

I want to serve by saving people time while improving their work

Collect plant traits manually or by machine?

Aerial portion

Leaf

count
area
color
angle

Stalk

diameter
color
strength



Reproductive portion

Flower

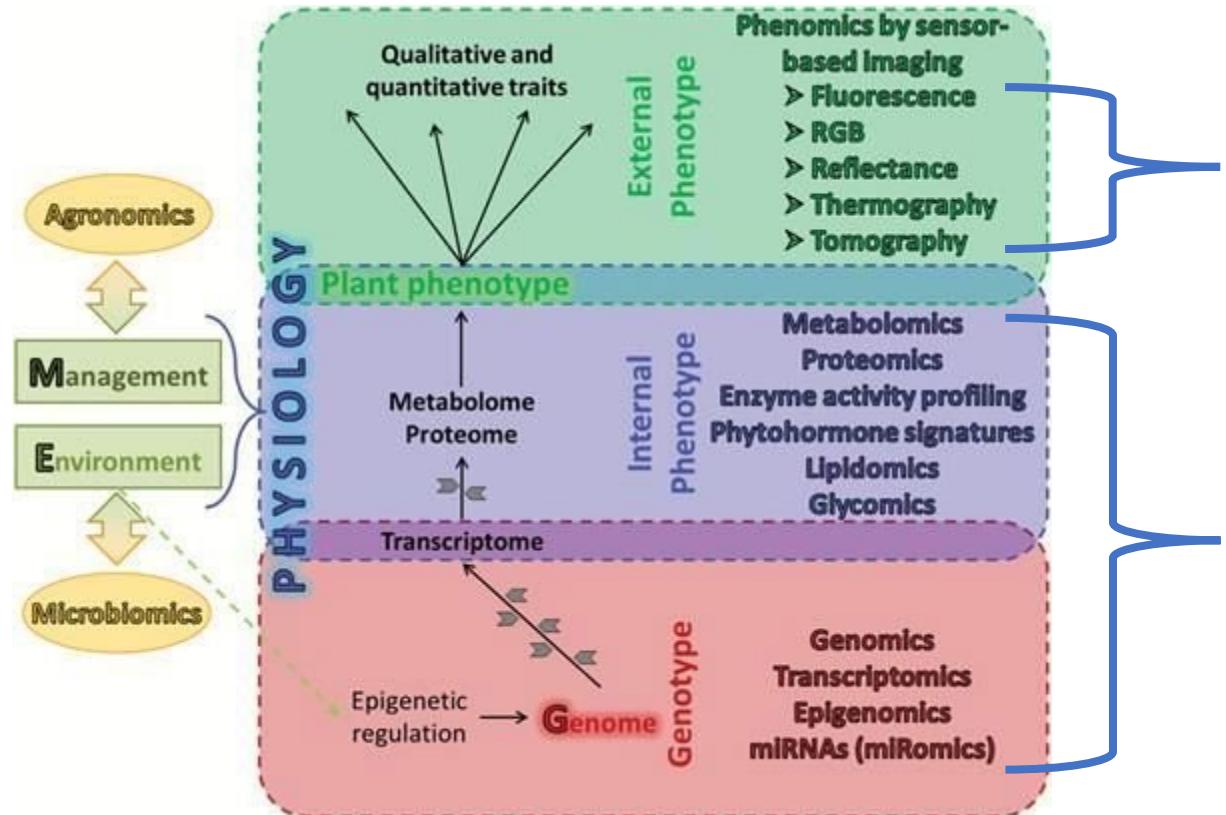
count
size
time

Fruit

size
color
firmness

Root portion

density
length
shallow or deep
diameter



Traits observable with imaging sensors



Integration of multi-omics techniques and physiological phenotyping within a holistic phenomics approach to study senescence in model and crop plants
<https://academic.oup.com/jxb/article-abstract/69/4/825/4372214>

Growth

Environment

Laboratory



Greenhouse



Field



Confluence R&D

Phenotyping

Instrument



TrayGazer

PlantGazer



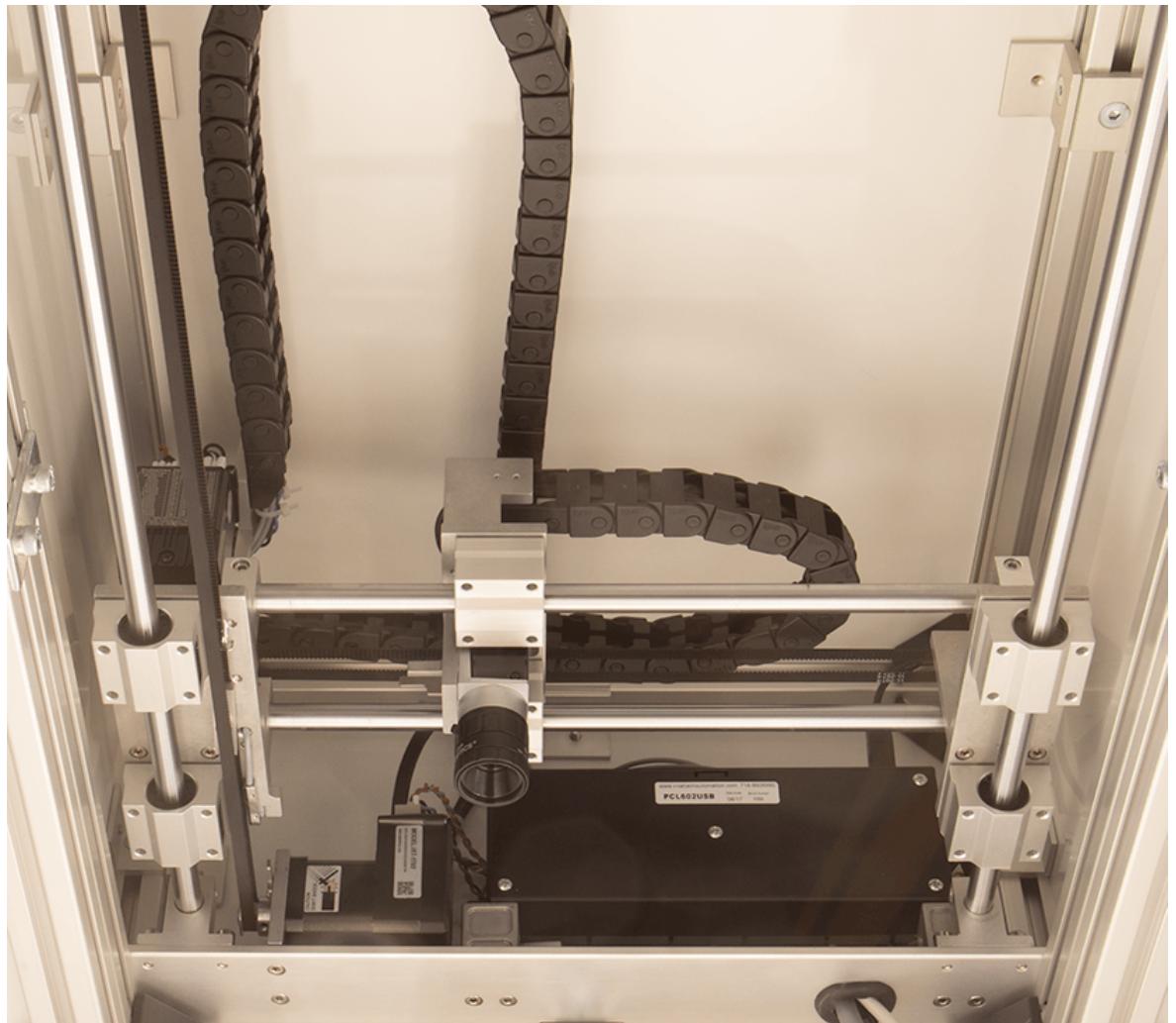
SpecGazer

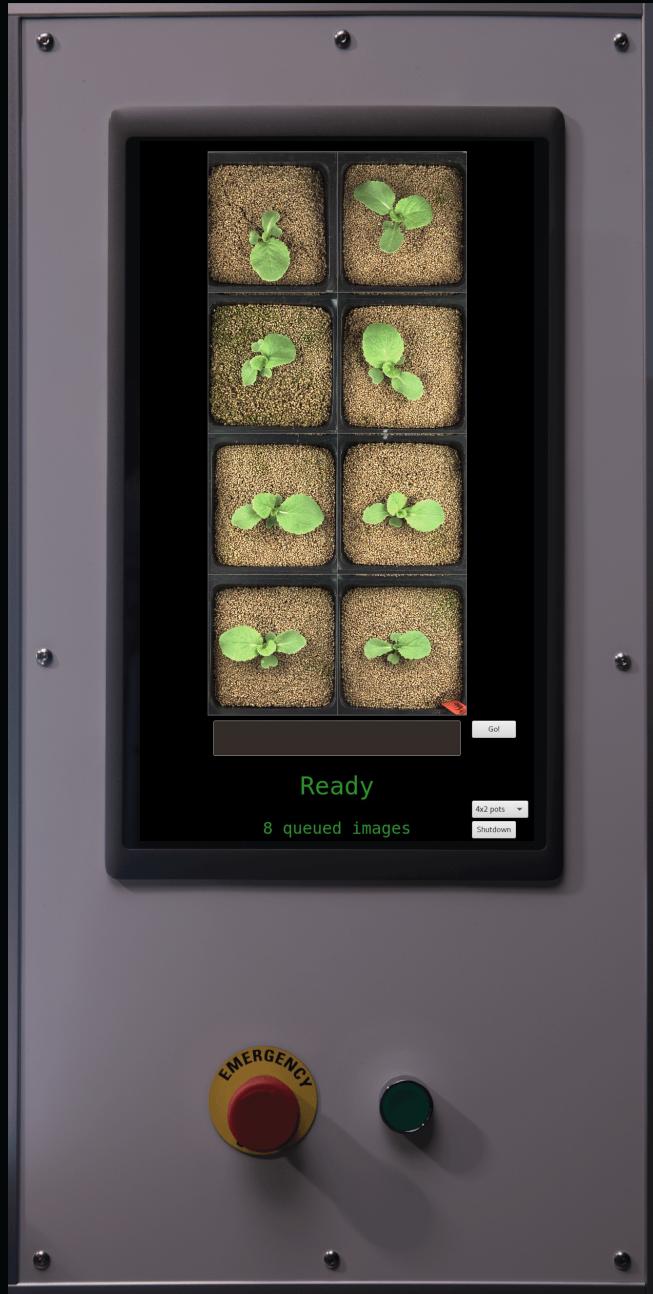












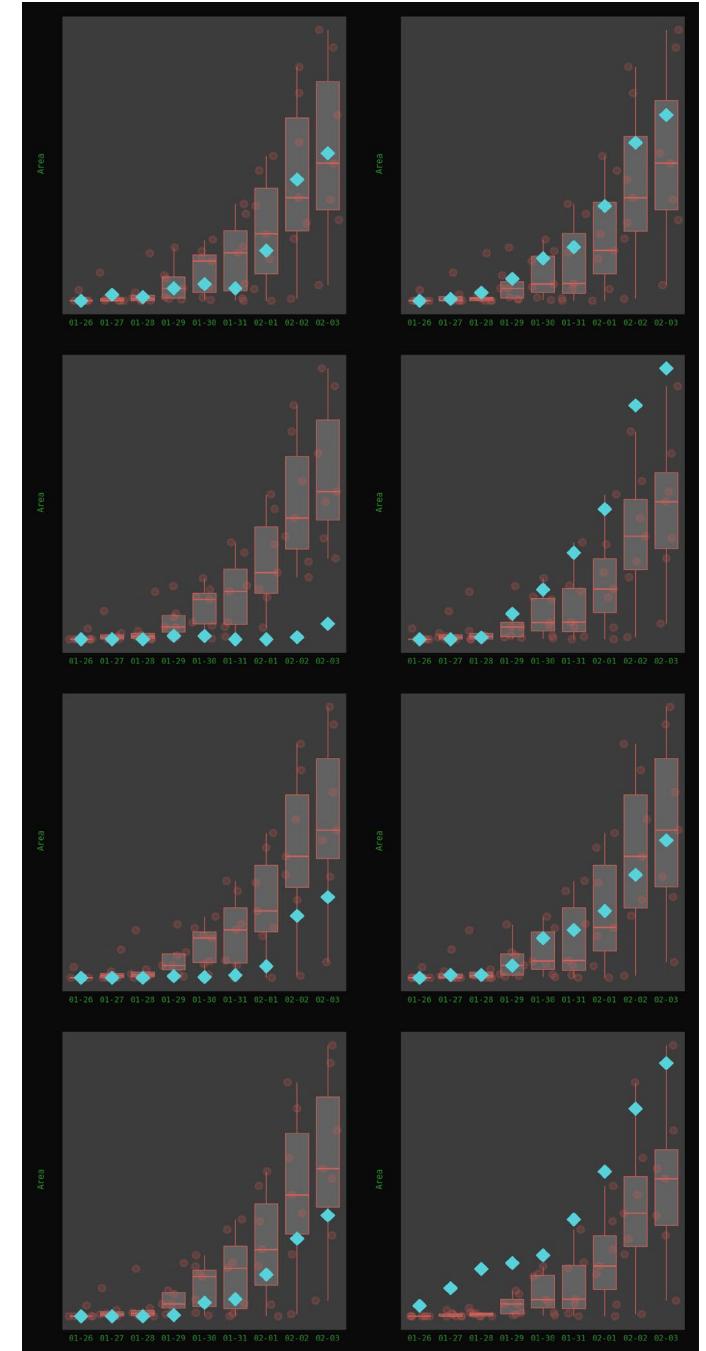
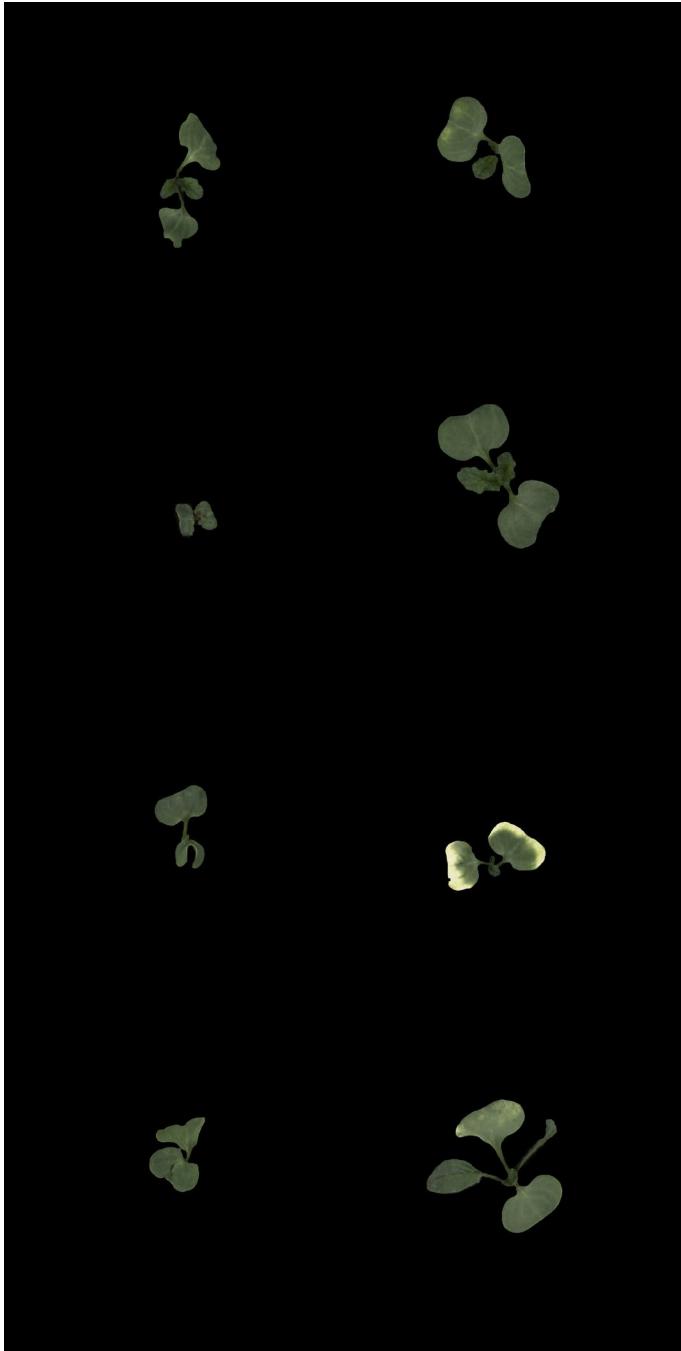
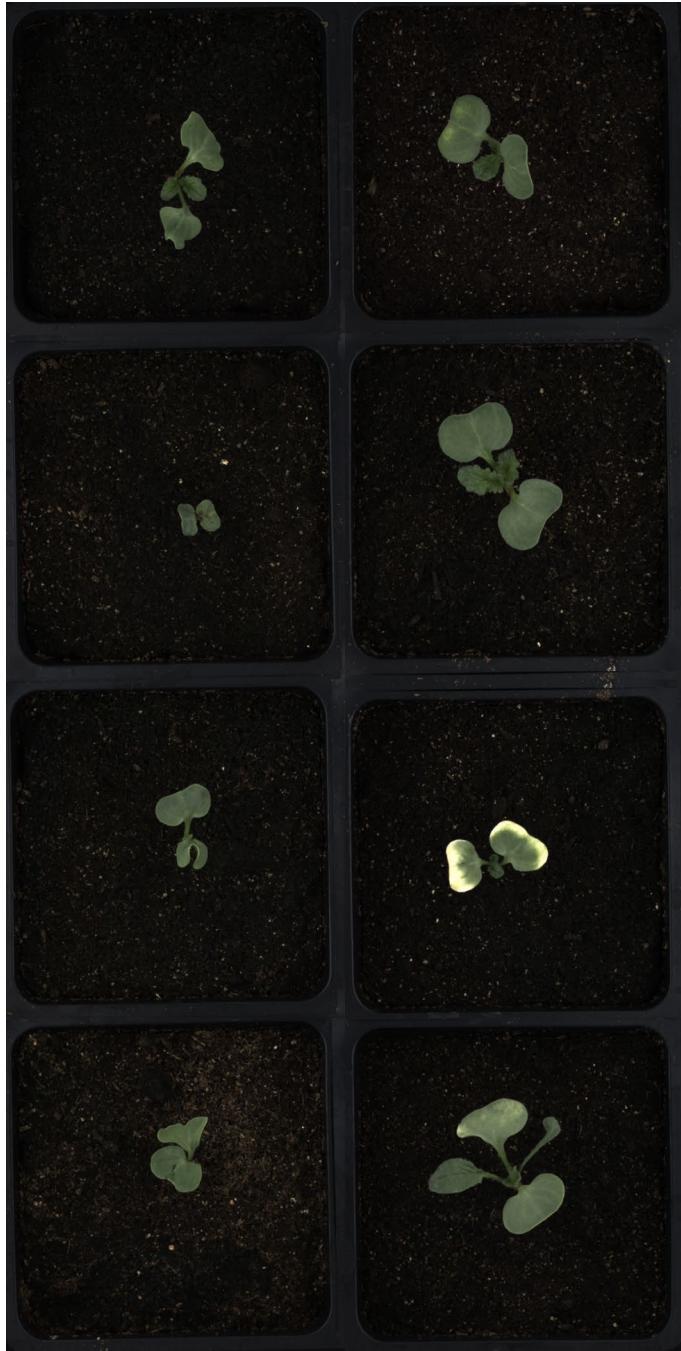


Image analysis – the basics

Experiment: Do our treatments have an impact on biomass compared to a control?

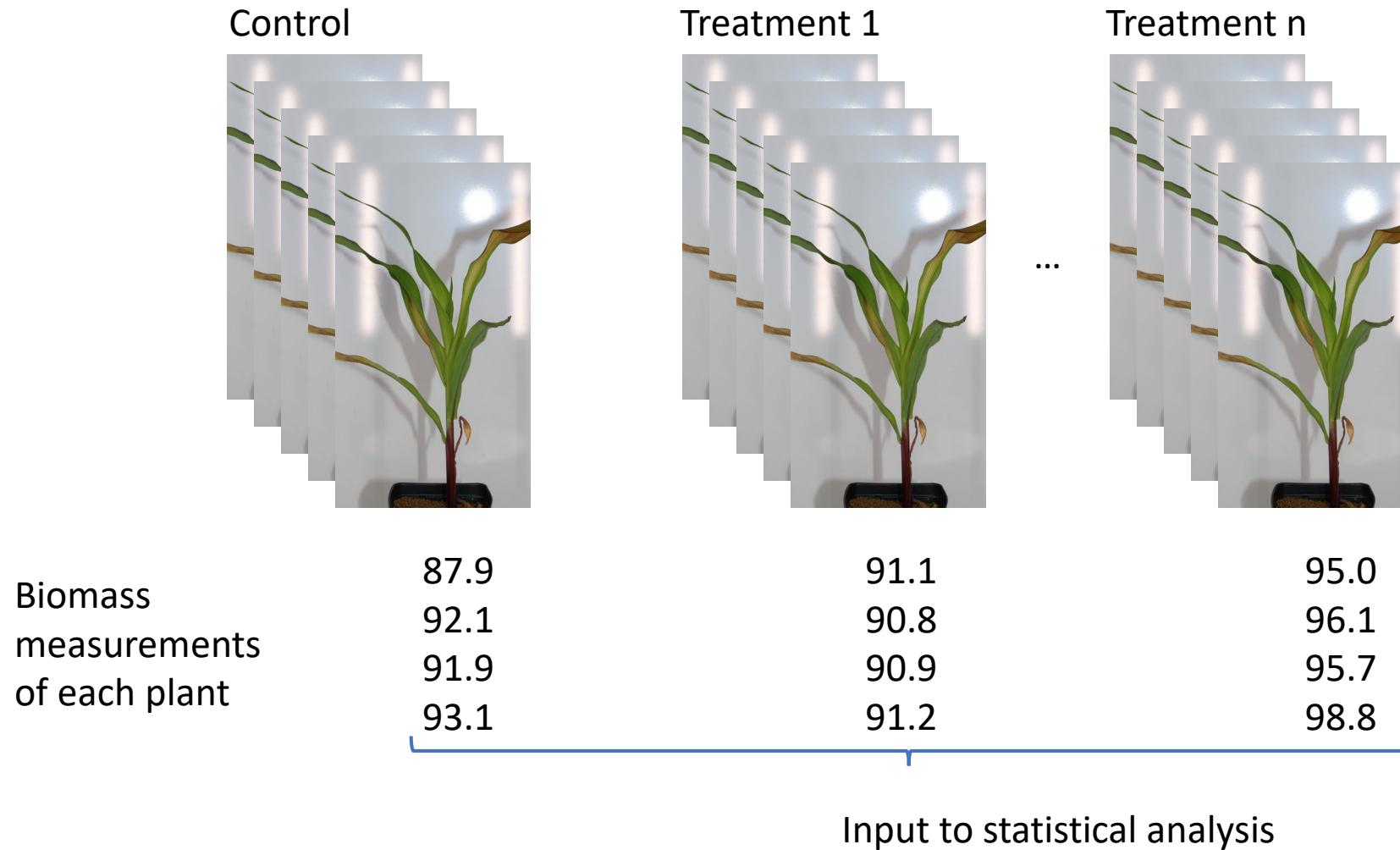
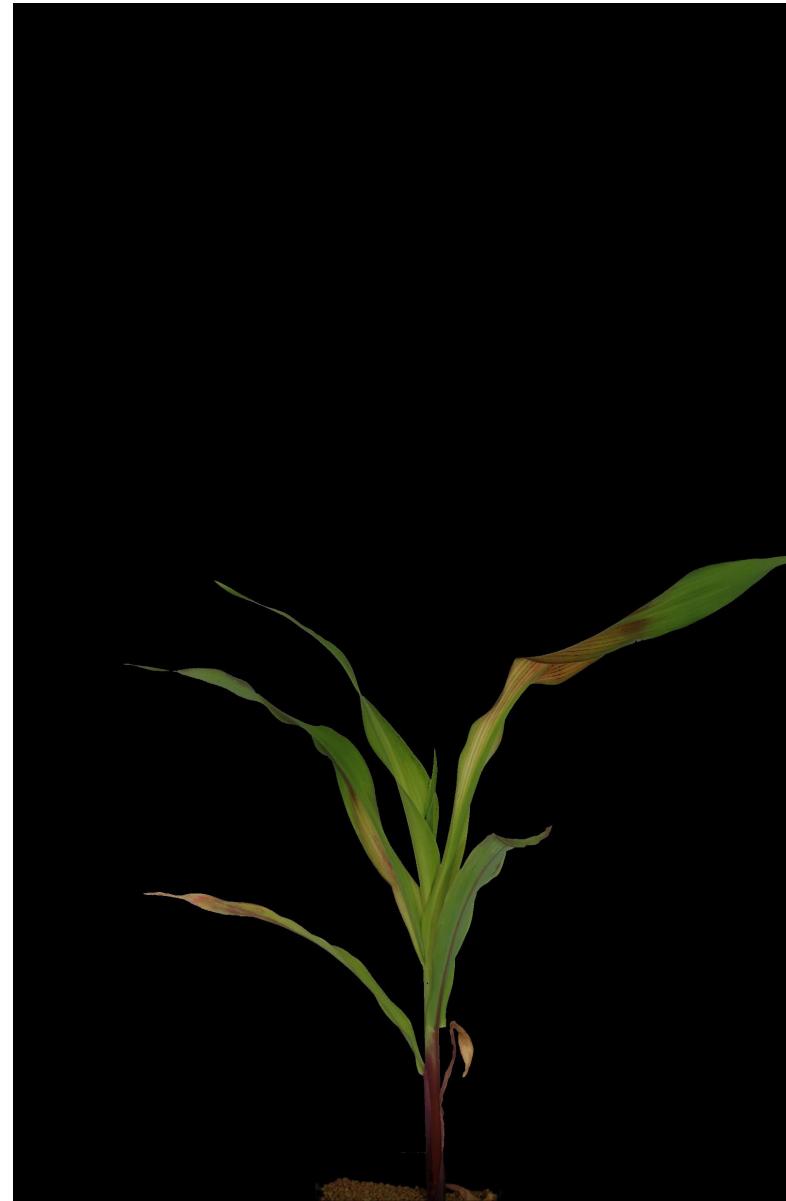


Image analysis – the basics

Step 1. Initial image
One of several angles



Step 2. Clean up image
Isolate the plant



Step 3. Analyze image
Measure and save results to DB

```
area_px2(circle) 11001646
area_px2(contour) 929423
area_px2(ellipse) 5639055
area_px2(hull) 5989246
area_px2(sum) 939472
area_px2(triangle) 7029336
centroid_px(x) 2036
centroid_px(y) 3851
circle_px(radius) 1841
ellipse_px(MA) 1475
ellipse(eccentricity) 0.59
ellipse_px(ma) 1325
height_px 2855
perimeter_px 23998
primary_angle -76.7
width_px 3153
```

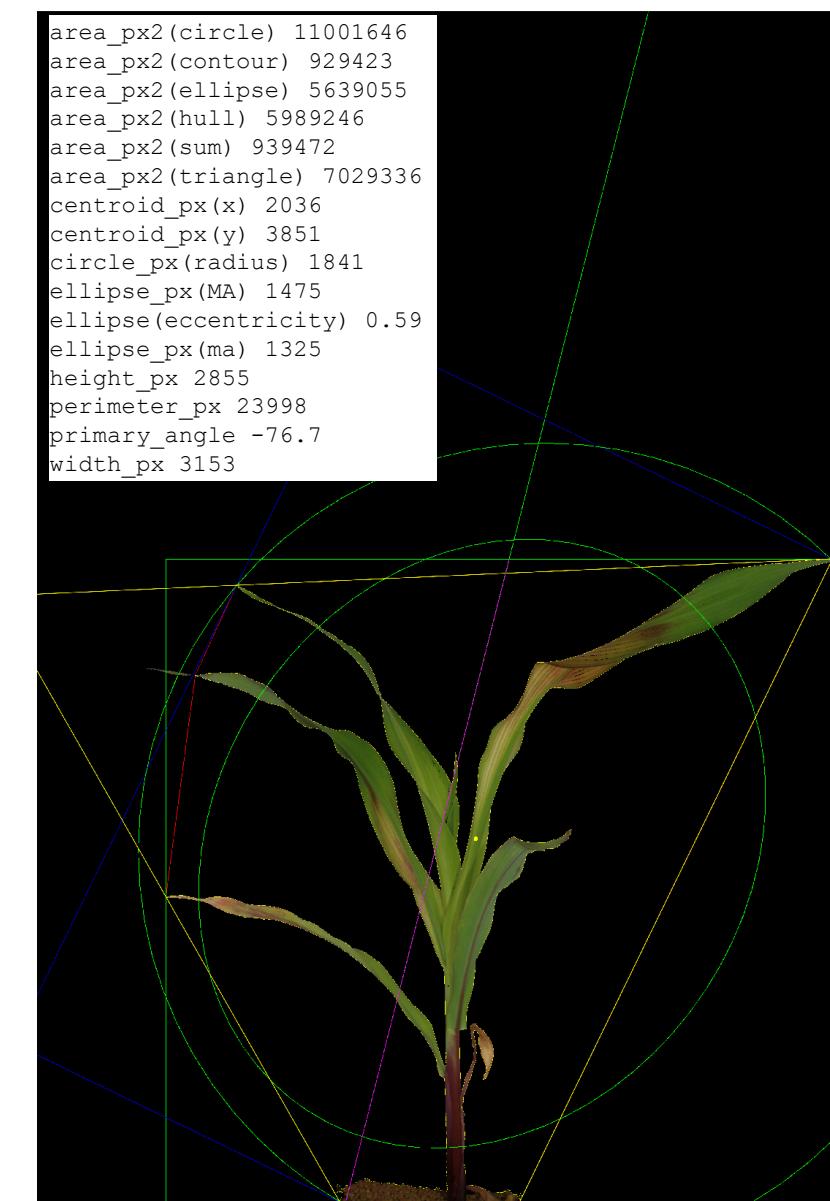


Image analysis – segmentation

classify each pixel as plant or not based on color



Original image



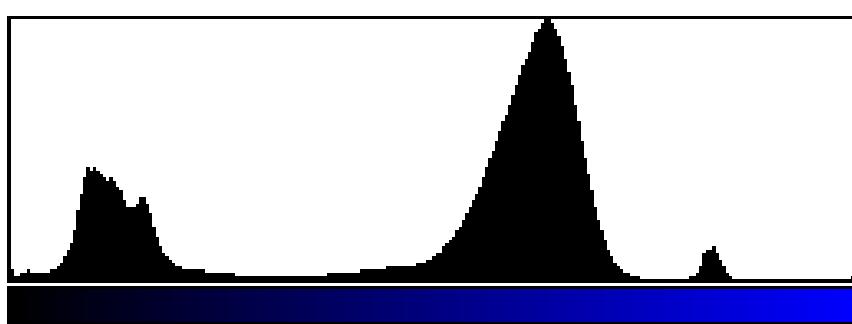
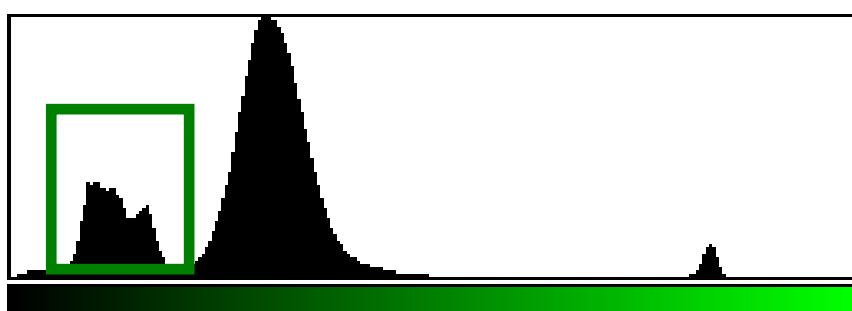
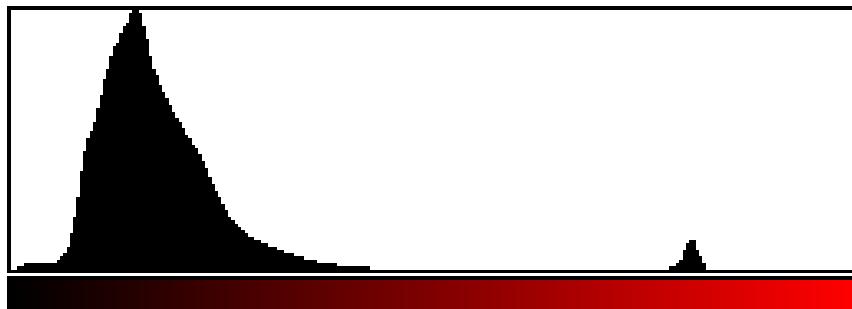
Mask



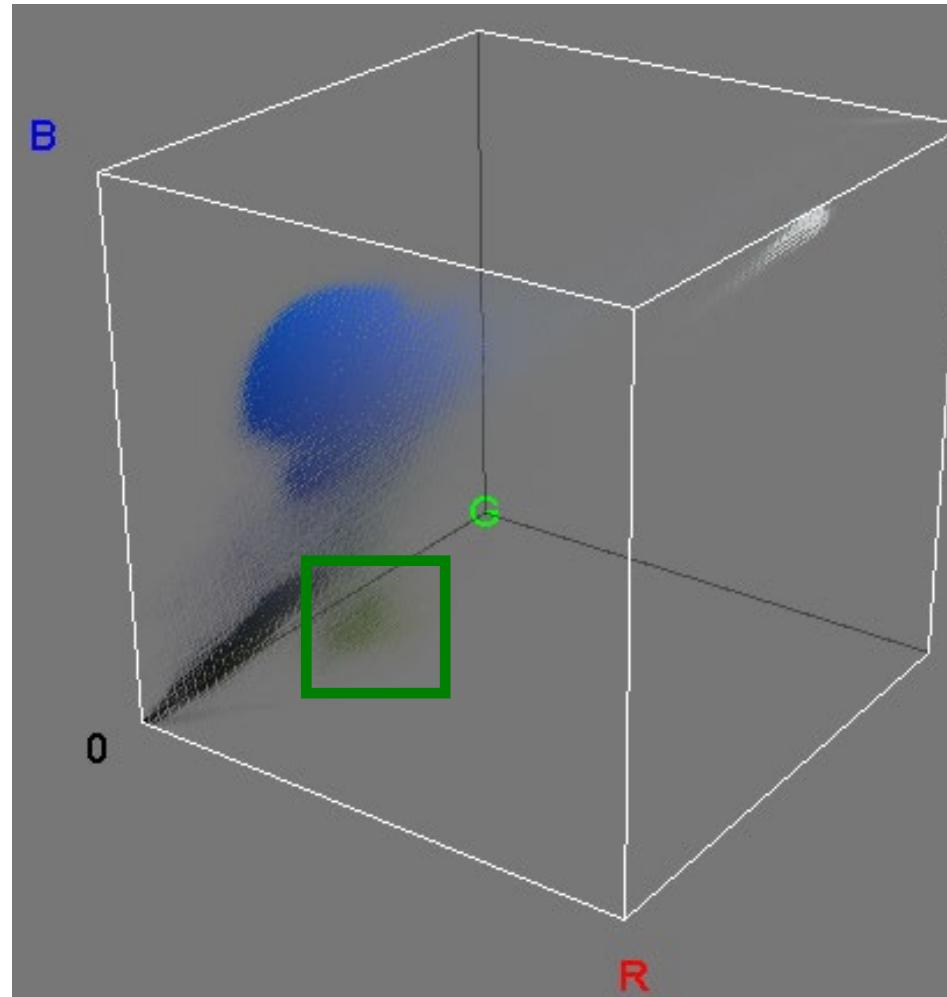
Segmented image

Image analysis – segmentation

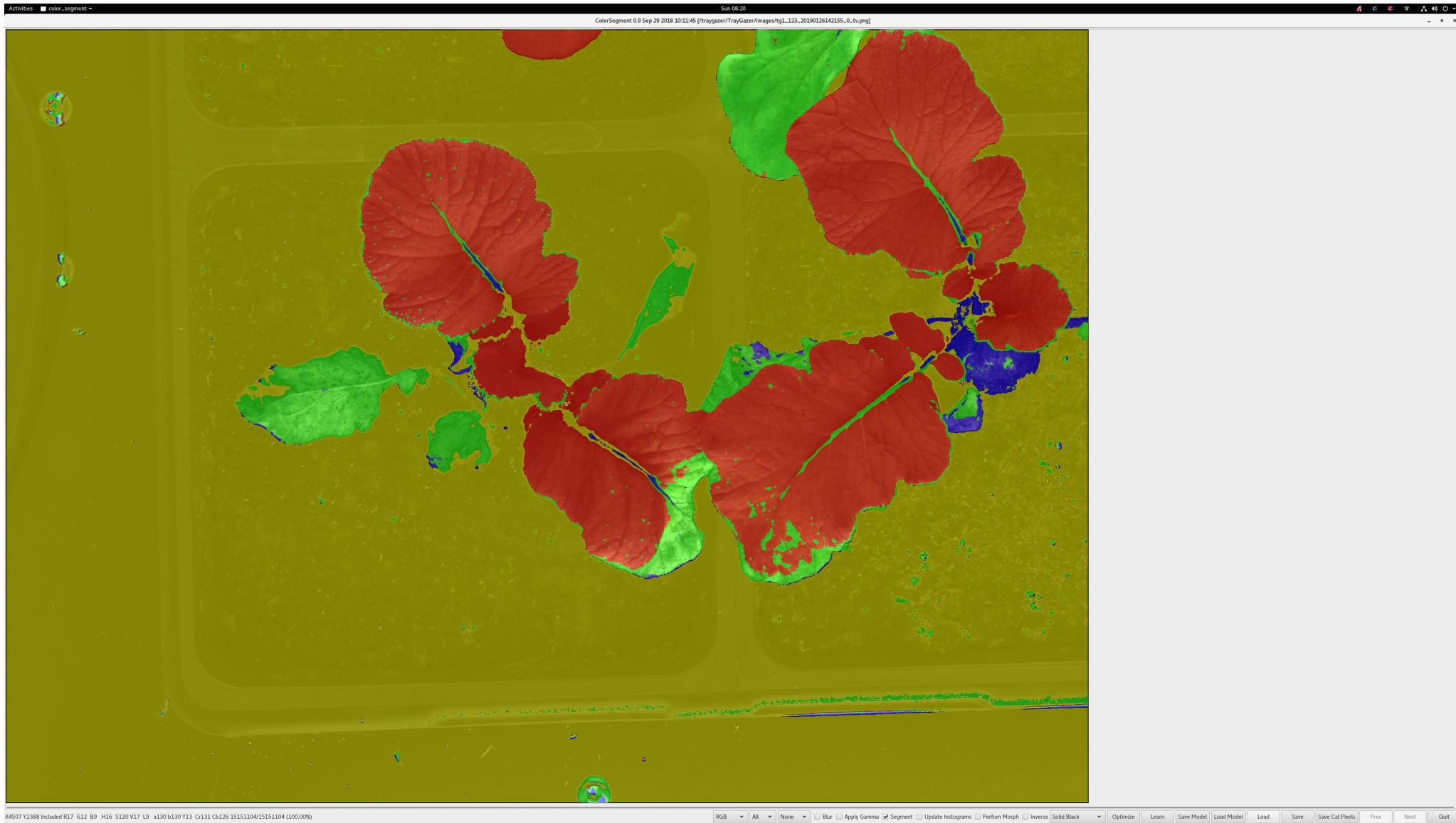
three histograms



3d color cube











Machine learning method



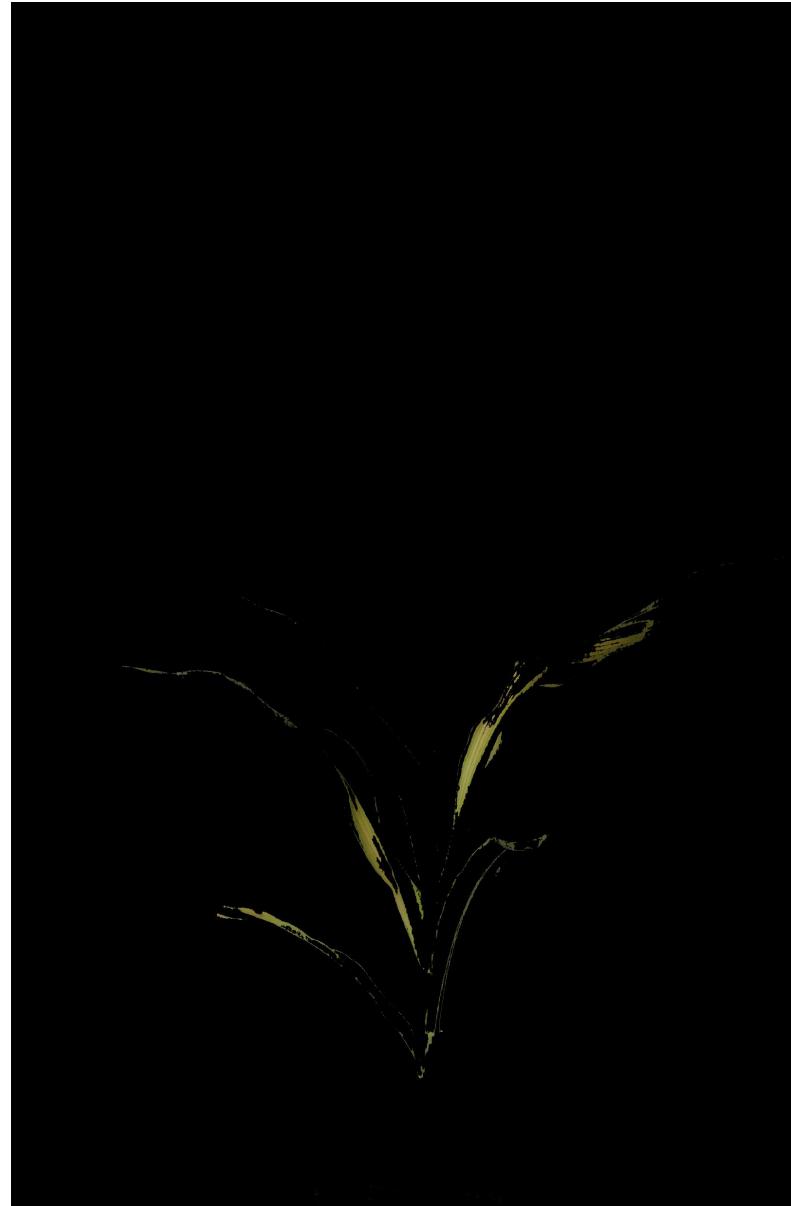
Traditional method

Image decomposition by color

Class 1. Green
Happy and healthy



Class 2. Yellowing
N deficit, soil wet or cool



Class 3. Browning
Heat stress, water stress, sugar buildup

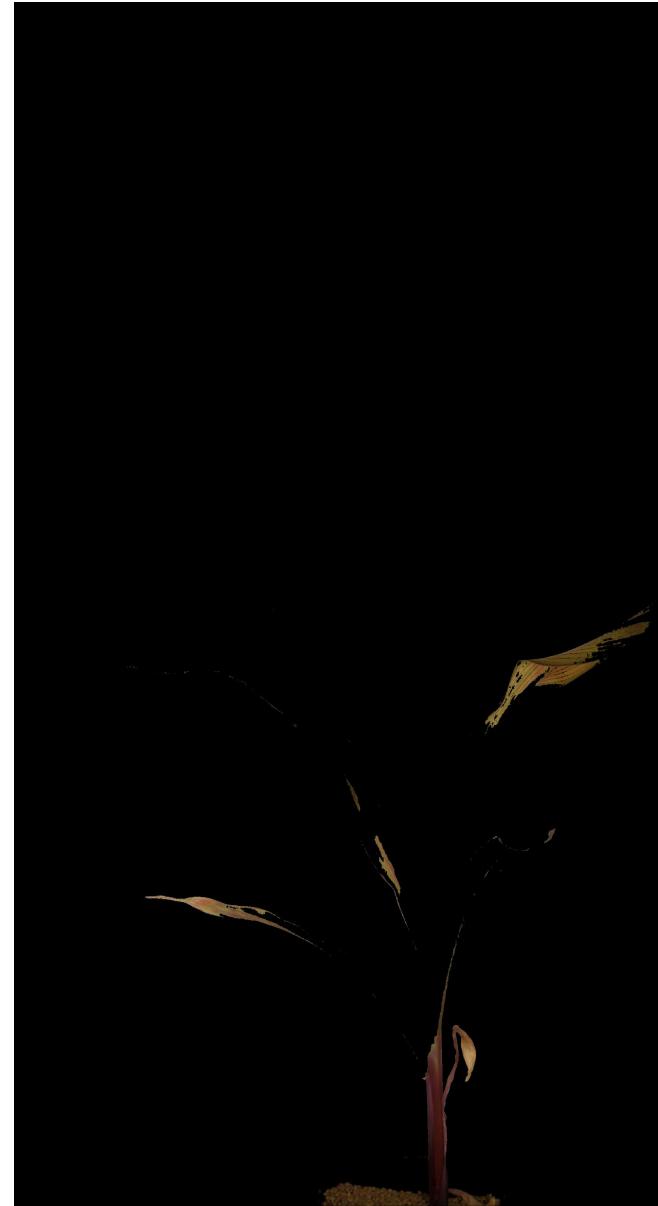
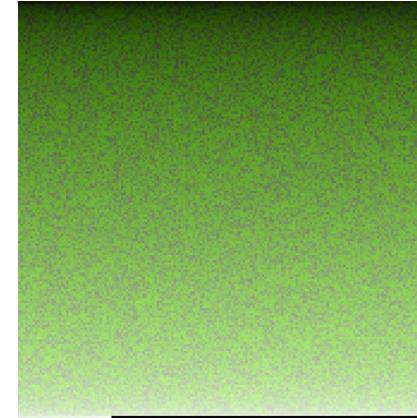


Image analysis - color

Shift in color (hue) may be indication of stress



“plant hues”

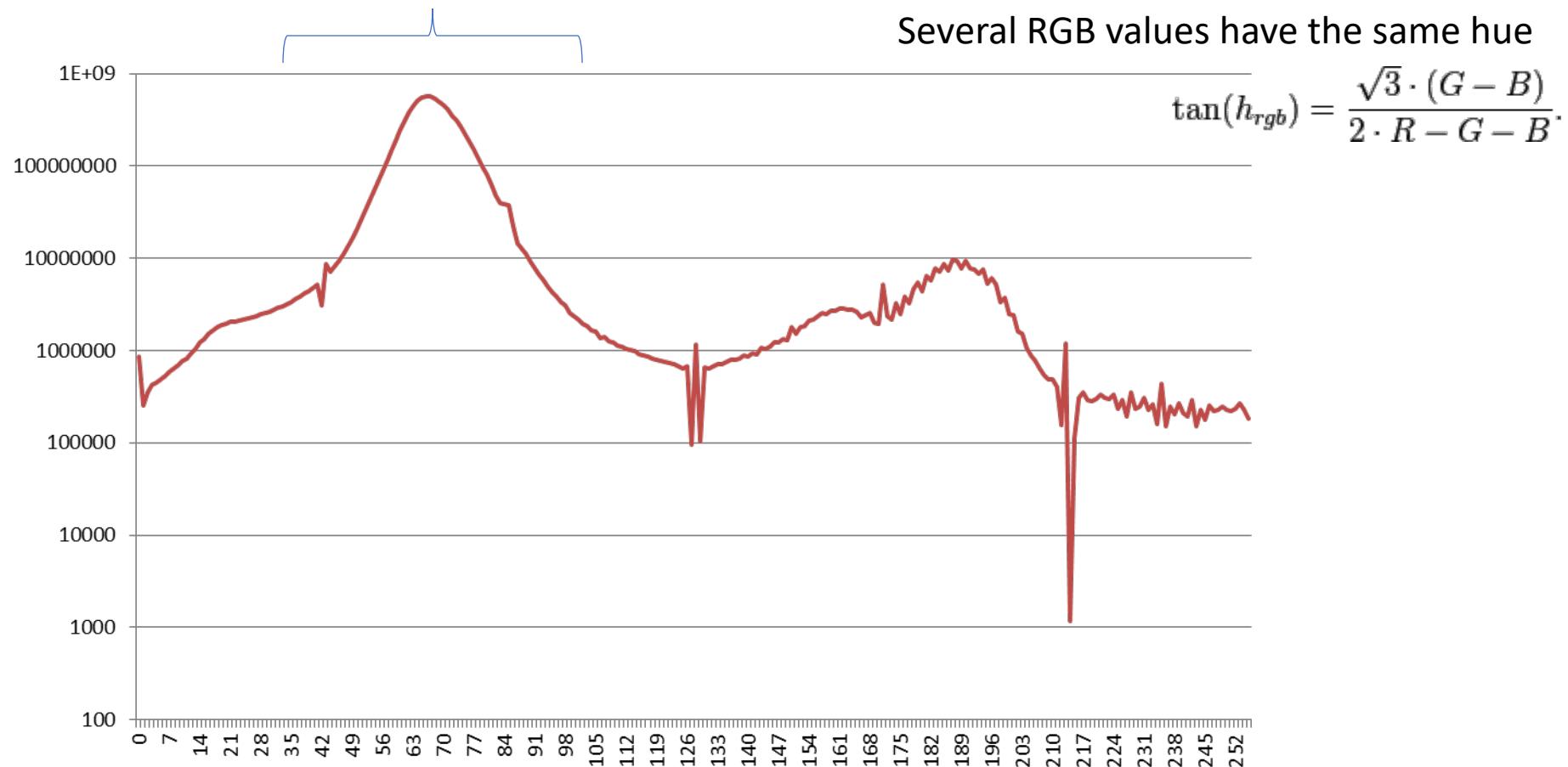


Image analysis - color

Plant colors occupy small region of hue axis
Poor use of available dynamic range
Large change required to detect

Construct a custom color space to increase the separation of phenotypes
Smaller changes are detectable

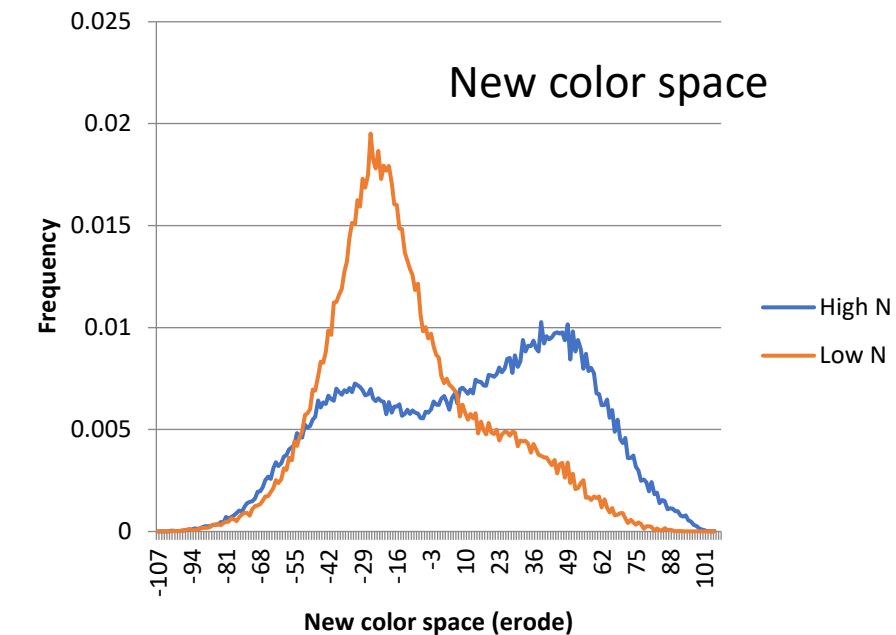
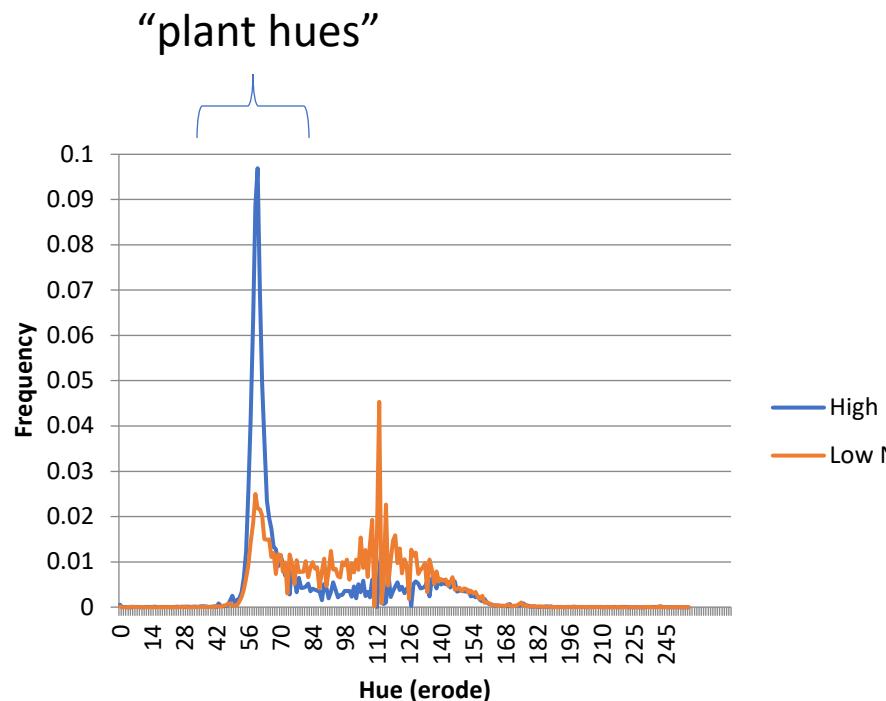


Image analysis - color

Measuring plant color is attempting to measure the ratio of pigments – chlorophylls and carotenoids

Some wavelengths are more critical for the measurement than others

(This graph shows absorption, inverse of reflection captured by cameras)

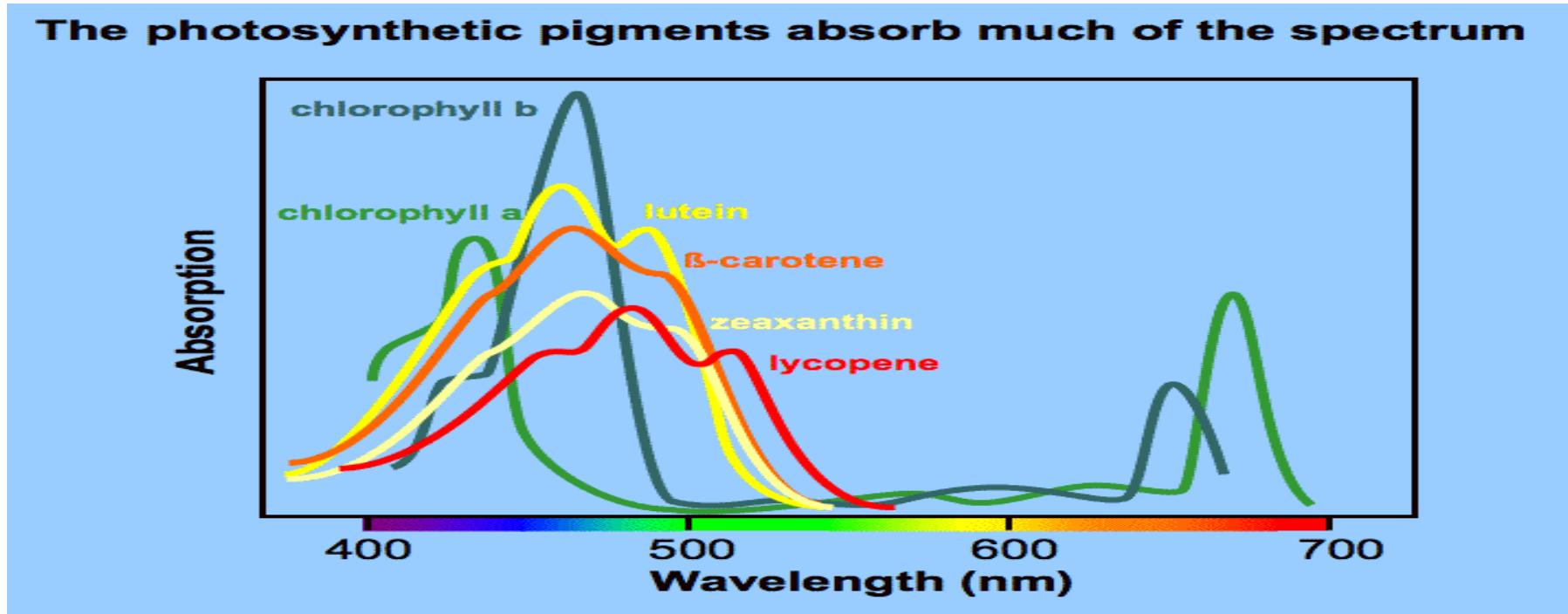


Image from http://plantphys.info/plant_physiology/light.shtml

Image analysis - color

A color camera is a grayscale camera with a Bayer filter attached

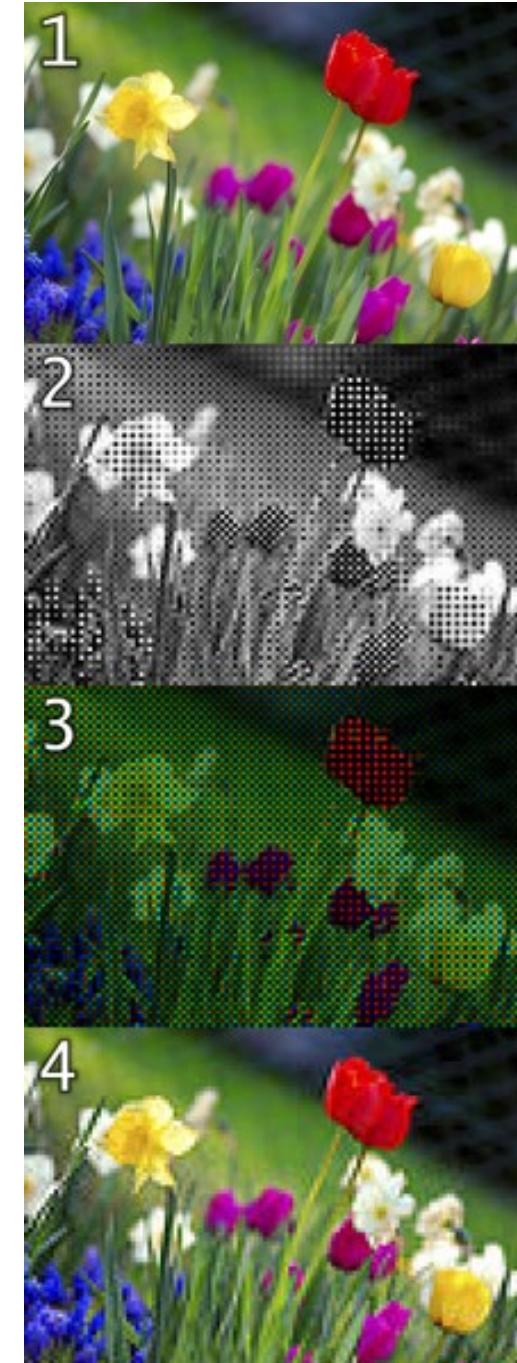
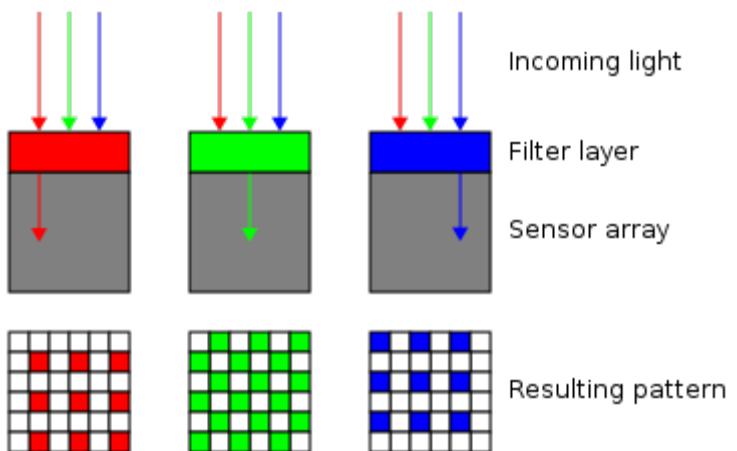
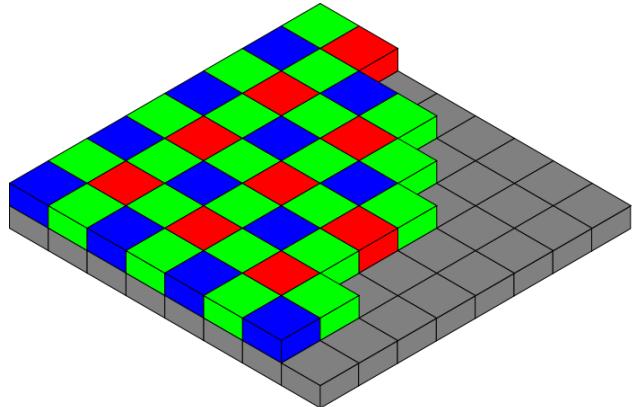
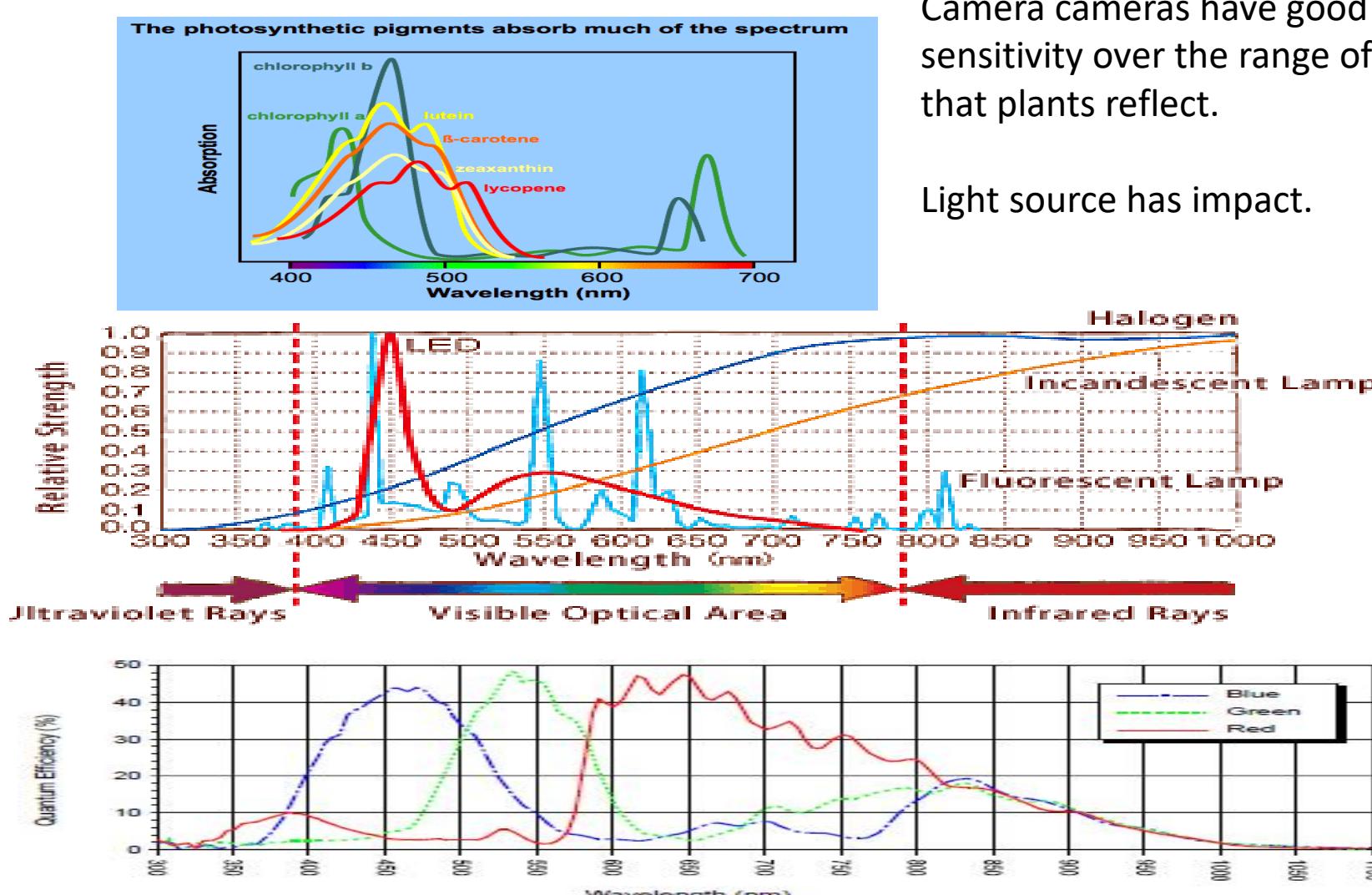


Image analysis - color

Plant pigments absorption vs. camera sensitivity vs. light source



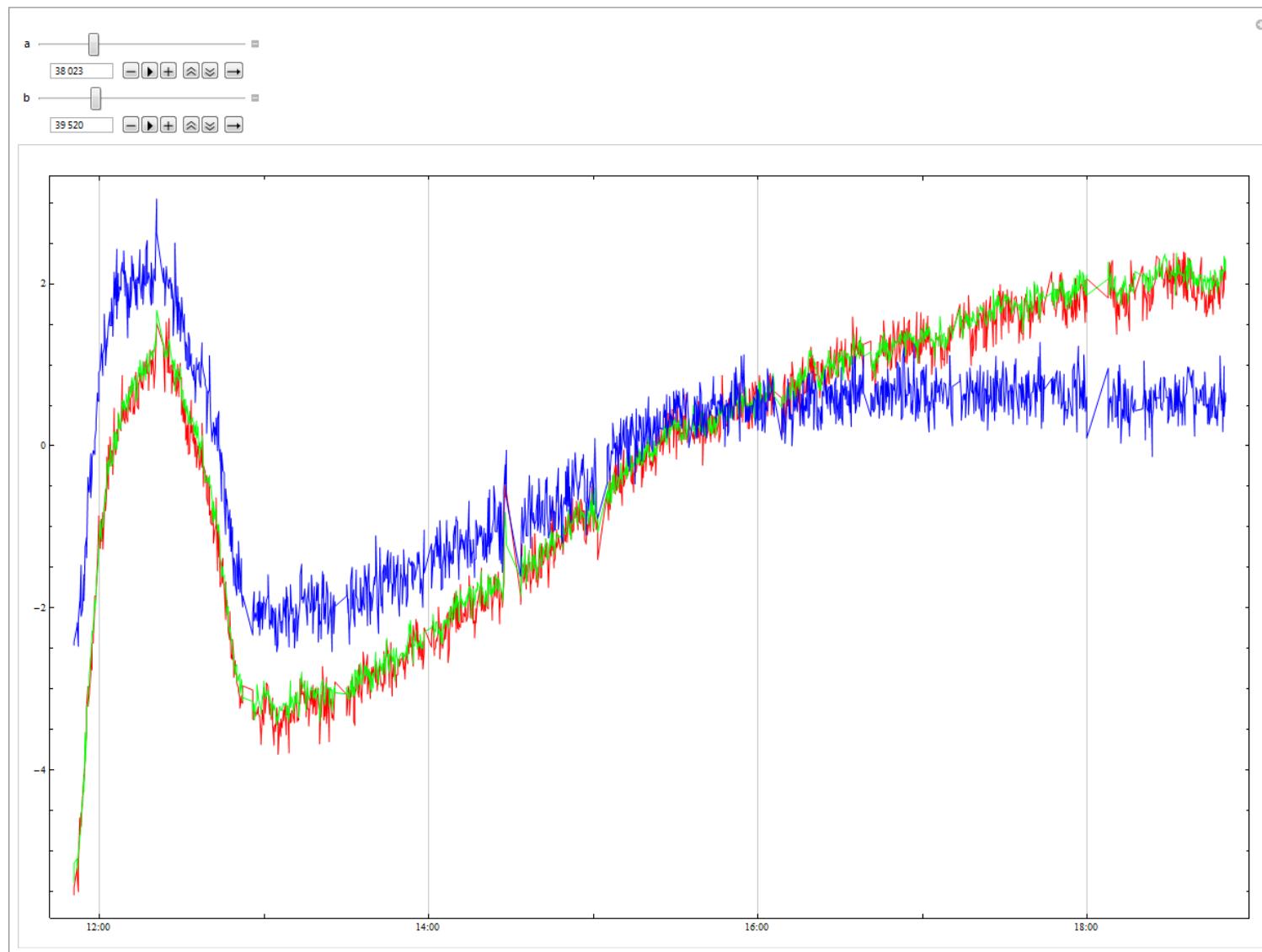
Camera cameras have good sensitivity over the range of colors that plants reflect.

Light source has impact.

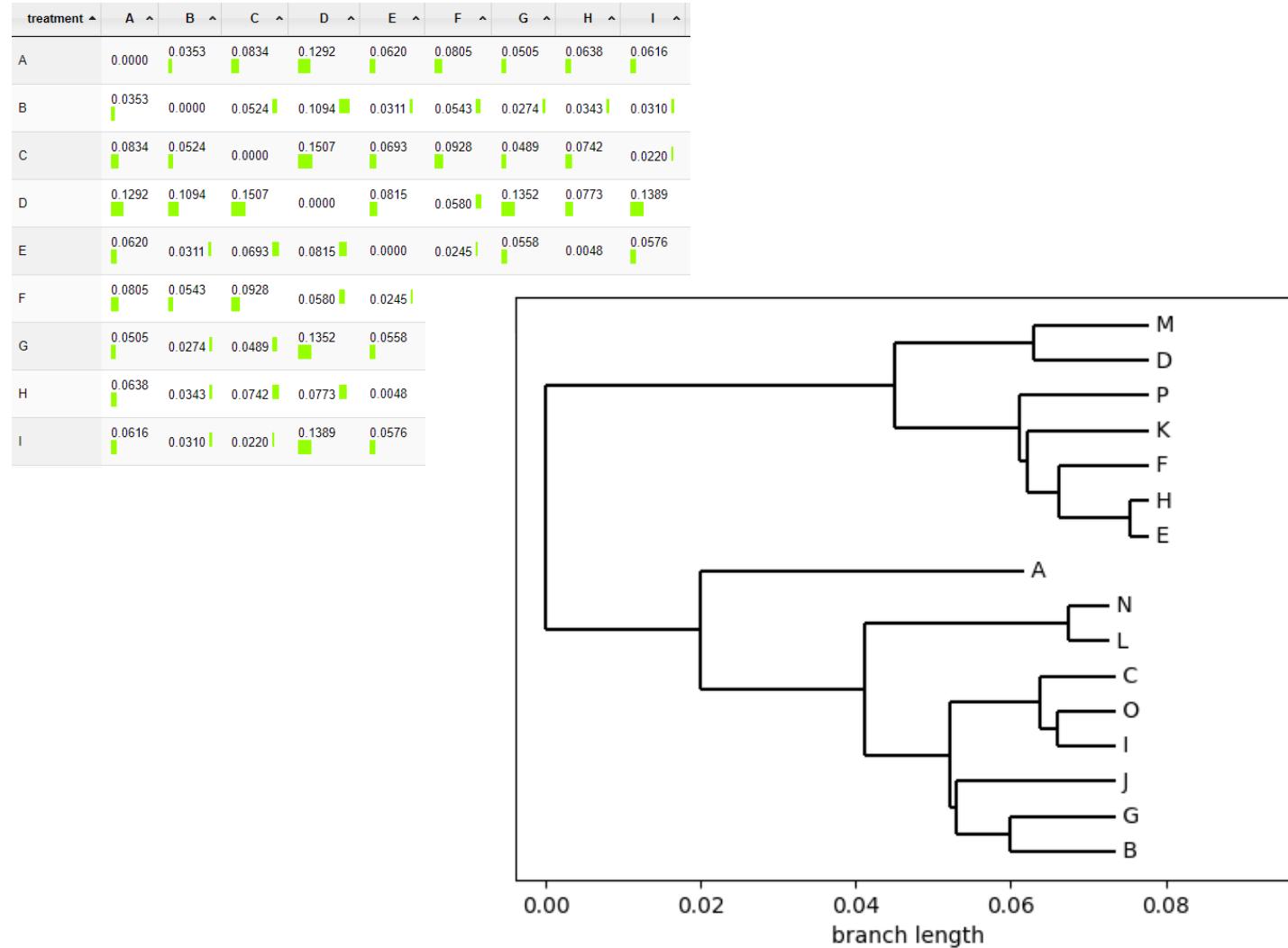
Fig. 18: acA2000-50gc, acA2040-25gc Spectral Response (From Sensor Data Sheet)

Image analysis – color – impact of ambient lighting

Setting sun, more red, less blue



Treatment clustering by color



Clustering of a group of mutants by day

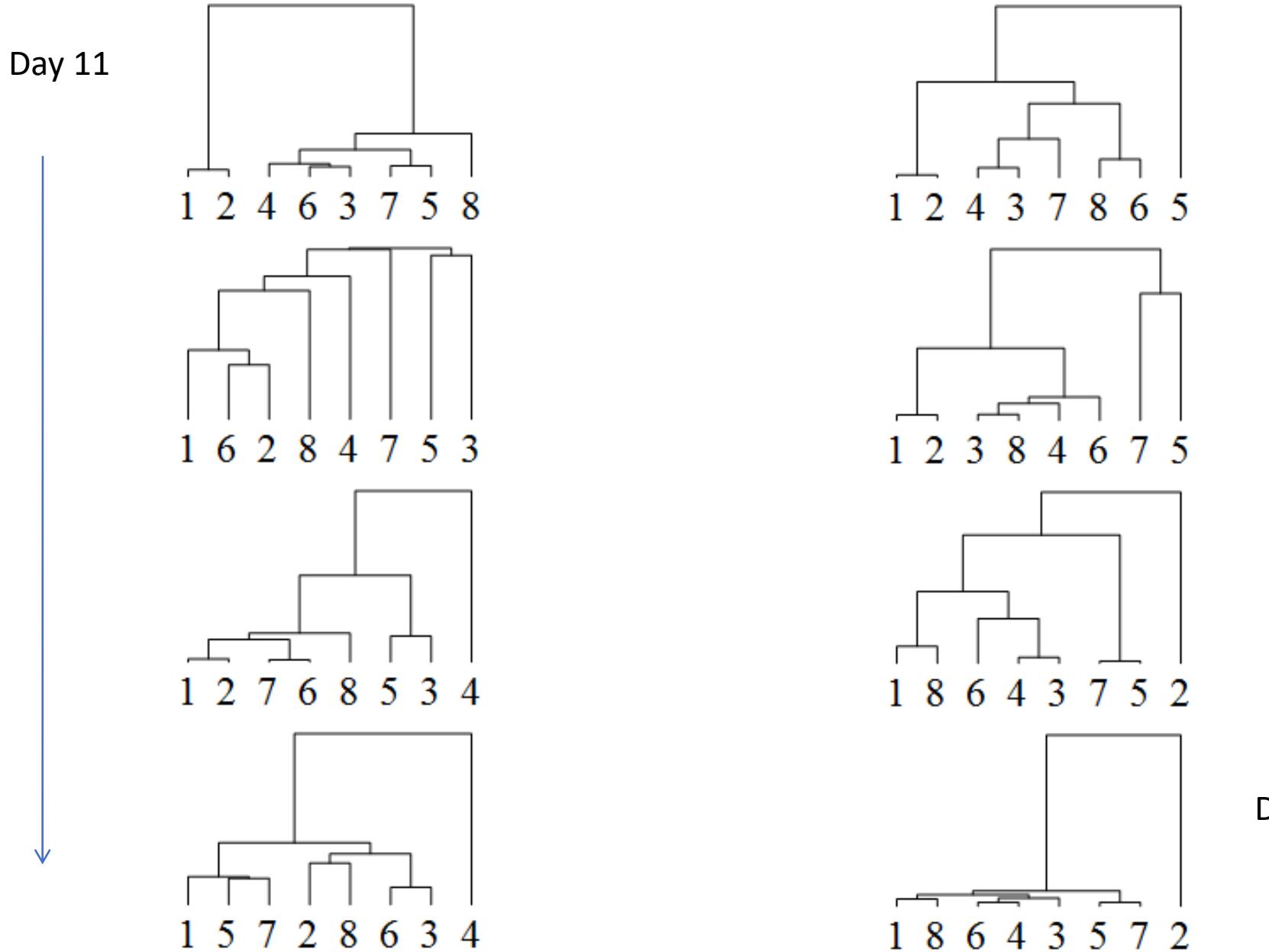
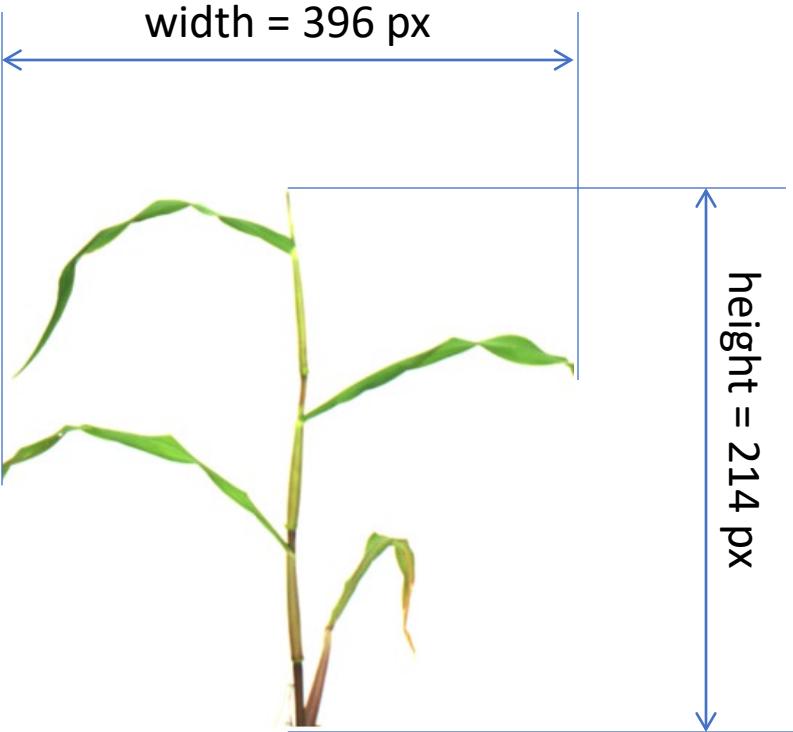


Image analysis – size



width = 396
height = 214
volume = 84,744
pixels = 10872
occupancy = 12.8%

Pixels can be converted to actual lengths units by

$$\text{scaling factor} = \text{length (mm)} / \# \text{ pixel}$$

Changing camera-subject distance or camera-lens magnification will change scaling factor.

Image analysis - morphology



skeletonization attempts to represent centers of plant structures with lines, which can be measured

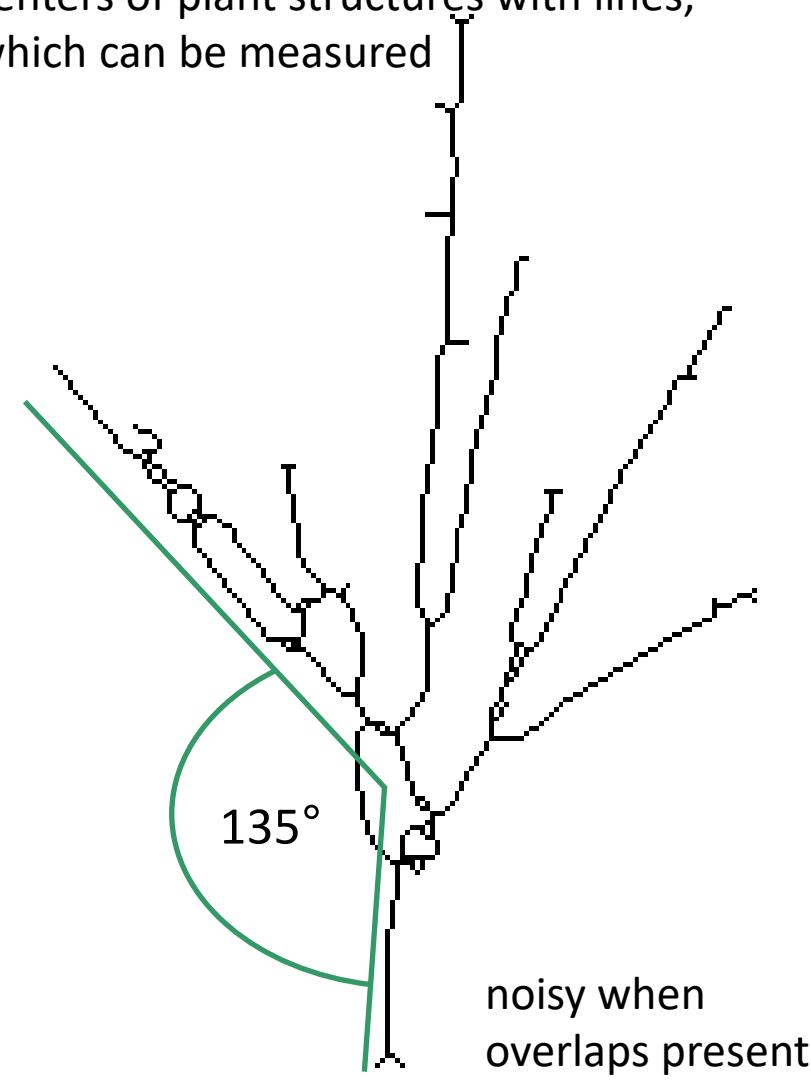


Image analysis – basic metrics

trait	treatment	stddev(treatment)	stddev(not treatment)	stddev(all)	mean(treatment)	mean(not treatment)	mean(all))	count(treatment)	count(not treatment)	count(all)
area_cm2	A	22.0	19.2	23.6	143.5	89.9	93.5	24	332	356
area_cm2	B	18.4	23.8	23.6	84.5	94.1	93.5	22	334	356
area_cm2	C	22.0	23.7	23.6	88.7	93.9	93.5	26	330	356
area_cm2	D	16.4	24.0	23.6	85.9	94.1	93.5	24	332	356

Metric name

angle_deg
area(sum)_cm2
area(contour)_cm2
area(hull)_cm2
area(ellipse)_cm2
area(triangle)_cm2
area(circle)_cm2
area_red
area_yellow
area_green
width_cm
height_cm
circle(radius)_cm
ellipse(eccentricity)
ellipse(ma)_cm
ellipse(MA)_cm
perimeter_cm
scaling_factor_px/cm
version
bgr_hist
hsv_hist
pro_hist

Metric description

- Angle of the principal axis of the plant, an approximation of the angle of the stalk
- The area (cm^2) of the image identified as plant (Synonym metrics: area, area_cm2)
- The area of the enclosing contour of the plant (similar to area(sum)_cm2)
- The area of the convex hull (the area inside of a stretched rubber band) around the plant (compare to area(sum)_cm2 for “fullness”)
- The area of the ellipse enclosing the plant
- The area of the triangle enclosing the plant
- The area of the circle enclosing the plant
- Similar to area(sum)_cm2 but only over “red” pixels
- Similar to area(sum)_cm2 but only over “yellow” pixels
- Similar to area(sum)_cm2 but only over “green” pixels
- The width of the plant between extreme points, along an edge parallel to the “ground”
- The height of the plant between extreme points, along an edge perpendicular to the “ground”
- The radius of the circle enclosing the plant
- How “oval” the ellipse is enclosing the plant
- The length of the minor axis (shortest axis) of the ellipse enclosing the plant
- The length of the major axis (longest axis) of the ellipse enclosing the plant
- The distance (cm) around the outermost enclosing contour
- Conversion factor from pixel to cm (set during instrument calibration)
- Version of the analysis software used to create these metrics
- Histogram of Blue-Green-Red color space usage (as a tuple, i.e. $\langle B,G,R \rangle : \text{count}$)
- Histogram of Hue-Saturation-Value color space usage
- Histogram of projected color space usage

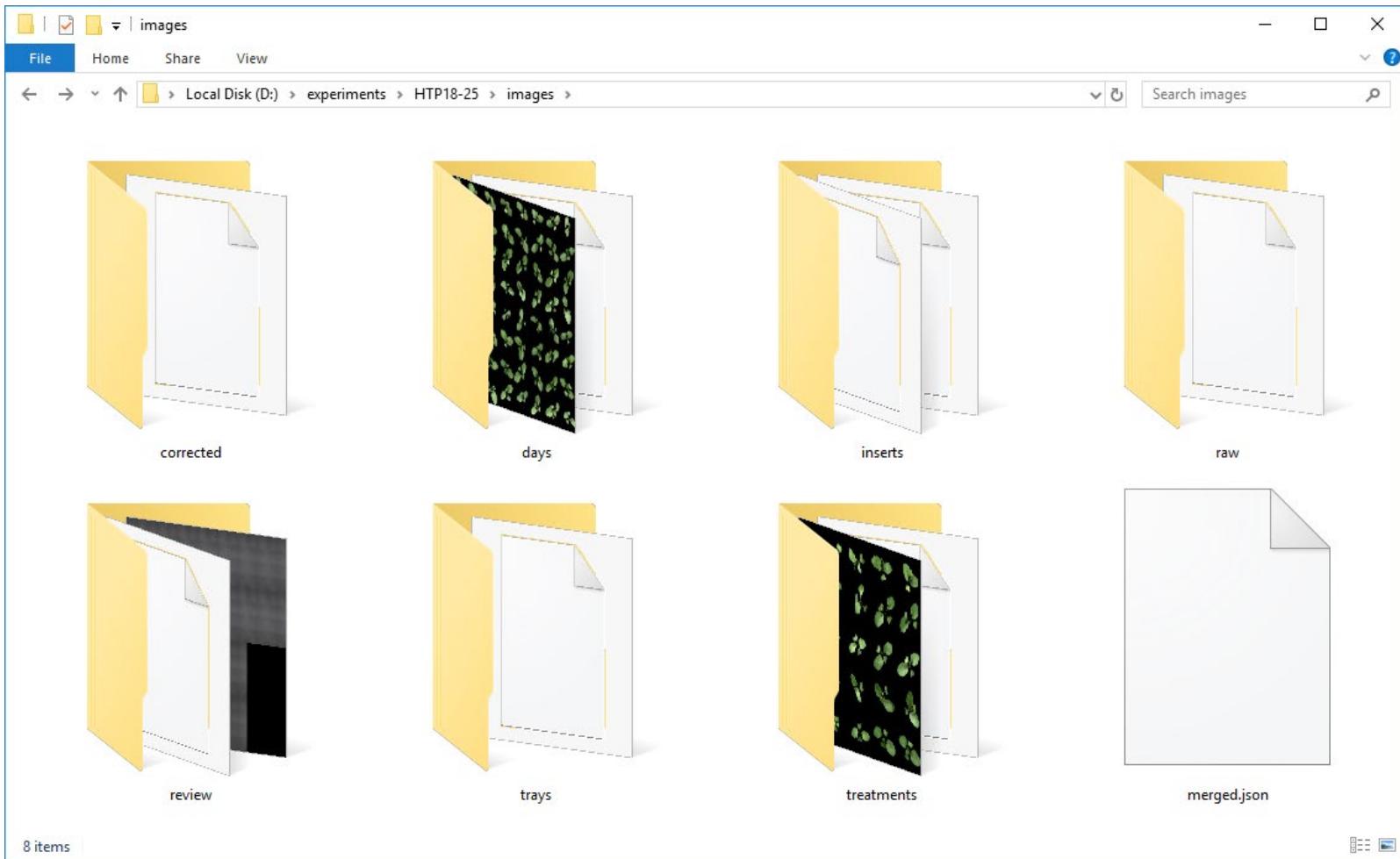
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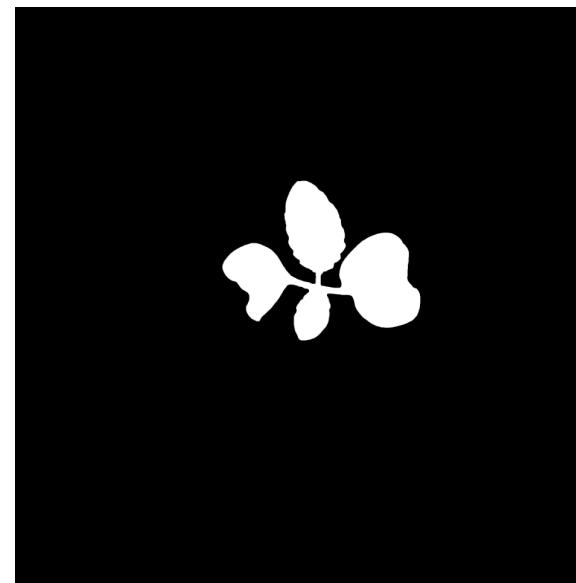
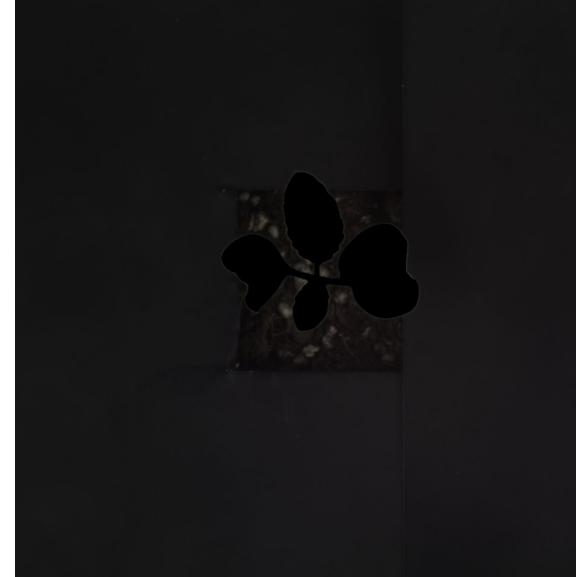
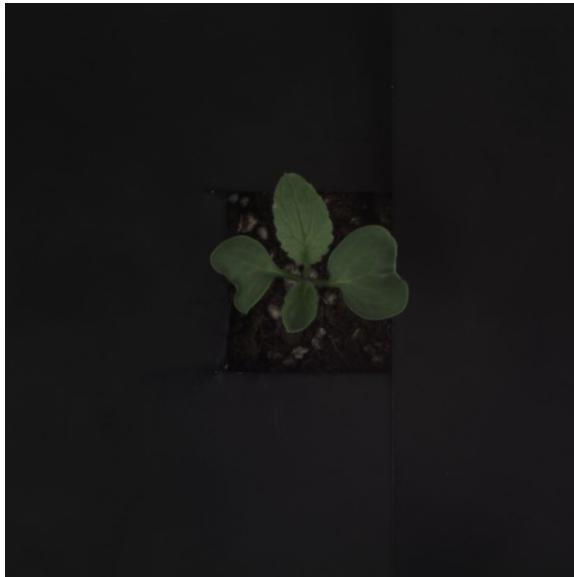
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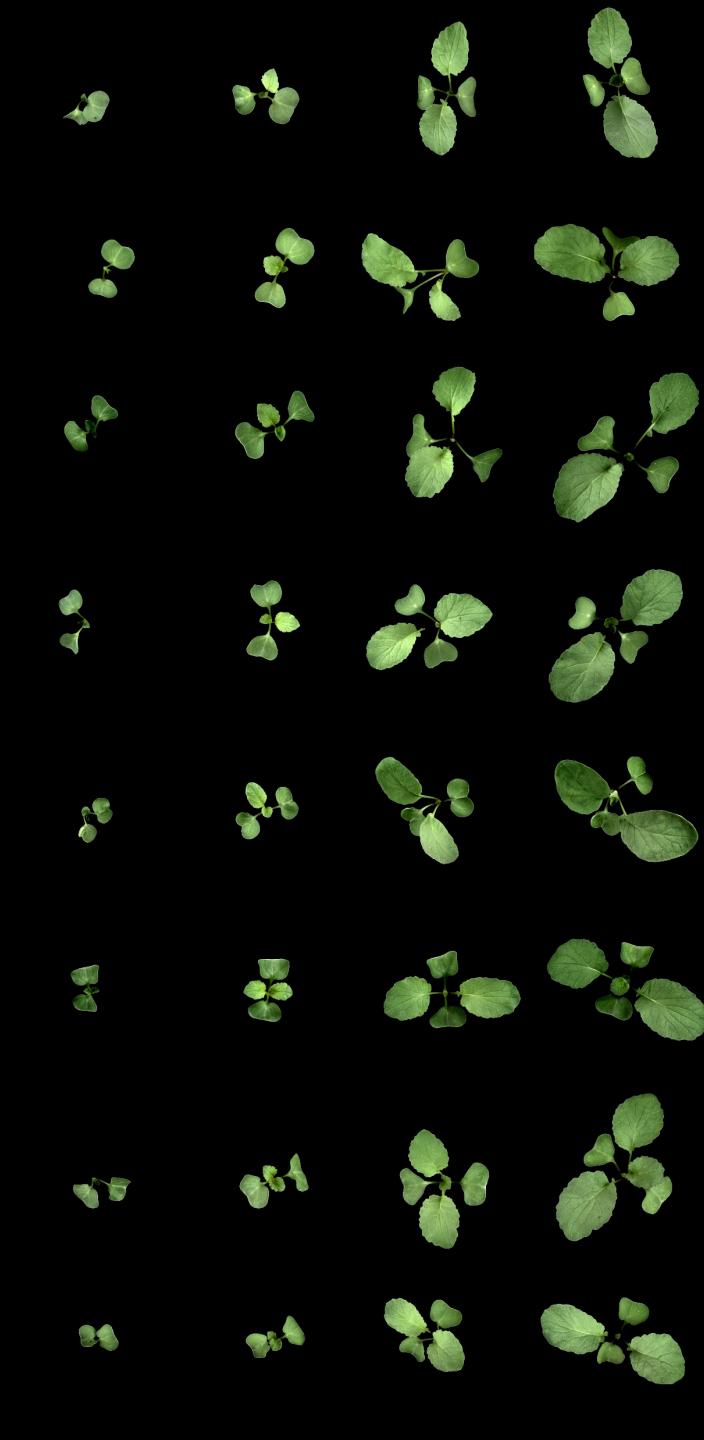
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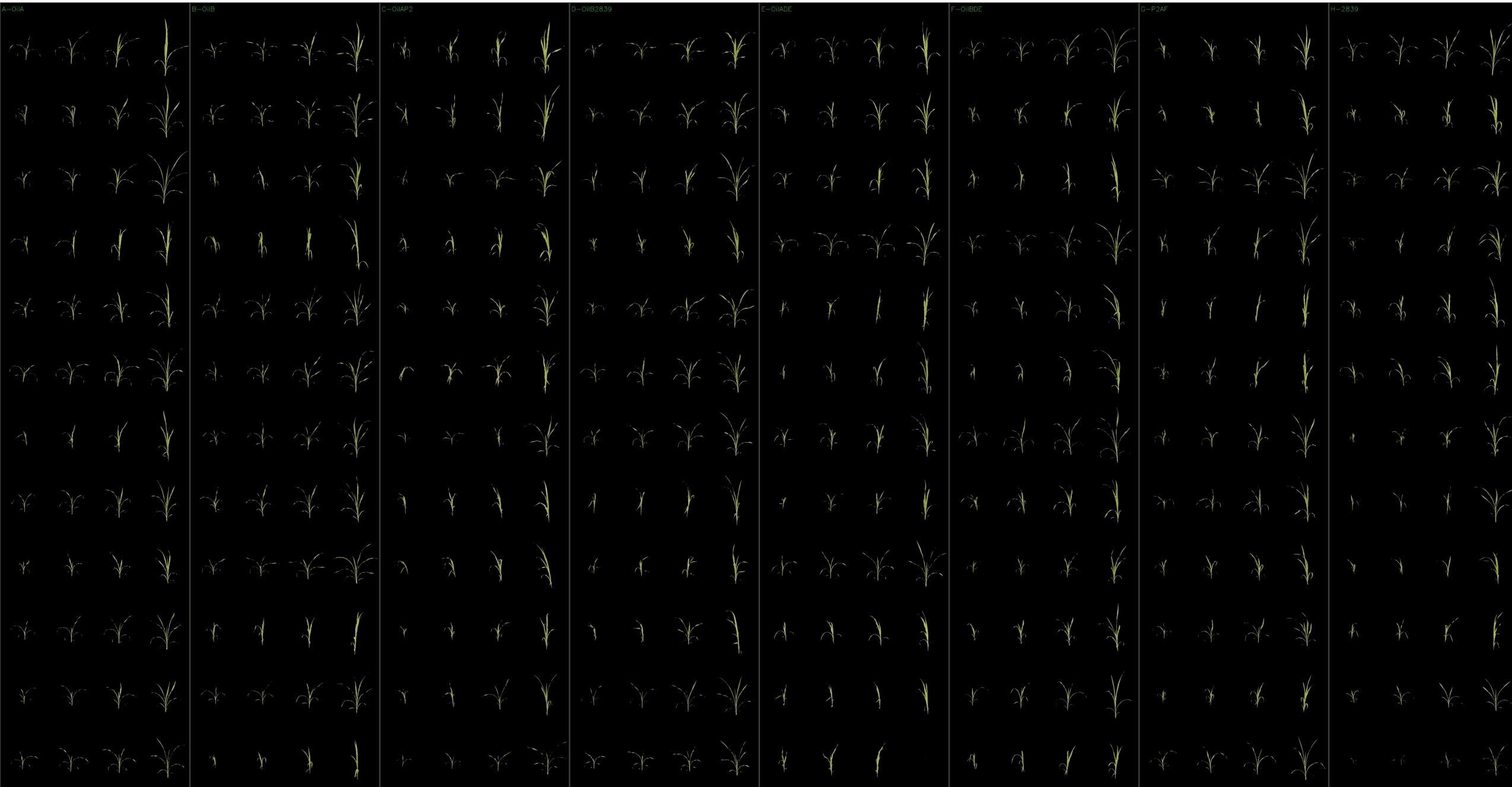
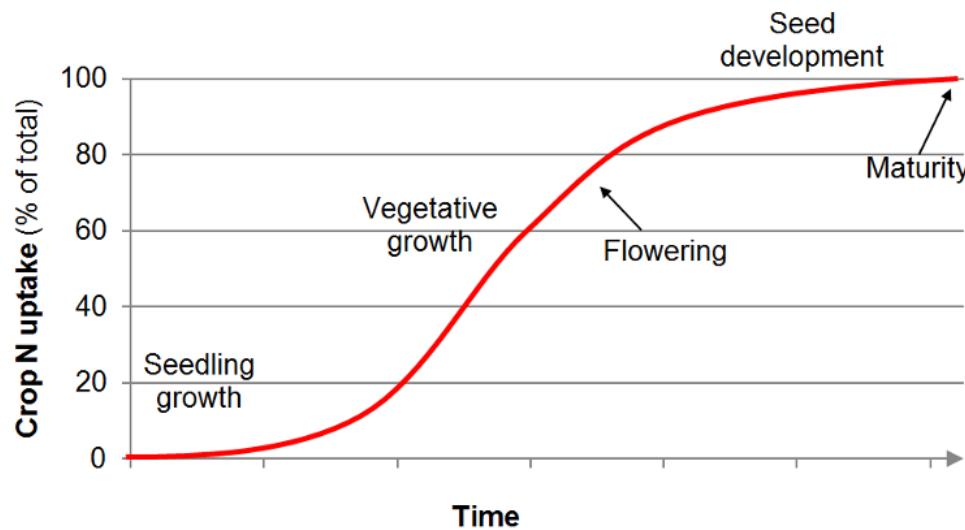
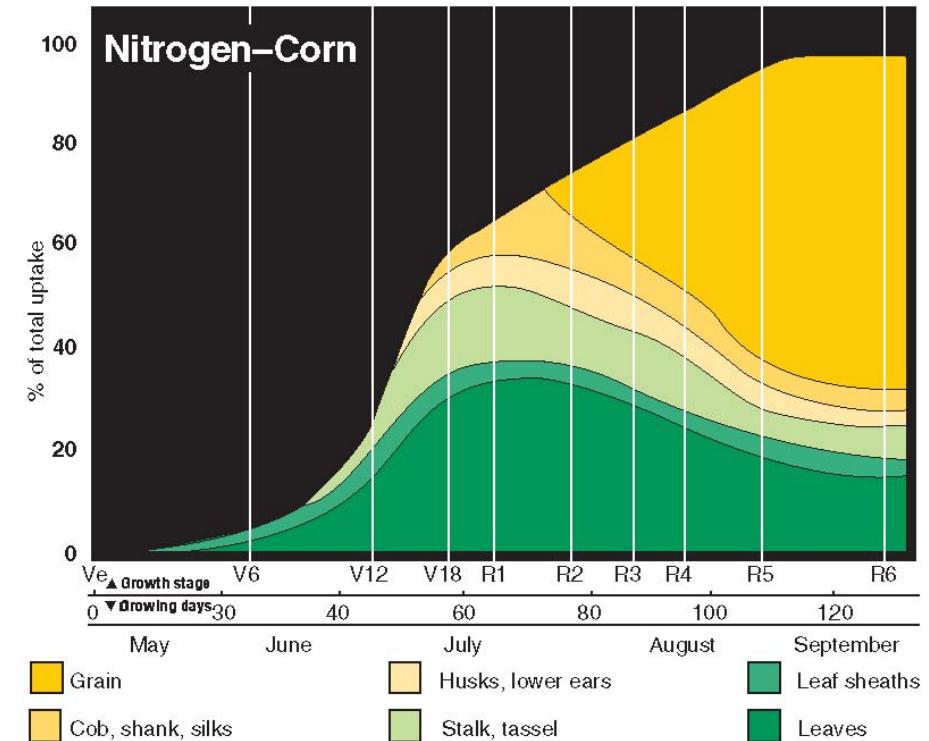


Image analysis – time series



Crop Nitrogen Uptake and Partitioning

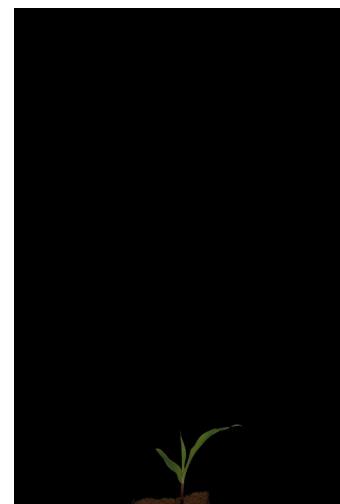
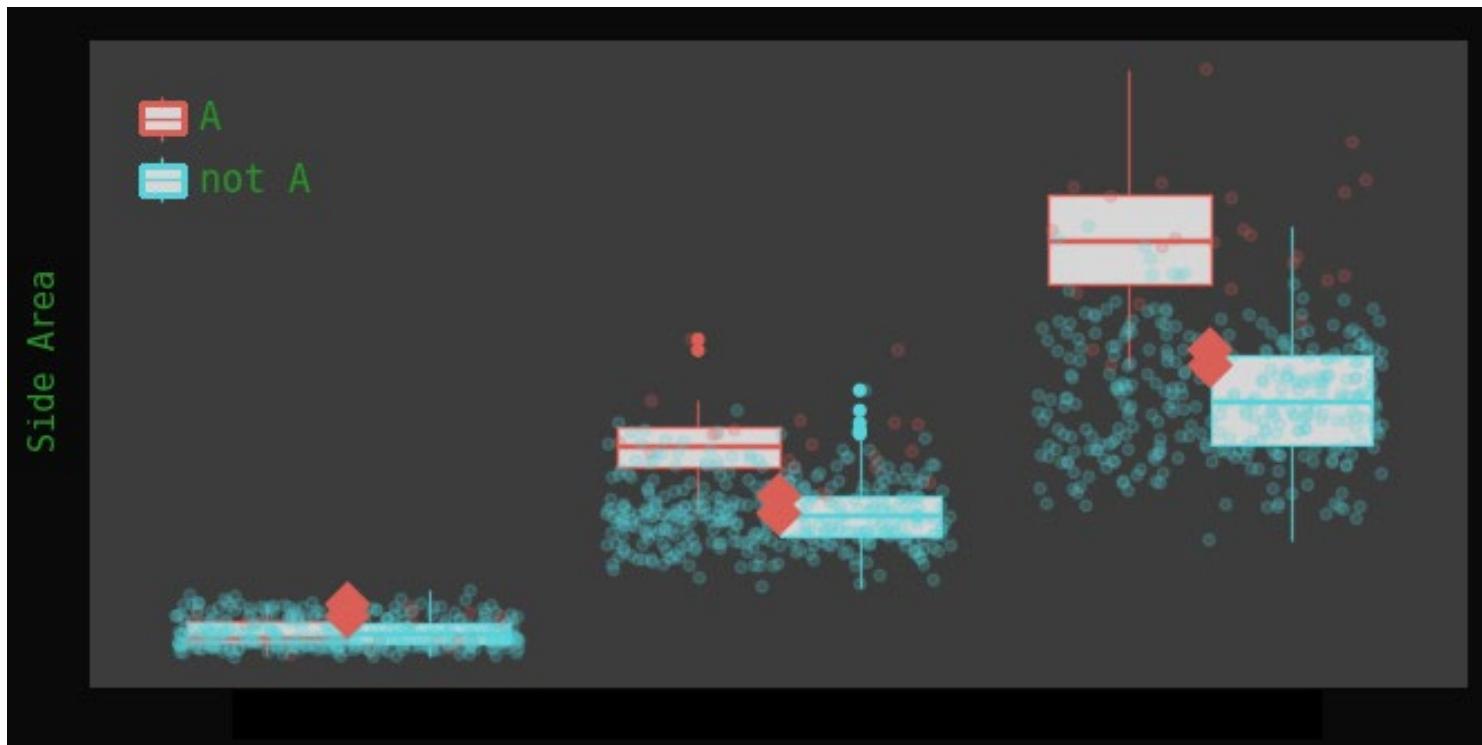
https://apps1.cdfa.ca.gov/FertilizerResearch/docs/N_Uptake.html



Best Management Practices for Nitrogen Fertilizer in Missouri

<https://plantsciences.missouri.edu/nutrientmanagement/nitrogen/practices.htm>

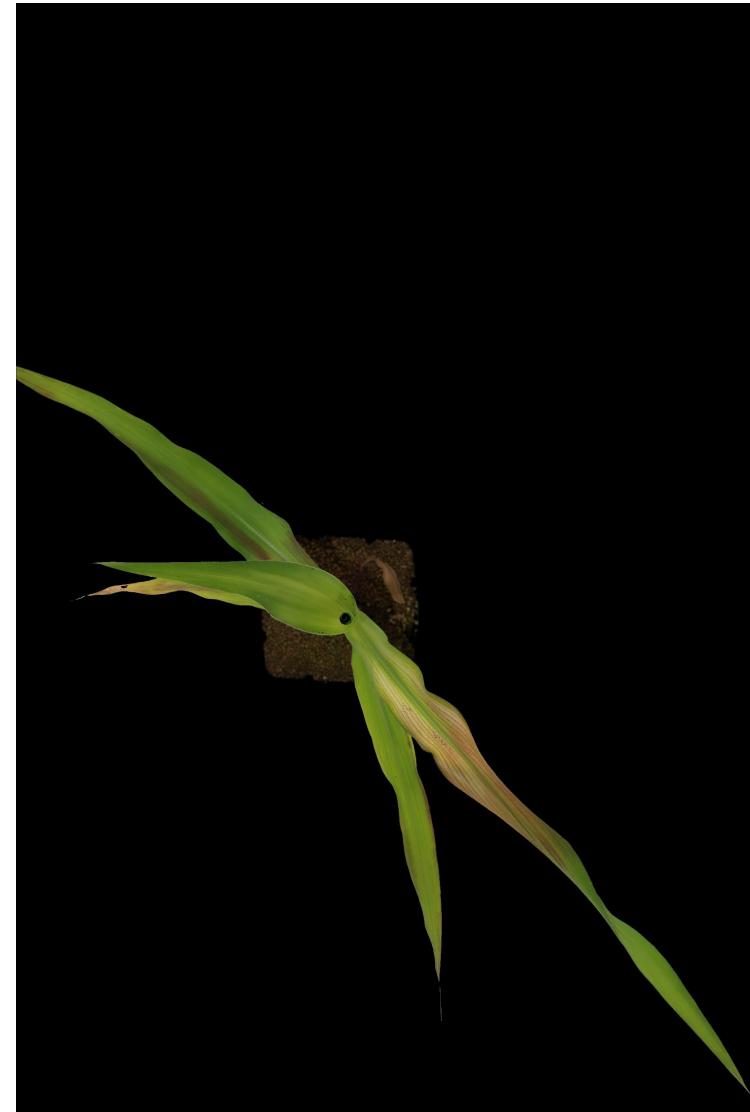
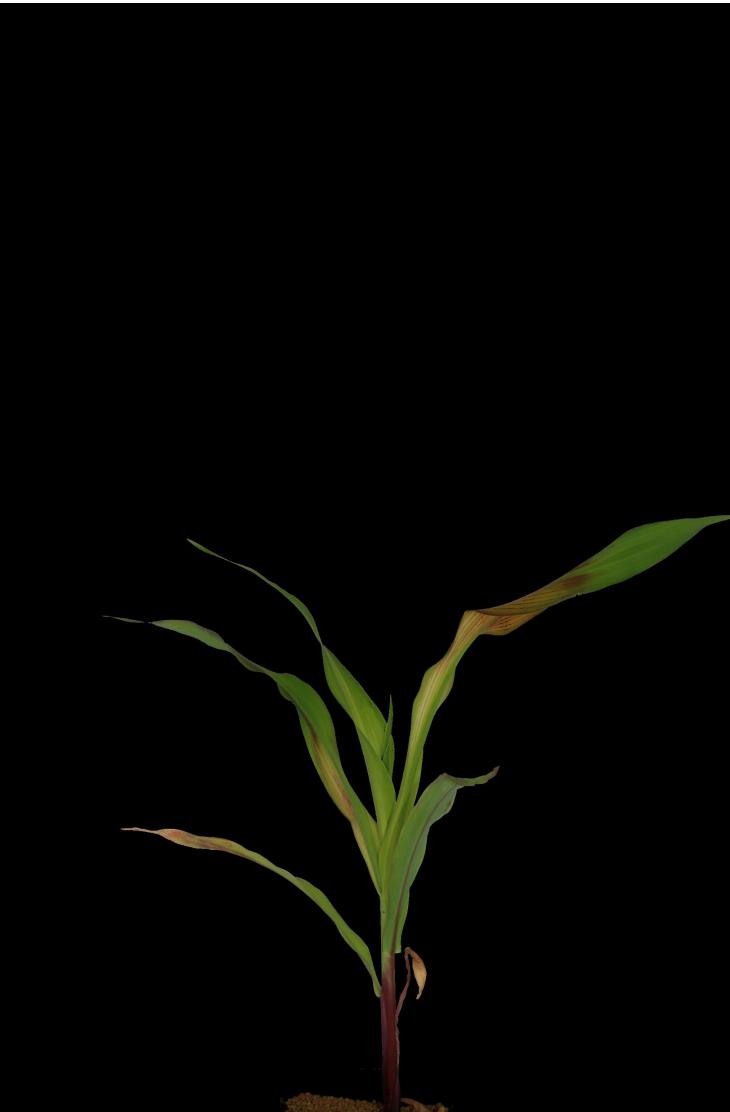
Image analysis – time series

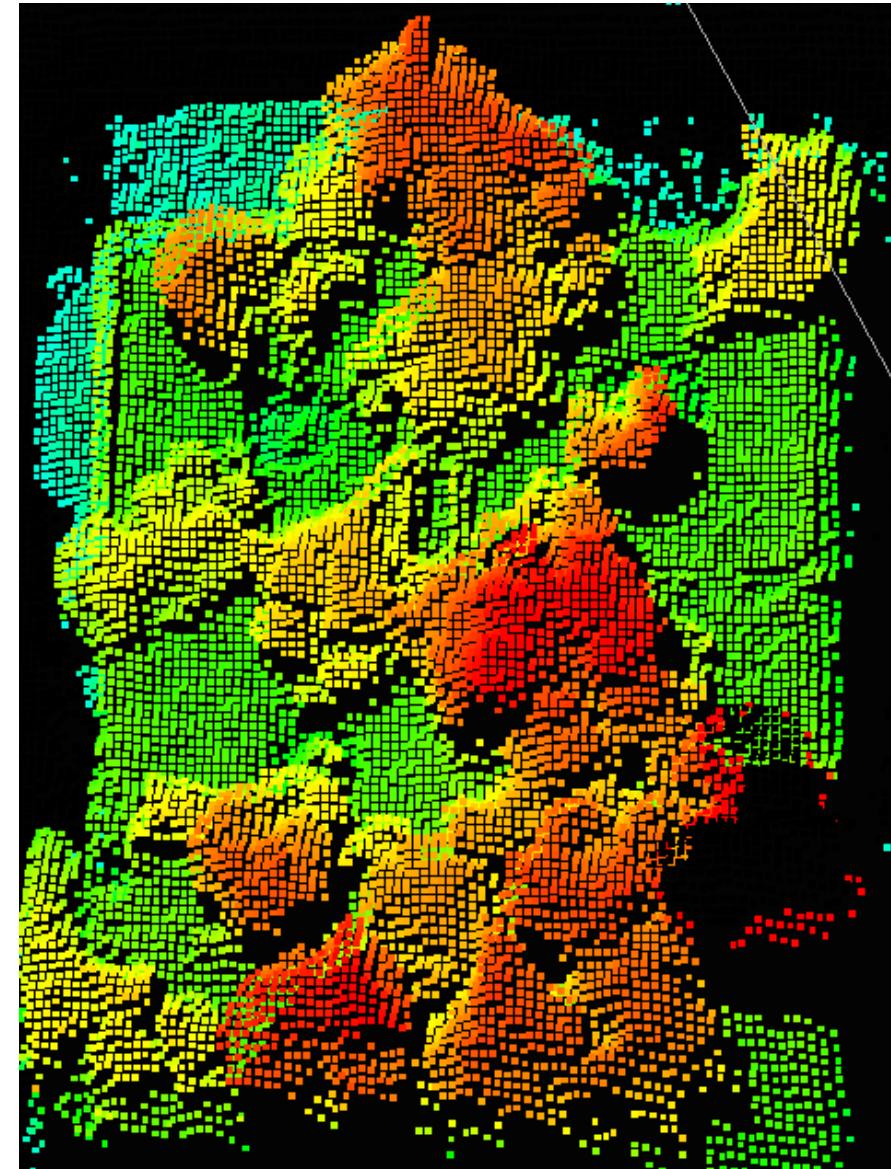


09/01 14:26 ... 09/01 14:31 ... 09/01 14:31

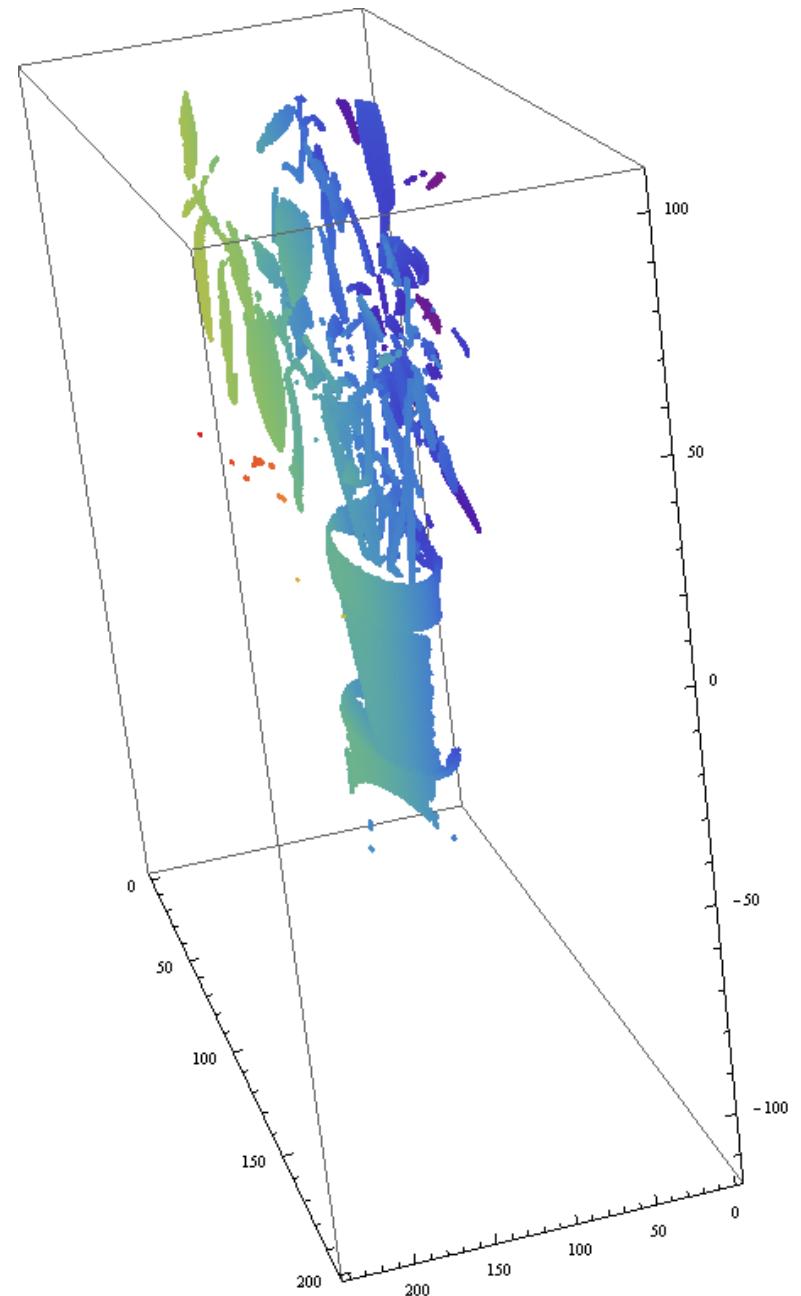
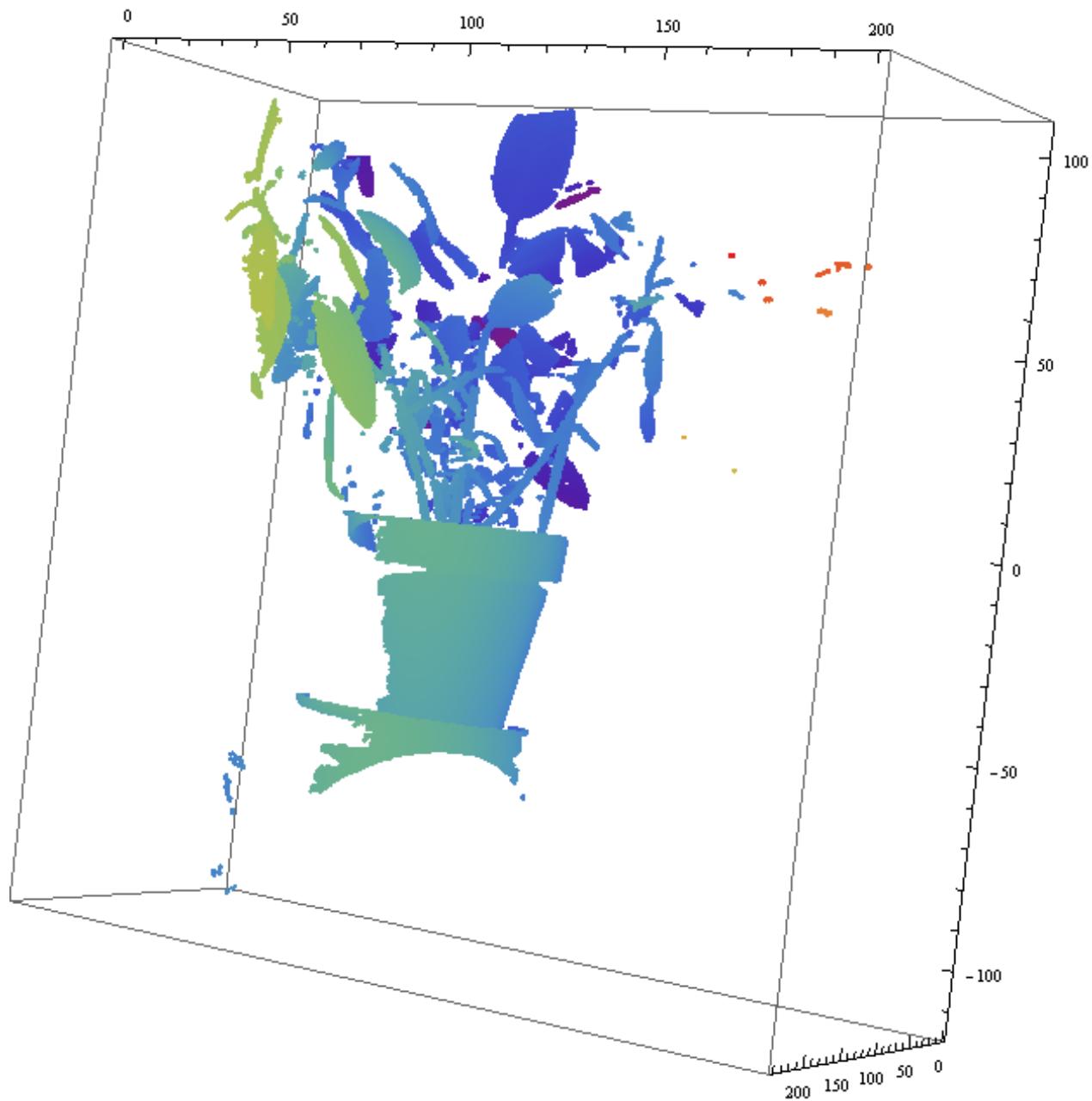


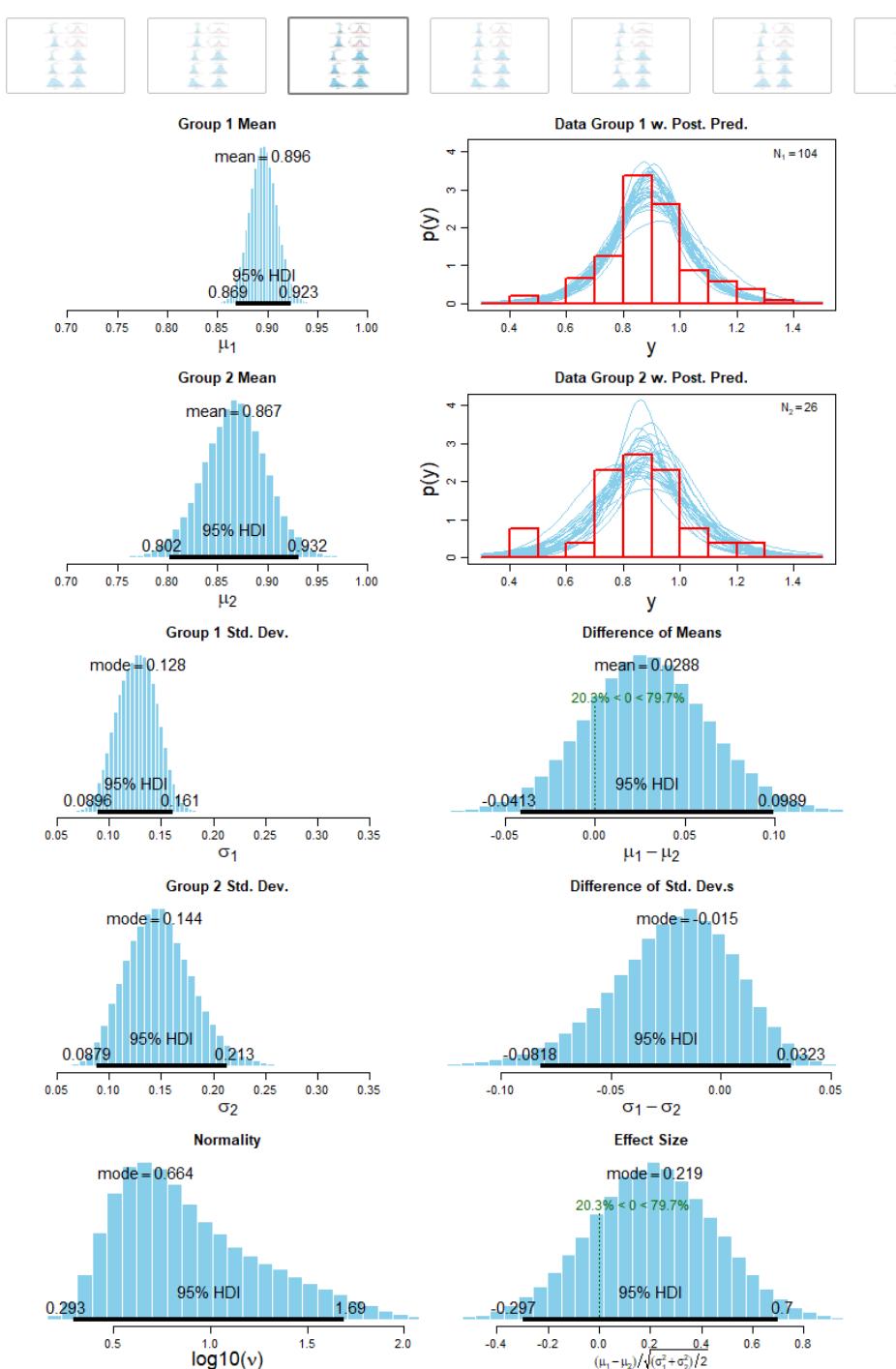
Image analysis – one source of variability - poorly placed plant





Internal depth map







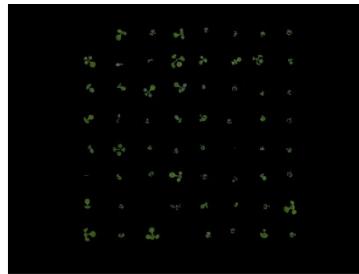




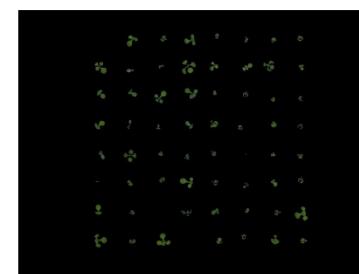


Other thoughts – image storage (don't use JPEG)

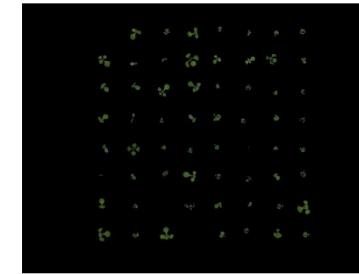
Original



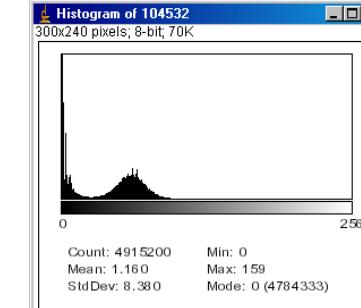
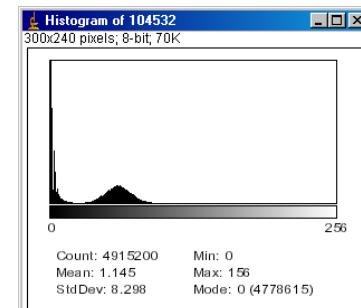
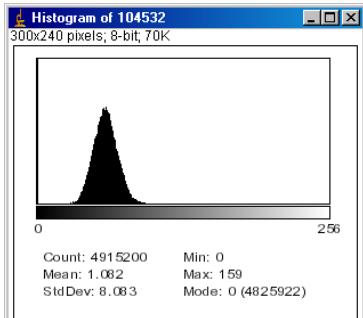
50% JPG



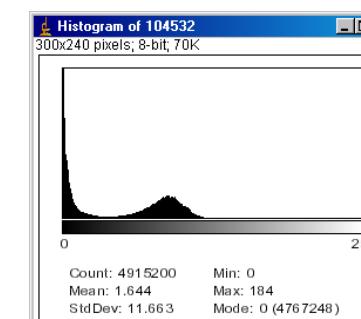
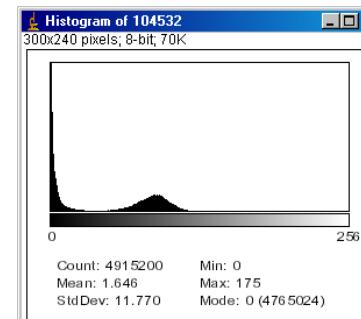
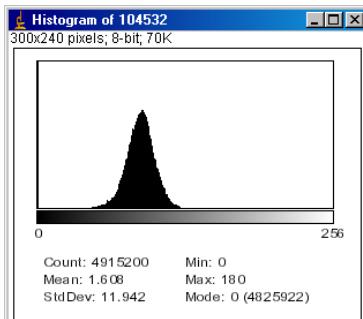
25% JPG



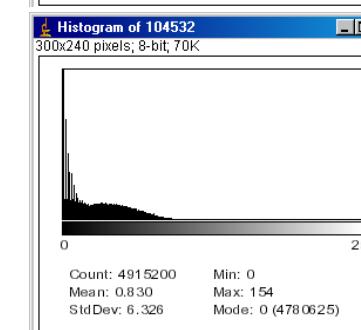
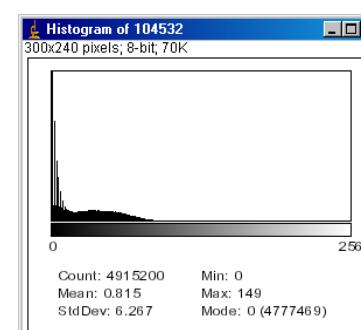
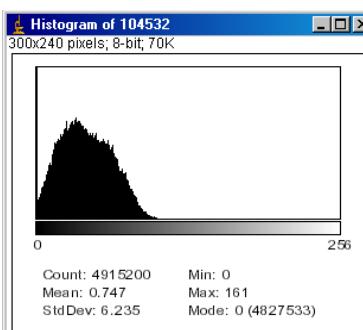
Red channel:



Green channel:



Blue channel:





Introduction meeting
Xi'an, China
December 3, 2019



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Shandong Shunfeng Biotechnology (Bellagen)
Introduction meeting
Jinan, China
December 6, 2019



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