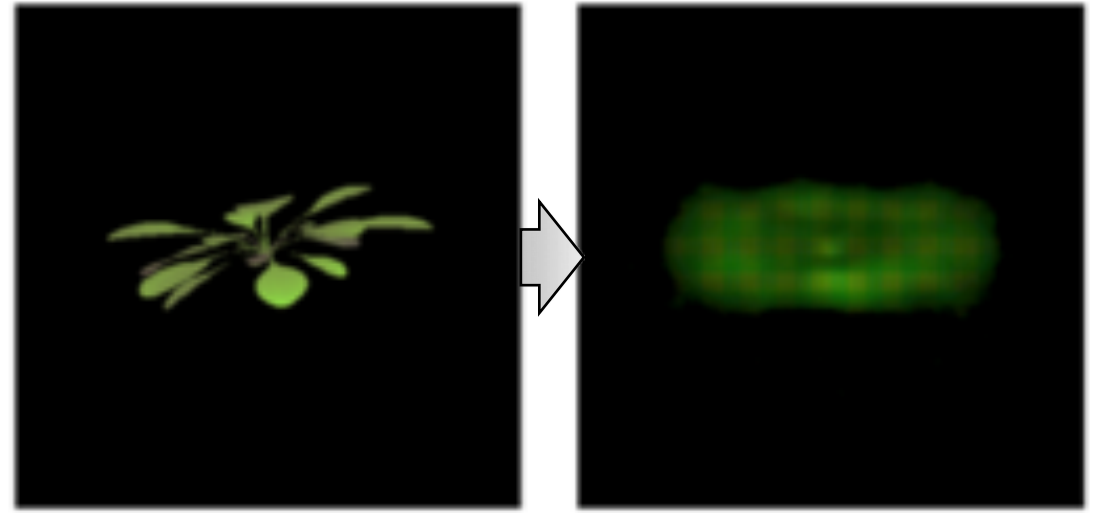
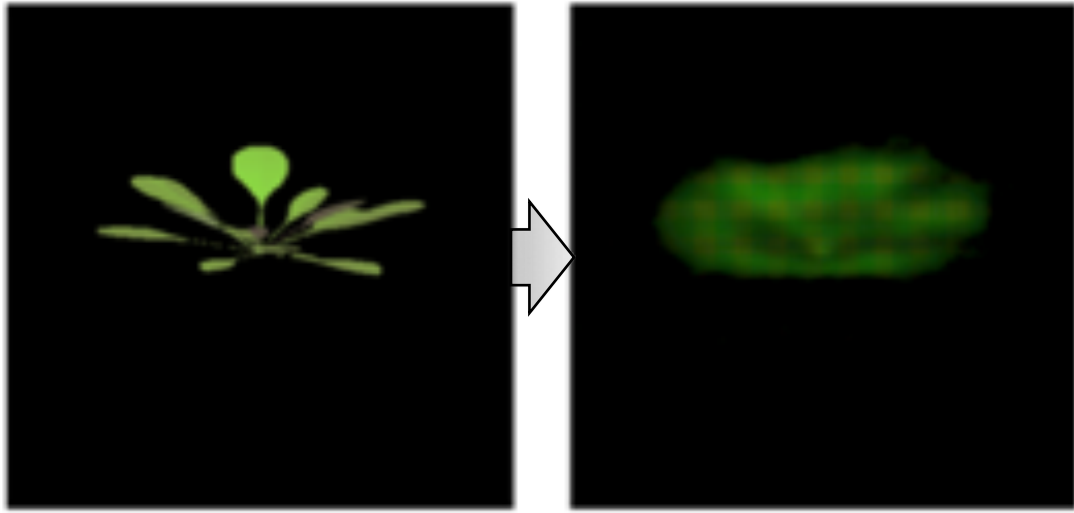
# Embedding Process



# Decoding Process

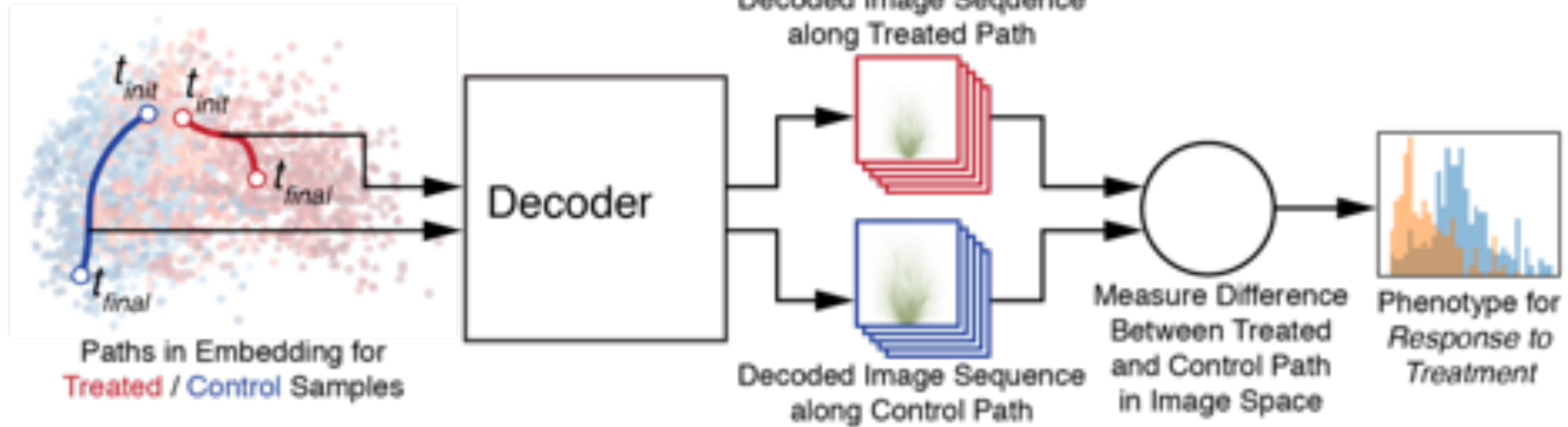


# Example decoded images



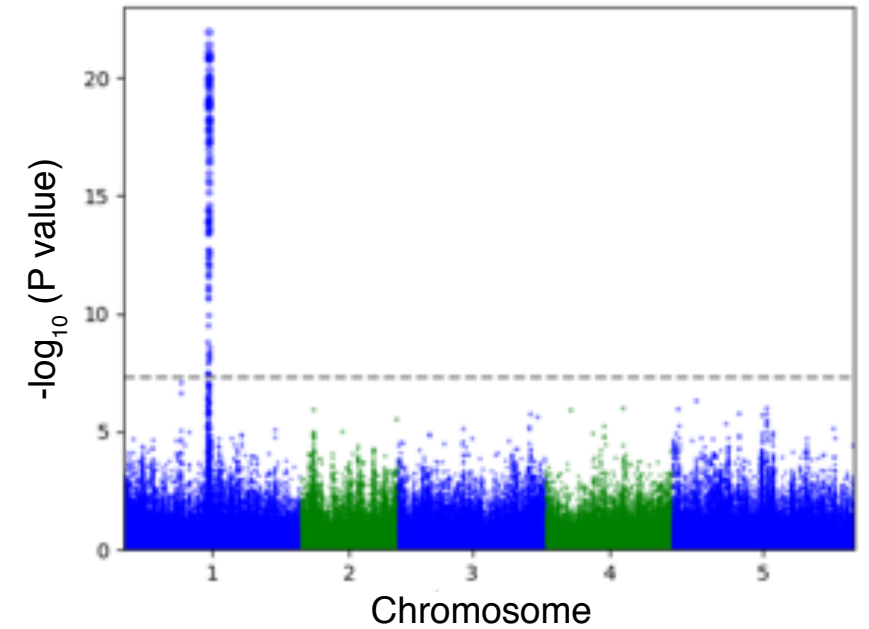
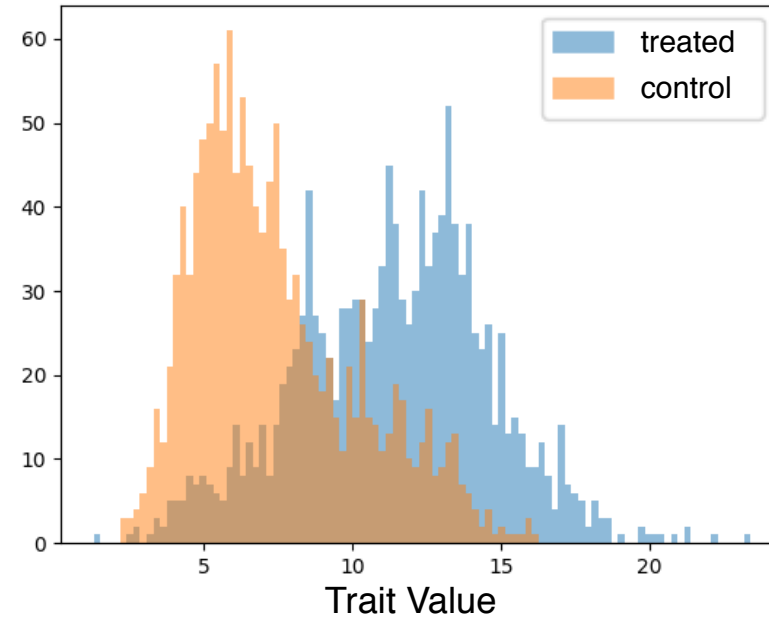
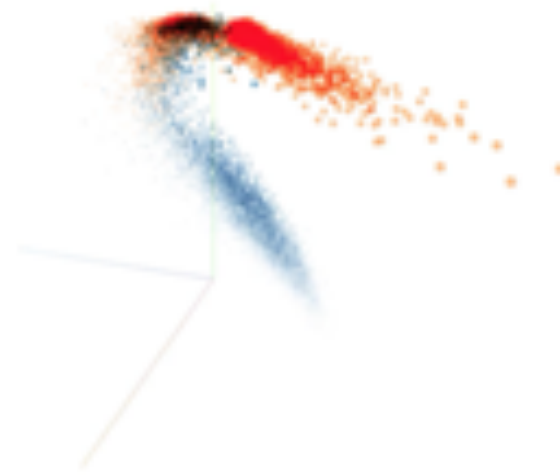


# Measuring Response-to-Treatment

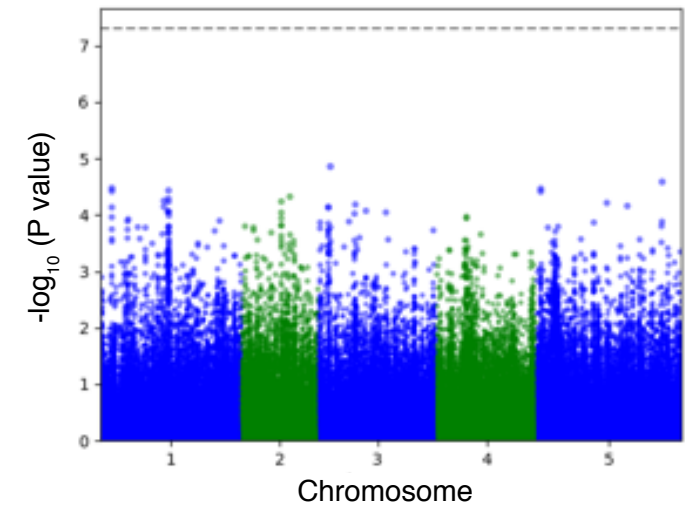
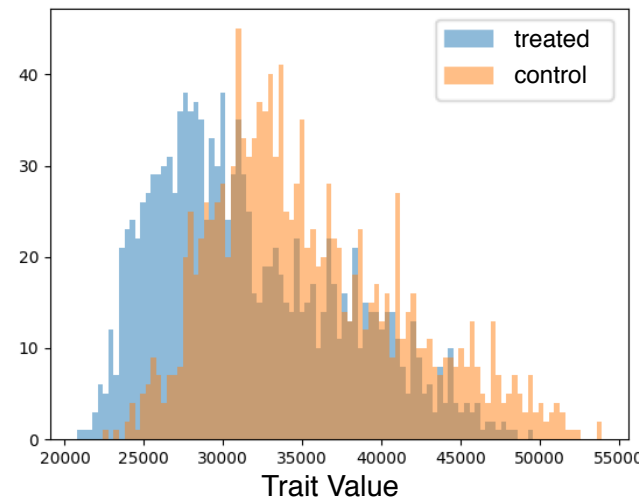




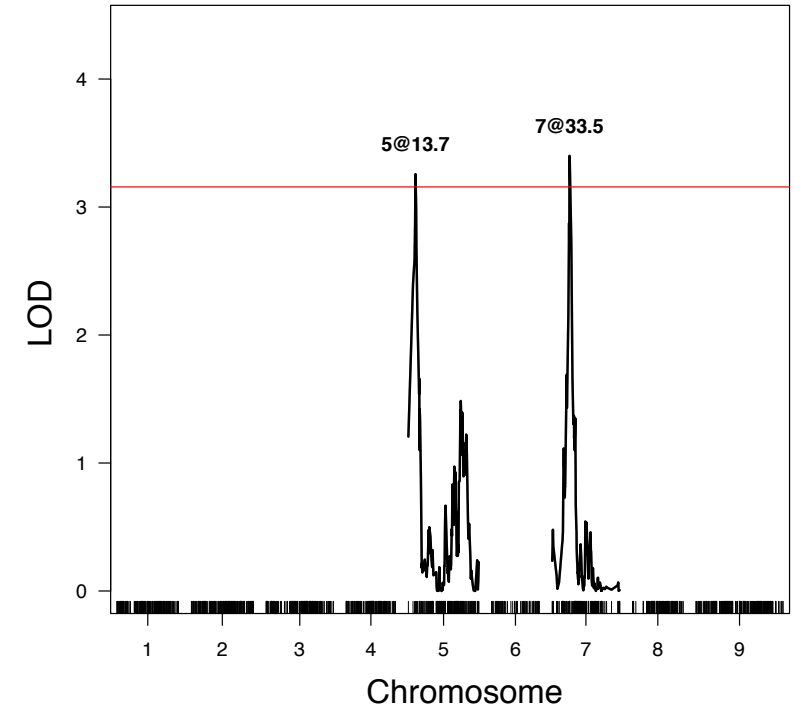
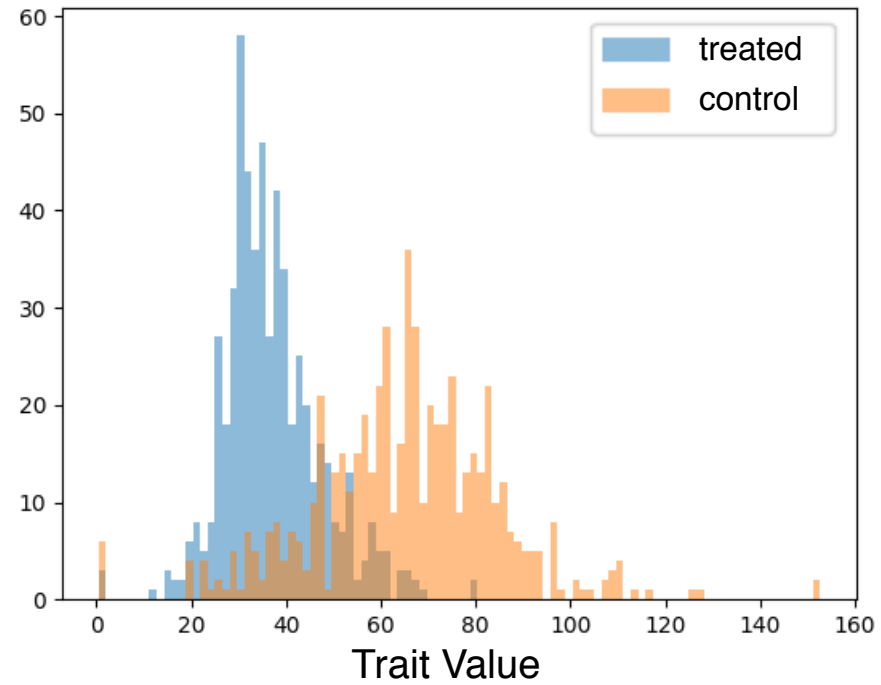
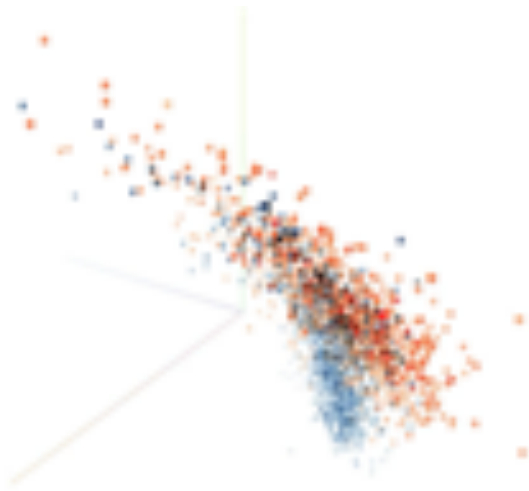
# Results: Synthetic Arabidopsis



What if we use  
simple image  
distance instead?

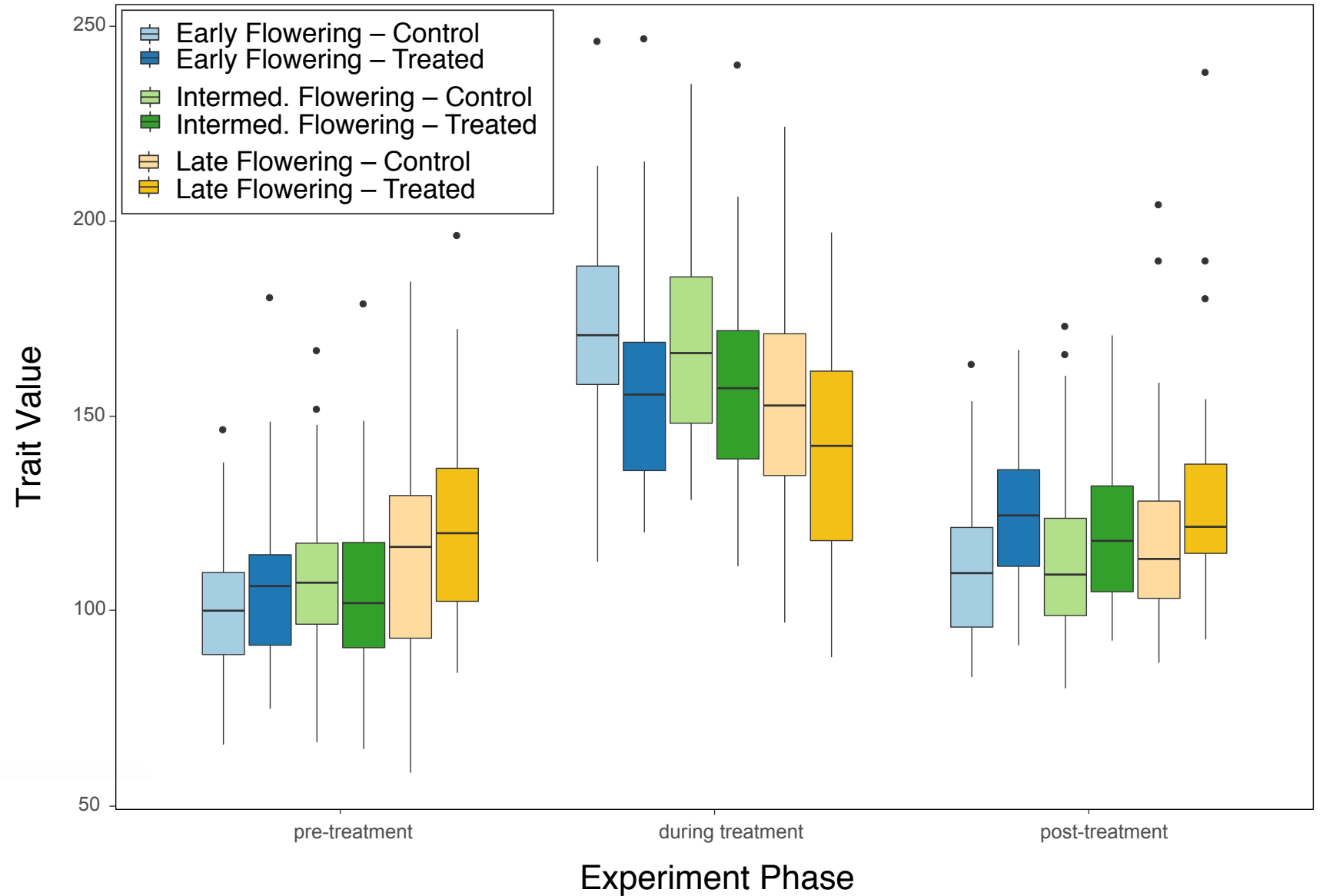
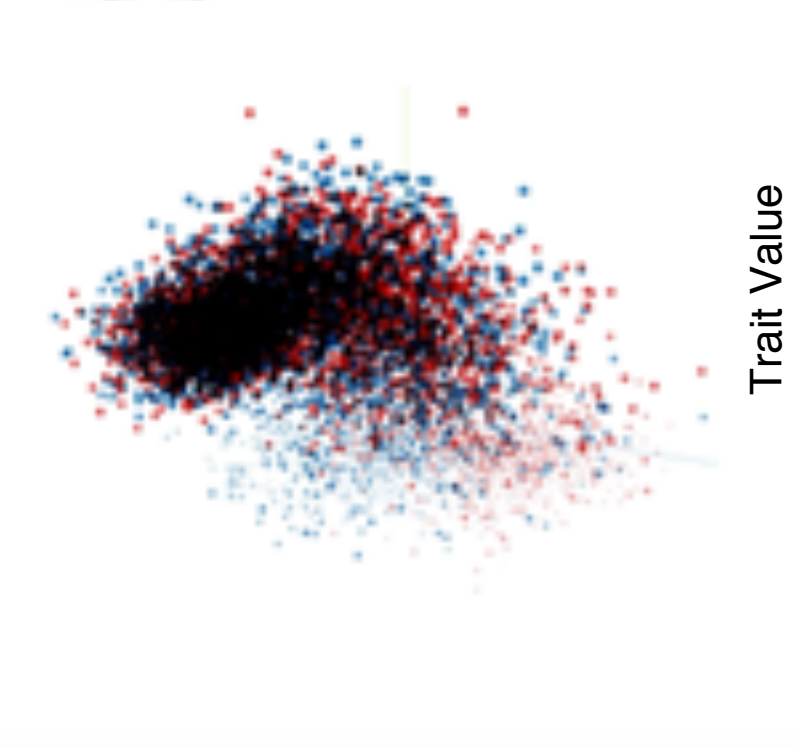


# Results: Setaria

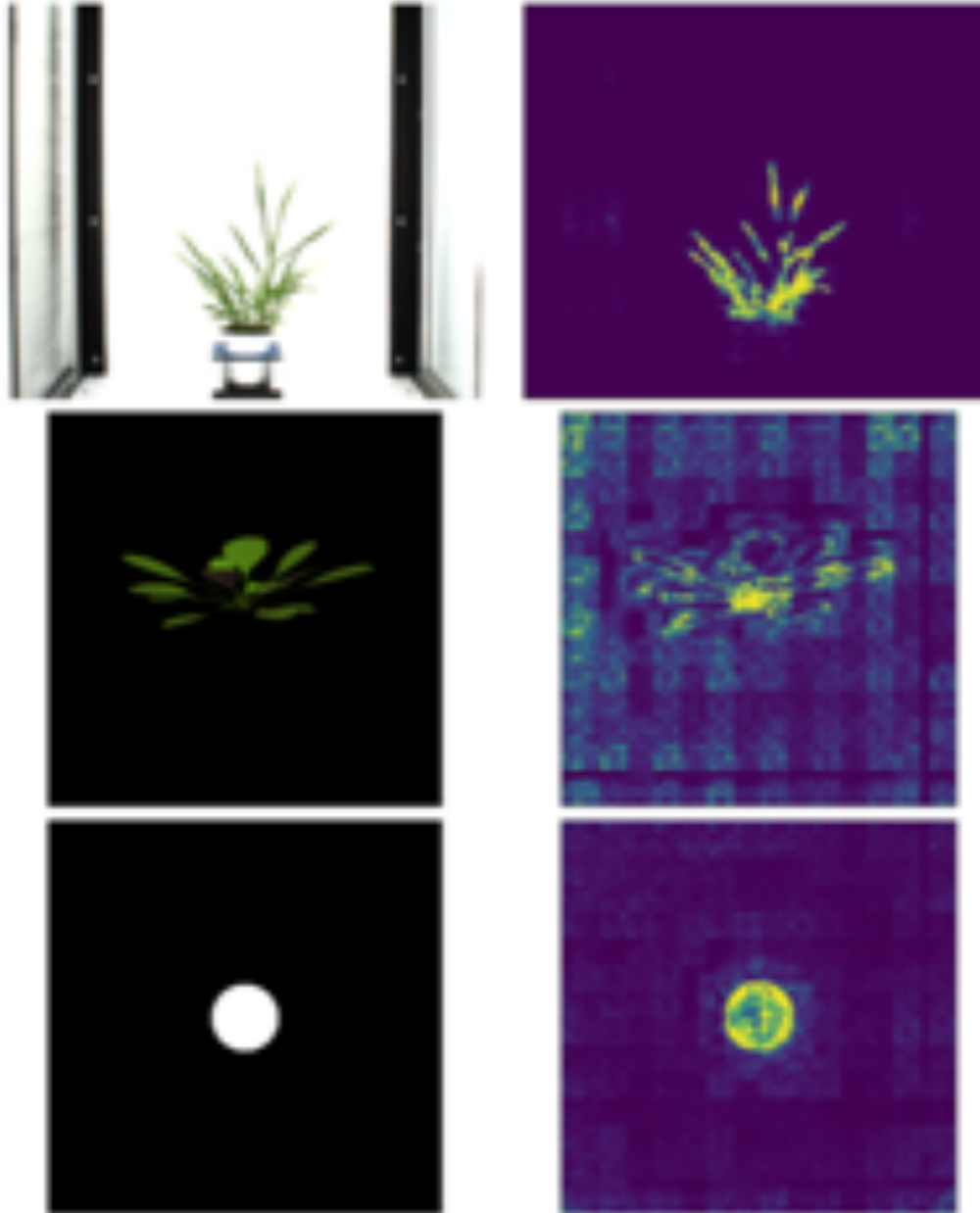




# Results: Canola

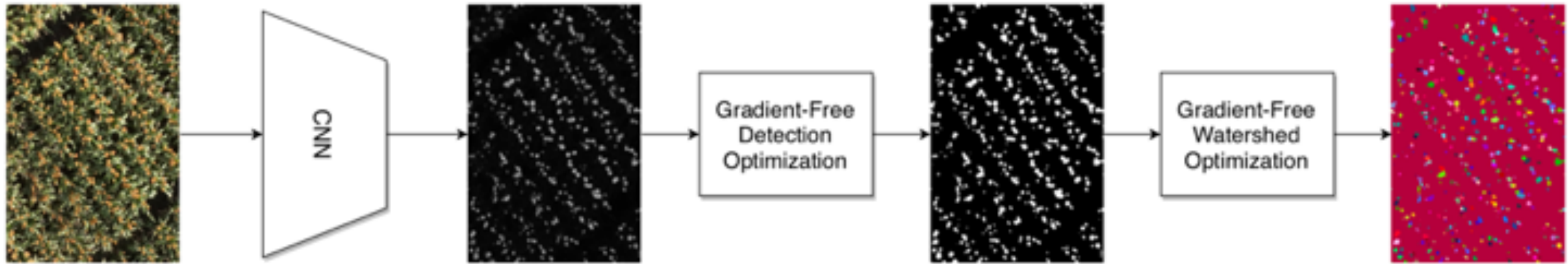


# Limitation: Explainability



# AutoCount: Unsupervised Organ Counting

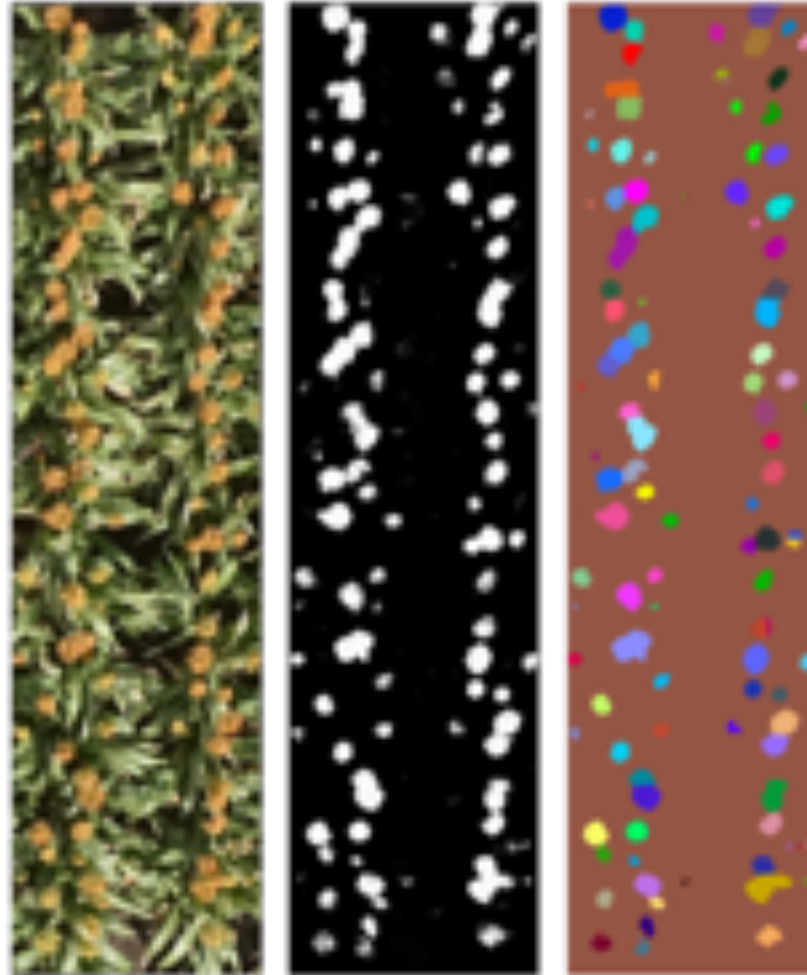
*To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)*





# AutoCount: Unsupervised Organ Counting

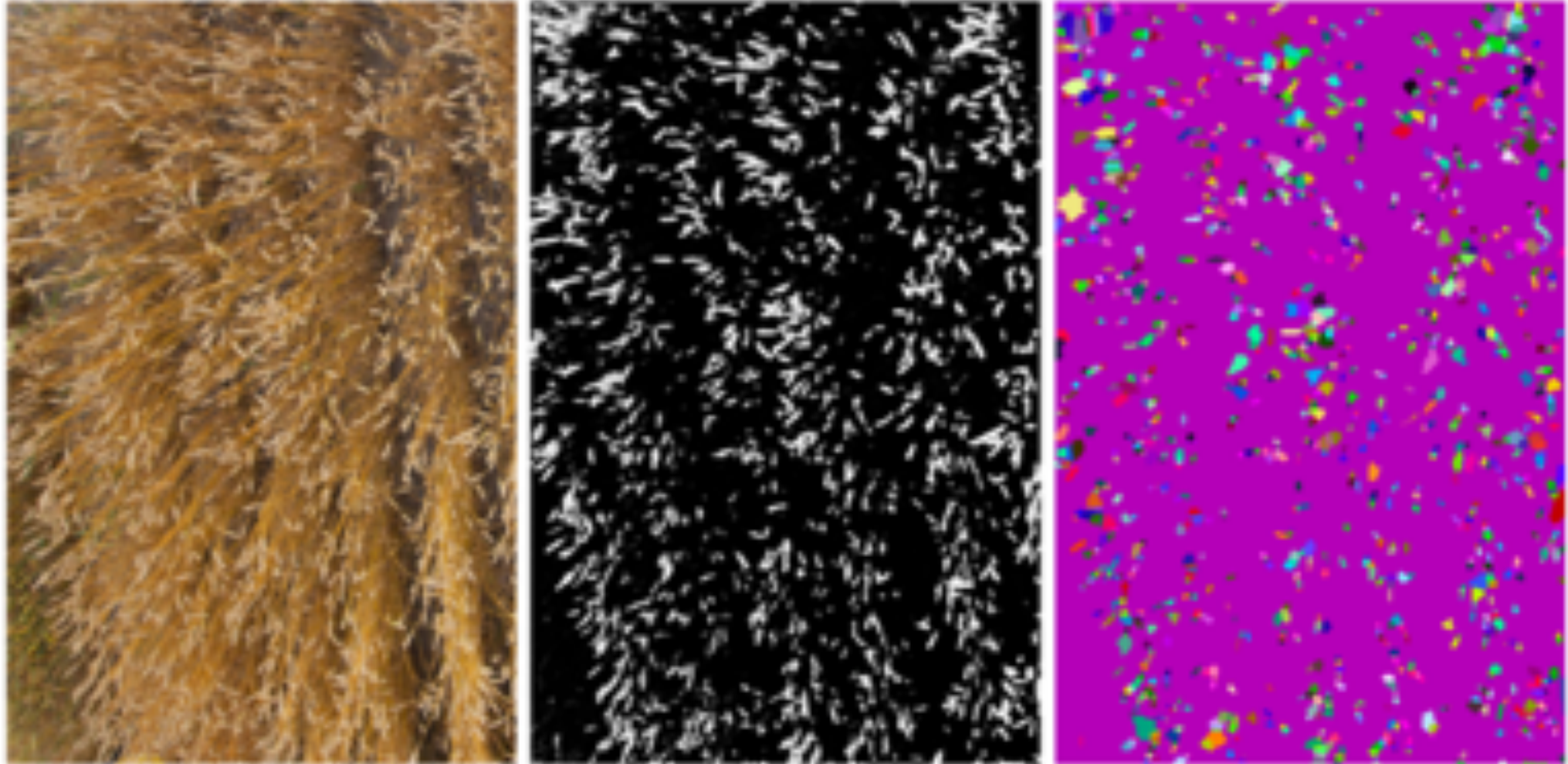
*To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)*



Ubbens, J., Ayalew, T., Shirtliffe, S., Josuttes, A., Pozniak, C. & Stavness, I. (2020). AutoCount: Unsupervised Segmentation and Counting of Organs in Field Images. ECCV Workshops, 2020, to appear.

# AutoCount: Unsupervised Organ Counting

*To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)*

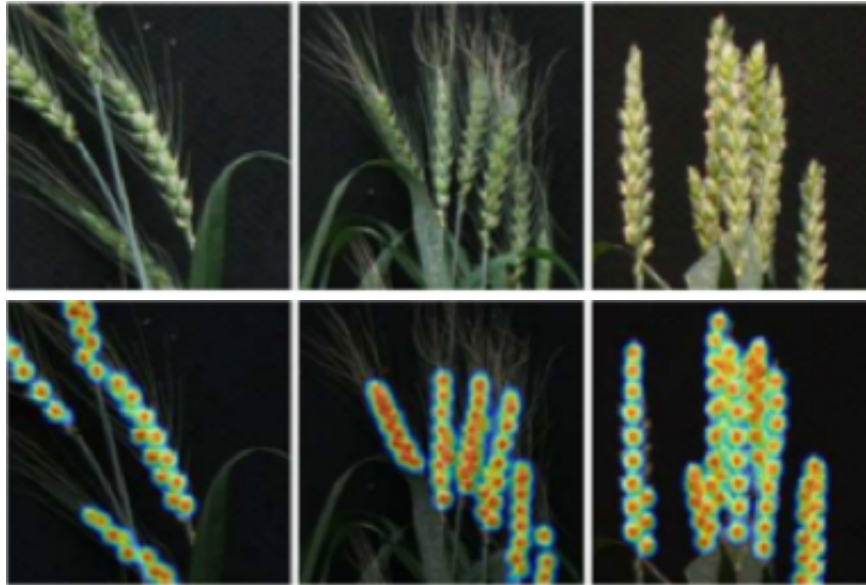


Ubbens, J., Ayalew, T., Shirtliffe, S., Josuttes, A., Pozniak, C. & Stavness, I. (2020). AutoCount: Unsupervised Segmentation and Counting of Organs in Field Images. ECCV Workshops, 2020, to appear.

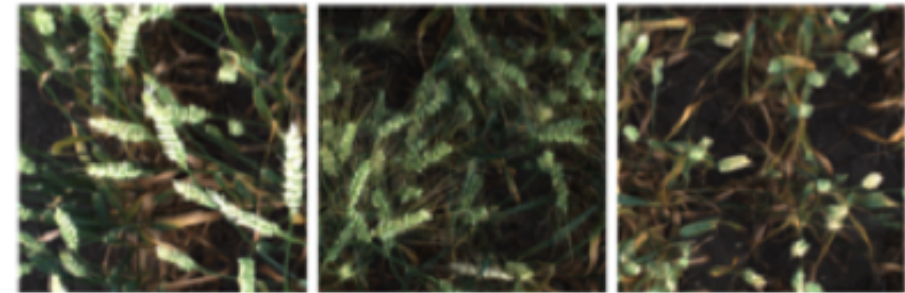
# Domain Adaptation for Organ Counting

To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)

Source:  
Indoor labeled dataset



Target:  
Outdoor *Unlabeled* dataset



GWHD

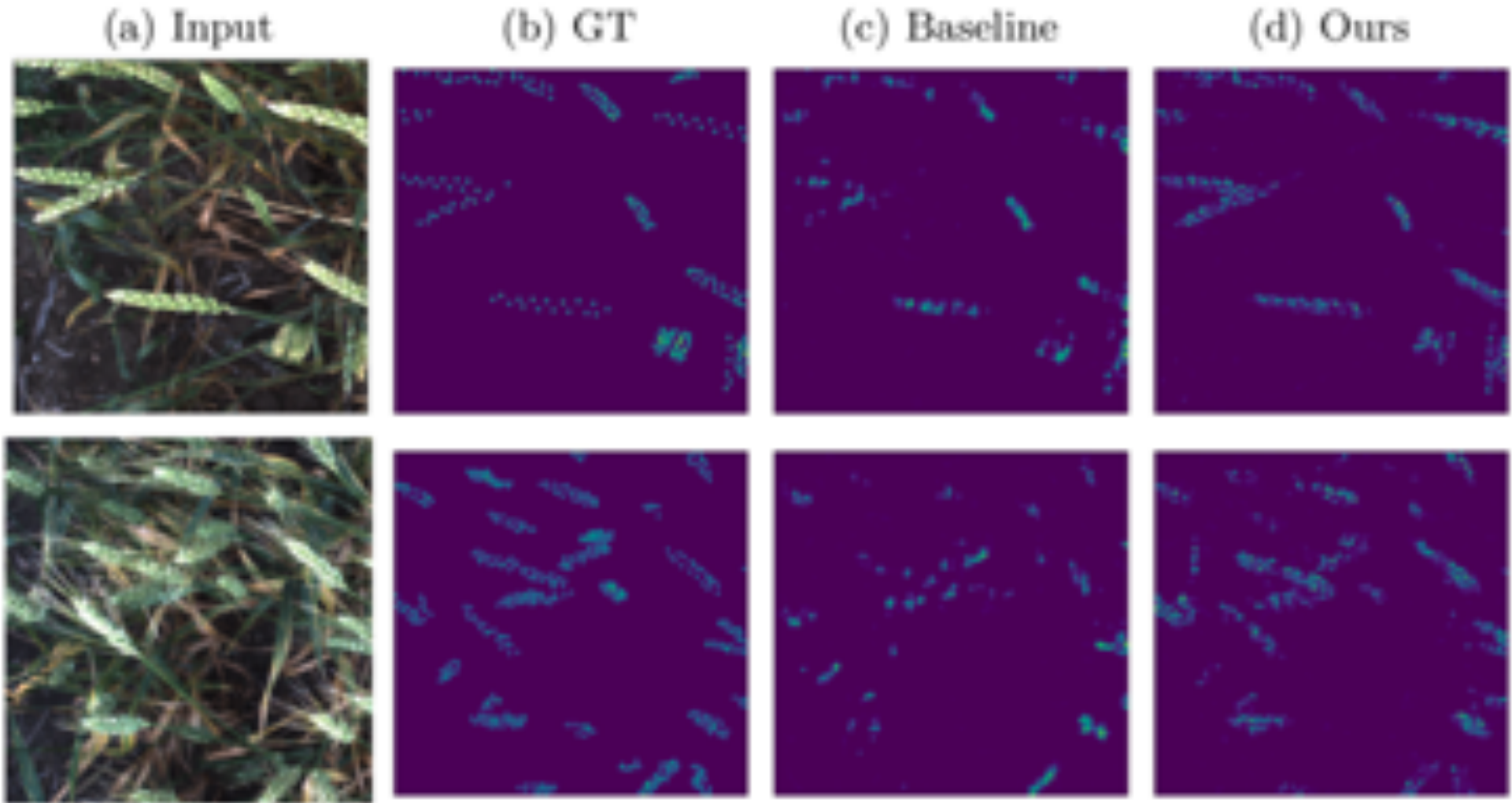


CropQuant



# Domain Adaptation for Organ Counting

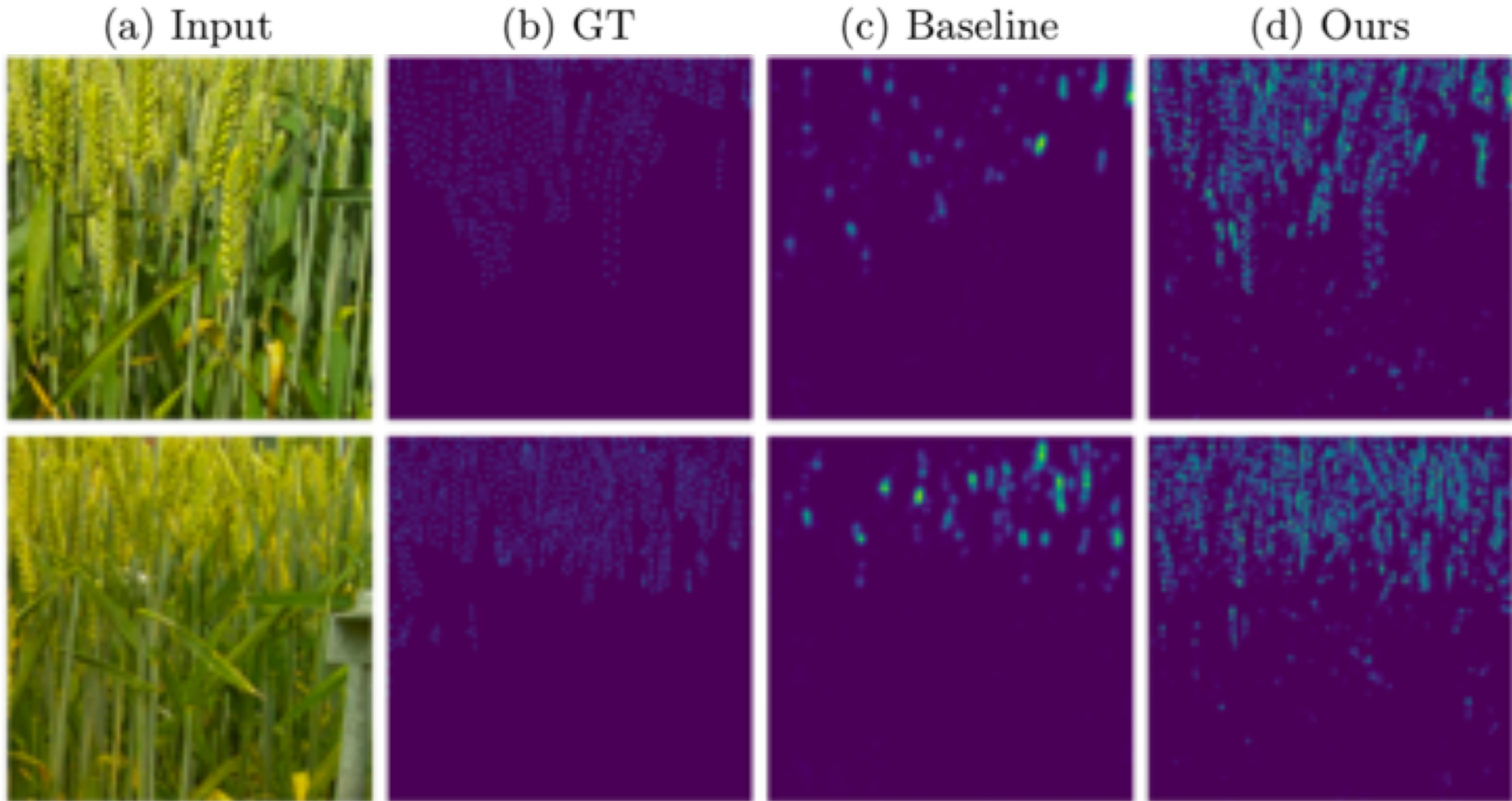
*To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)*



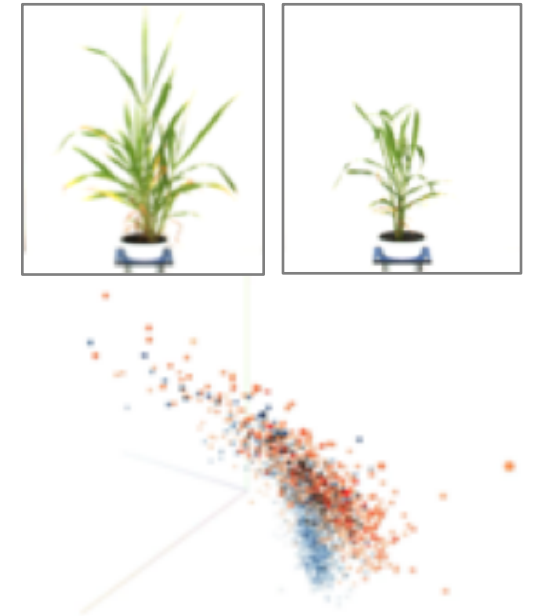
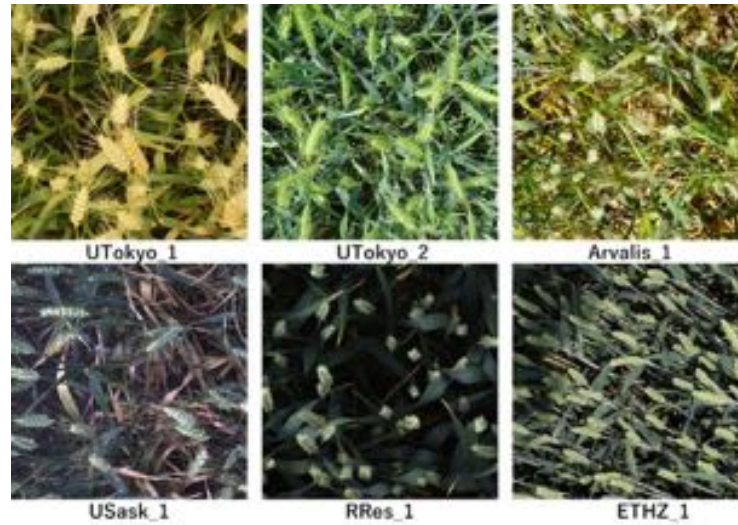
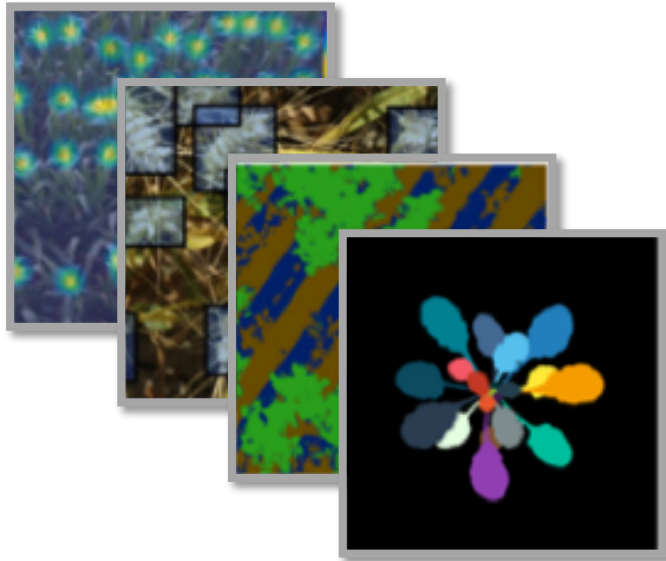
Ubbens, J., Ayalew, T., & Stavness, I. (2020). Unsupervised Domain Adaptation For Plant Organ Counting. ECCV Workshops, 2020, *to appear*.

# Domain Adaptation for Organ Counting

*To appear: [www.plant-phenotyping.org/CVPPP2020](http://www.plant-phenotyping.org/CVPPP2020)*



Ubbens, J., Ayalew, T., & Stavness, I. (2020). Unsupervised Domain Adaptation For Plant Organ Counting. ECCV Workshops, 2020, to appear.



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