Strawberry Plants Wetness Detection using Color and Thermal Imaging

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Strawberry Advisory System

- **Strawberry Advisory System (SAS)** is an advising system for strawberry crop growers
- Provides recommendations for timing fungicide applications for control of Anthracnose and Botrytis fruit rots

Weather Information

Latest Data Report - Plant City Station

Date/Time	Temp(F)	RH(%)	Rain(in)	Wet	LWD	Mean Temp(F)	BII	AII
2019-04-16 09:15:00	70.09	49.60	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 09:00:00	68.94	50.90	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 08:45:00	67.86	52.99	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 08:30:00	66.42	59.46	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 08:15:00	64.35	64.25	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 08:00:00	62.89	67.55	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 07:45:00	61.32	71.00	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 07:30:00	59.88	74.50	0.00	NO	9.25	55.93	0.12	0.05
2019-04-16 07:15:00	57.79	79.10	0.00	YES	9.25	55.93	0.12	0.05
2019-04-16 07:00:00	55.78	83.60	0.00	YES	9.00	55.88	0.11	0.05
2019-04-16 06:45:00	54.36	87.70	0.00	YES	8.75	55.88	0.11	0.05
2019-04-16 06:30:00	52.86	91.10	0.00	YES	8.50	55.92	0.10	0.05
2019-04-16 06:15:00	52.65	92.00	0.00	YES	8.25	56.02	0.10	0.05
2019-04-16 06:00:00	52.61	92.80	0.00	YES	8.00	56.12	0.09	0.04
2019-04-16 05:45:00	52.61	94.70	0.00	YES	7.75	56.23	0.09	0.04
2019-04-16 05:30:00	52.29	96.00	0.00	YES	7.50	56.35	0.08	0.04
2019-04-16 05:15:00	52.30	95.60	0.00	YES	7.25	56.49	0.08	0.04
2019-04-16 05:00:00	52.61	96.00	0.00	YES	7.00	56.64	0.08	0.04
2019-04-16 04:45:00	52.81	96.10	0.00	YES	6.75	56.79	0.07	0.04
2019-04-16 04:30:00	53.22	95.50	0.00	YES	6.50	56.95	0.07	0.04
2019-04-16 04:15:00	53.65	94.00	0.00	YES	6.25	57.10	0.06	0.04
2019-04-16 04:00:00	54.05	93.00	0.00	YES	6.00	57.24	0.06	0.04
2019-04-16 03:45:00	54.48	92.20	0.00	YES	5.75	57.38	0.06	0.04
2019-04-16 03:30:00	54.77	92.90	0.00	YES	5.50	57.51	0.06	0.04
2019-04-16 03:15:00	54.90	93.00	0.00	YES	5.25	57.64	0.05	0.04
2019-04-16 03:00:00	55.71	91.80	0.00	YES	5.00	57.78	0.05	0.04
2019-04-16 02:45:00	55.81	91.40	0.00	YES	4.75	57.89	0.05	0.04
2019-04-16 02:30:00	55.56	92.10	0.00	YES	4.50	58.00	0.04	0.04
2019-04-16 02:15:00	55.90	92.30	0.00	YES	4.25	58.15	0.04	0.04
2019-04-16 02:00:00	56.21	92.10	0.00	YES	4.00	58.29	0.04	0.04
2019-04-16 01:45:00	56.25	93.20	0.00	YES	3.75	58.42	0.04	0.03
2019-04-16 01:30:00	56.12	93.60	0.00	YES	3.50	58.58	0.03	0.03

Daily weather updates available on the website.

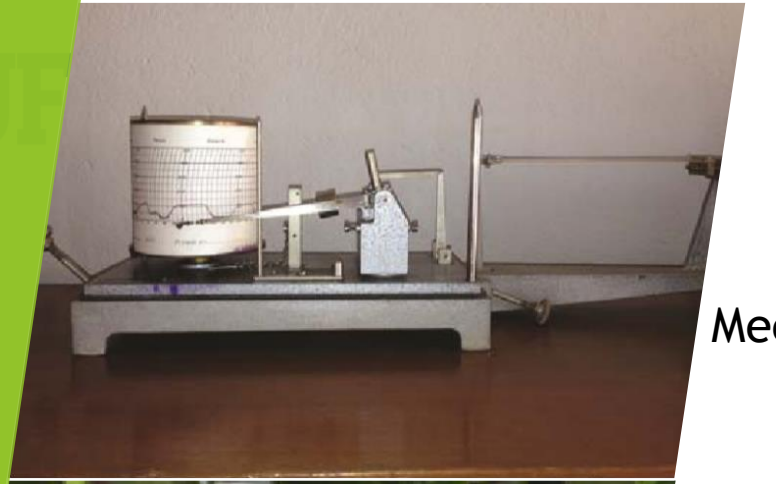
Data collected every 15 minutes.

- Weather Information from Plant City Station.
- The Variables:
  - ***Temp (F)*** *- Ambient Temperature*
  - ***RH*** *- % Relative Humidity*
  - ***Rain*** *- Total Rainfall in inches*
  - ***Wet*** *- Accumulated hours of Leaf Wetness ('yes' or 'no')*
  - ***LWD*** *- Leaf Wetness Duration*
  - ***Mean Temp (F)*** *- Average Temperature during the wetness period*
  - ***BII*** *- Botrytis Infection Index*
  - ***AII*** *- Anthracnose Infection Index*

Leaf Wetness Duration (LWD)

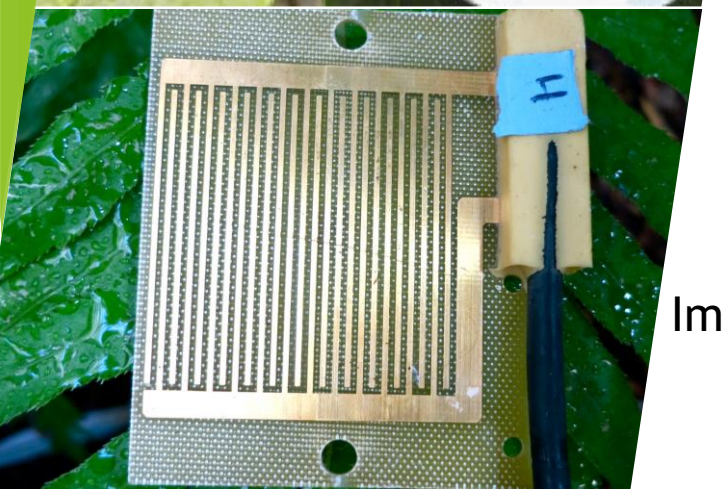
- Leaf wetness is the amount of water present over the surface of crop.
- Causes:
  - Water intercepted by canopy during rainfall and fog
  - Over-head irrigation
  - Dew
  - Guttation (the secretion of droplets of water from the pores of plants)
- The duration for which this water is present on the crop is the **Leaf Wetness Duration (LWD).**

Current Solutions



Mechanical Sensor

Dielectric Sensor



Impedance Sensor

- **Sensors**
  - **Mechanical Sensors** - record changes in weight of the sensor resulting from the presence of water
  - **Electronic Sensors -** measure variation in impedance or dielectric constant due to presence of water
- **Mathematical Models -** using meteorological data available from most weather stations

LWD Modeling: Methodology

Study Area and Data Source

FAWN

Problems

- Placement of sensors, calibration, maintenance, and field accessibility.
- Regular maintenance of these sensors is required.
- The wires attaching sensors to dataloggers also attract rodents

Rowlandson, T., Gleason, M., Sentelhas, P., Gillespie, T., Thomas, C., & Hornbuckle, B. (2015). Reconsidering leaf wetness duration determination for plant disease management. Plant Disease,99, 310–319

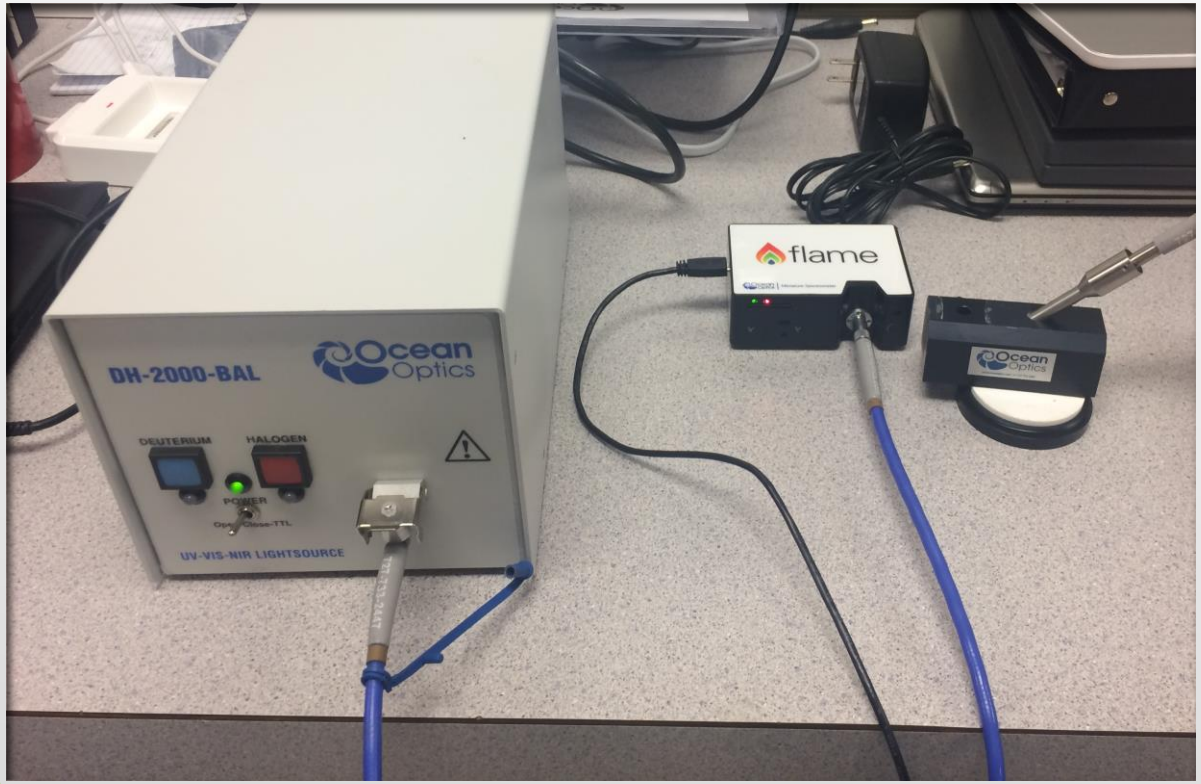
Objective

- *To develop a system for the detection of Leaf Wetness of strawberry plant using various techniques.*

Approaches

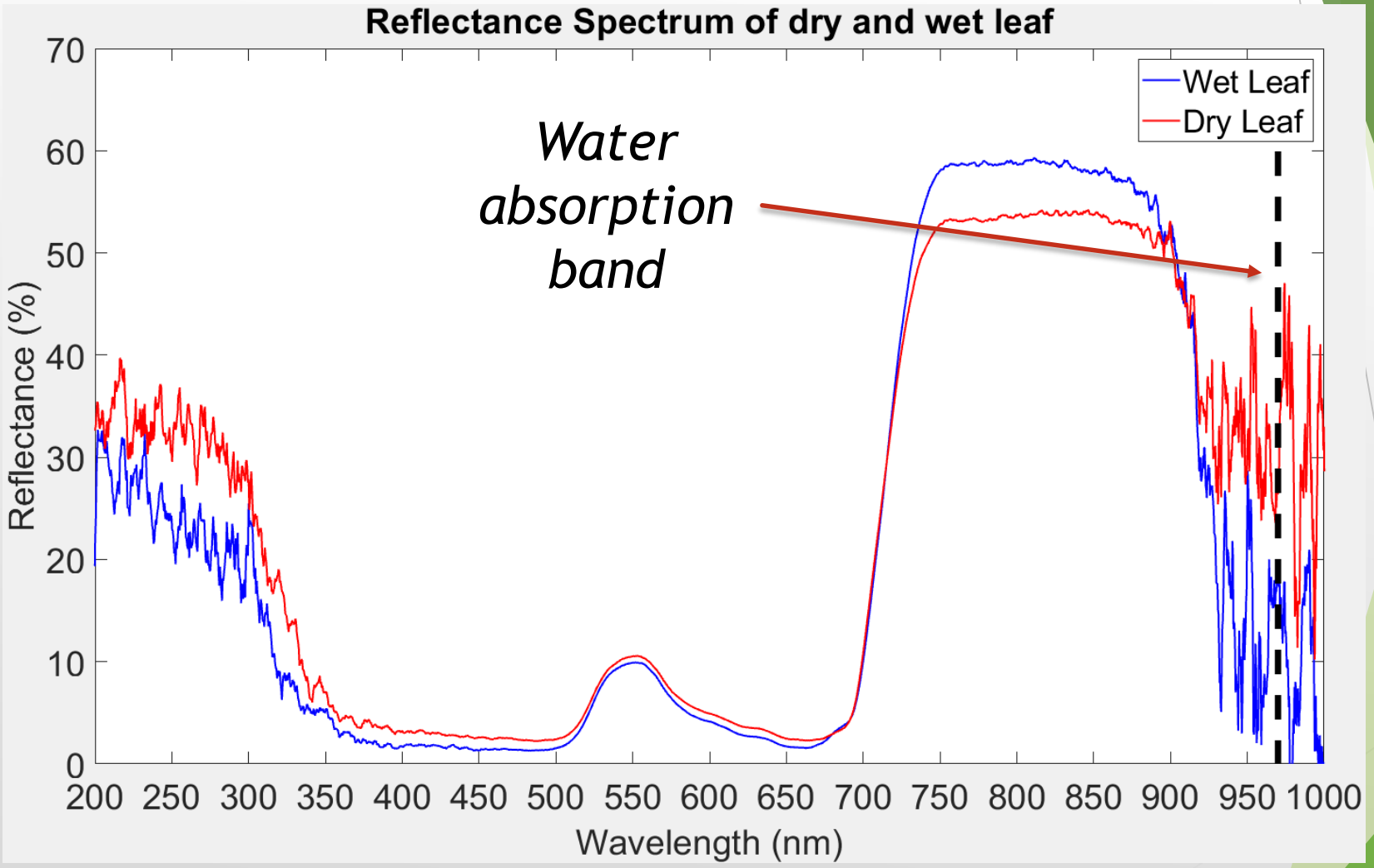
- Spectroscopy
- Color Vision
- Thermal Imaging

Spectroscopy



- Deals with interaction between matter and electromagnetic radiation
- Water has absorption bands in the regions of:
  - 970 nm – NIR
  - 1430 nm – SWIR
  - 1950 nm – SWIR
- Presence of water can be detected using a spectrometer by analyzing the spectrum of wet leaves
- ***Spectrometers in SWIR range costs more than $15,000***

Spectrum & Issues



Challenges

- Noisy Spectrum around 970 nm
- Used for point measurement, need greater field of view

Color Imaging

How Do Objects Appear When Wet?

- The wet surface appears darker and more shiny as compared to the dry surface

Dataset

Dry Plant

Wet Plant

- Dataset Information:

  Date: February 19 - March 8

  Weather Conditions:

Date	Avg Wind Speed (mph)	Ambient Temperature (F)	Relative Humidity (%)
2/19/19	2.7	80.96	65.1
2/21/19	0.6	74.3	51.6
2/28/19	0.8	85.64	72.9-85.2
3/8/19	1.3	87.08	50-54.8

  Number of Images: approximately 20 different plants per dataset

- To create the effect of wetness artificially, the dry plants were sprayed with water using a hand pump

Strawberry Harvesting & Data Collection at Citra

Plants Grown for Testing in the Lab

Dry Plant

Wet Plant

Preprocessing

- The images acquired were cropped to appropriate size so that maximum plant area could be analyzed
- To remove the clutter present in the background, color based segmentation was done using MATLAB's color thresholder application

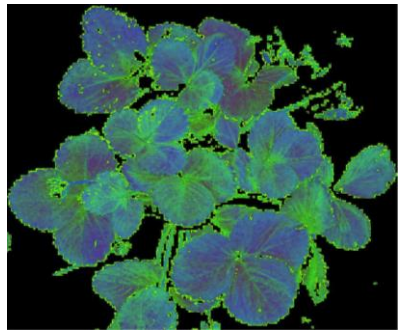
Color Space Analysis

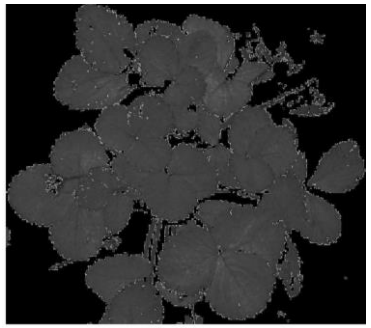

RGB


R


G


B


HSV

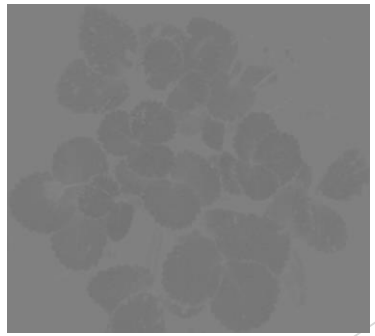

H

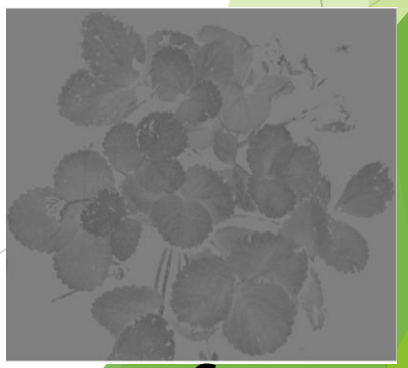

S


V


YCbCr


Y


Cb


Cr

Color Space Analysis


RGB

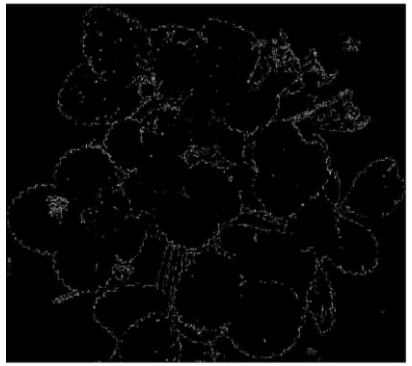

R


G


B


Lab


L


a


b


YIQ


Y


I


Q

RGB Color Space

Dry Plant

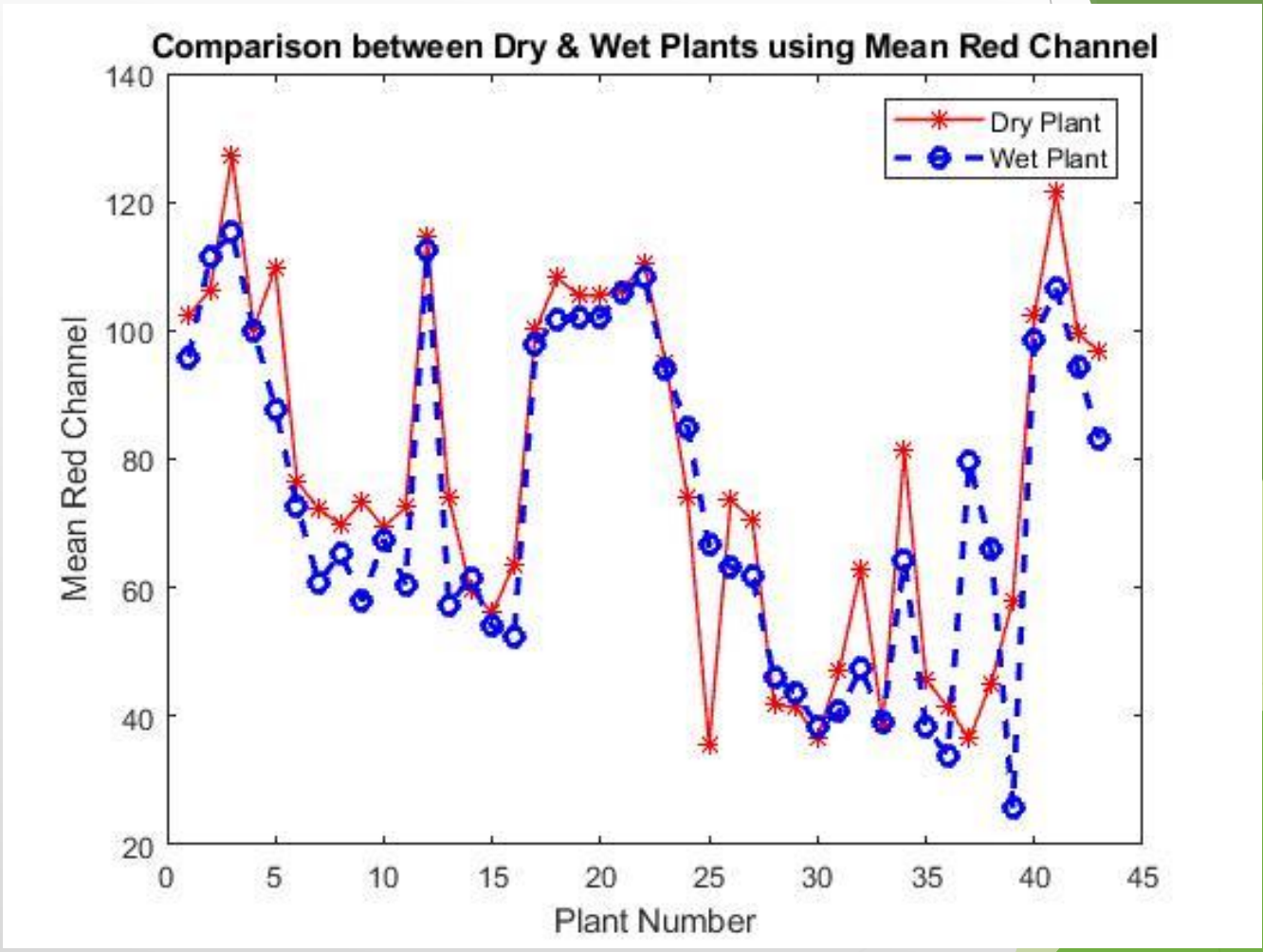
Wet Plant

- RGB Images consists of:
  - Red Channel
  - Green Channel
  - Blue Channel

Red Channel

D
R
Y

W
E
T

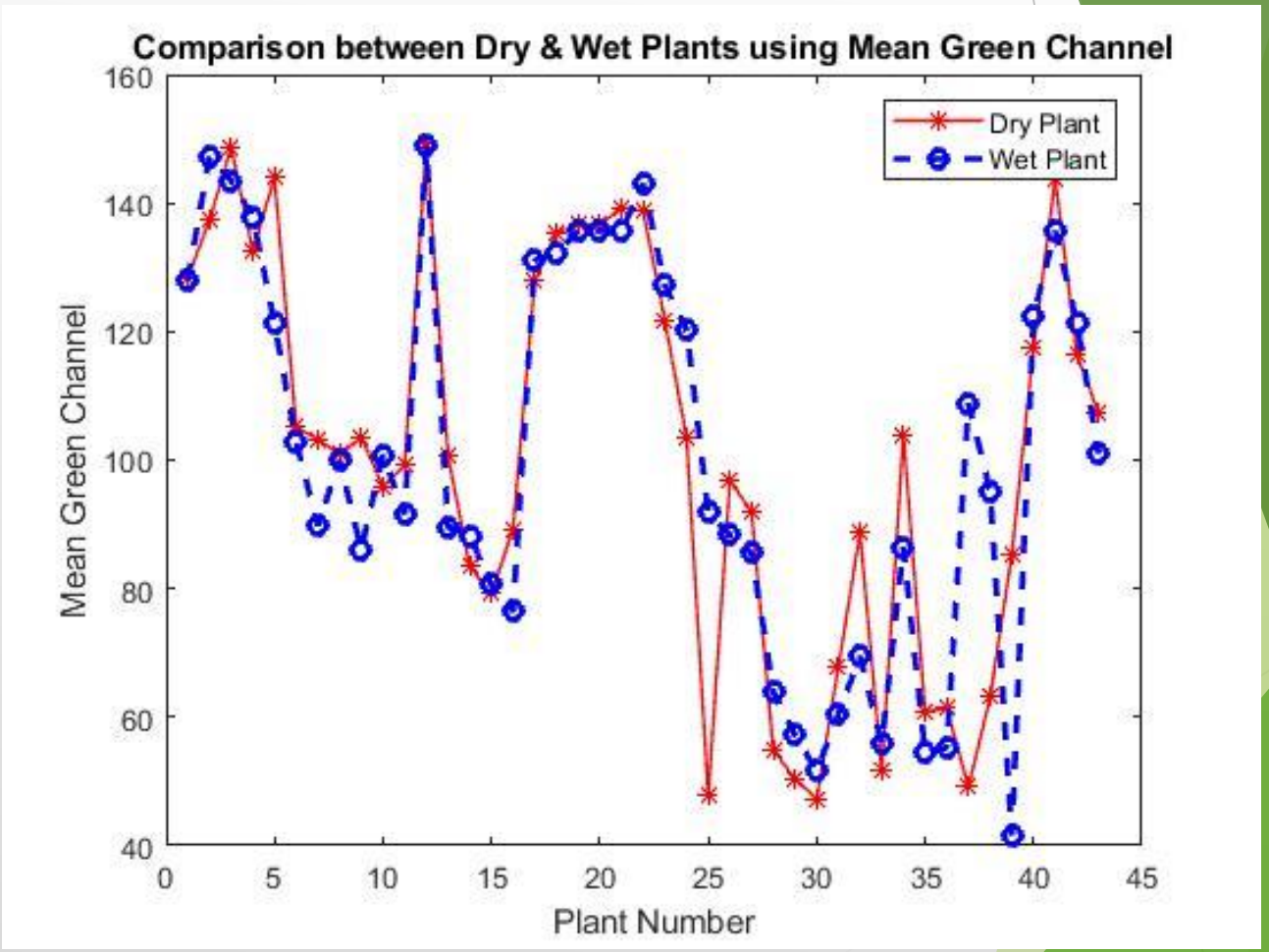


- No constant trend identified

Green Channel

DRY

WET

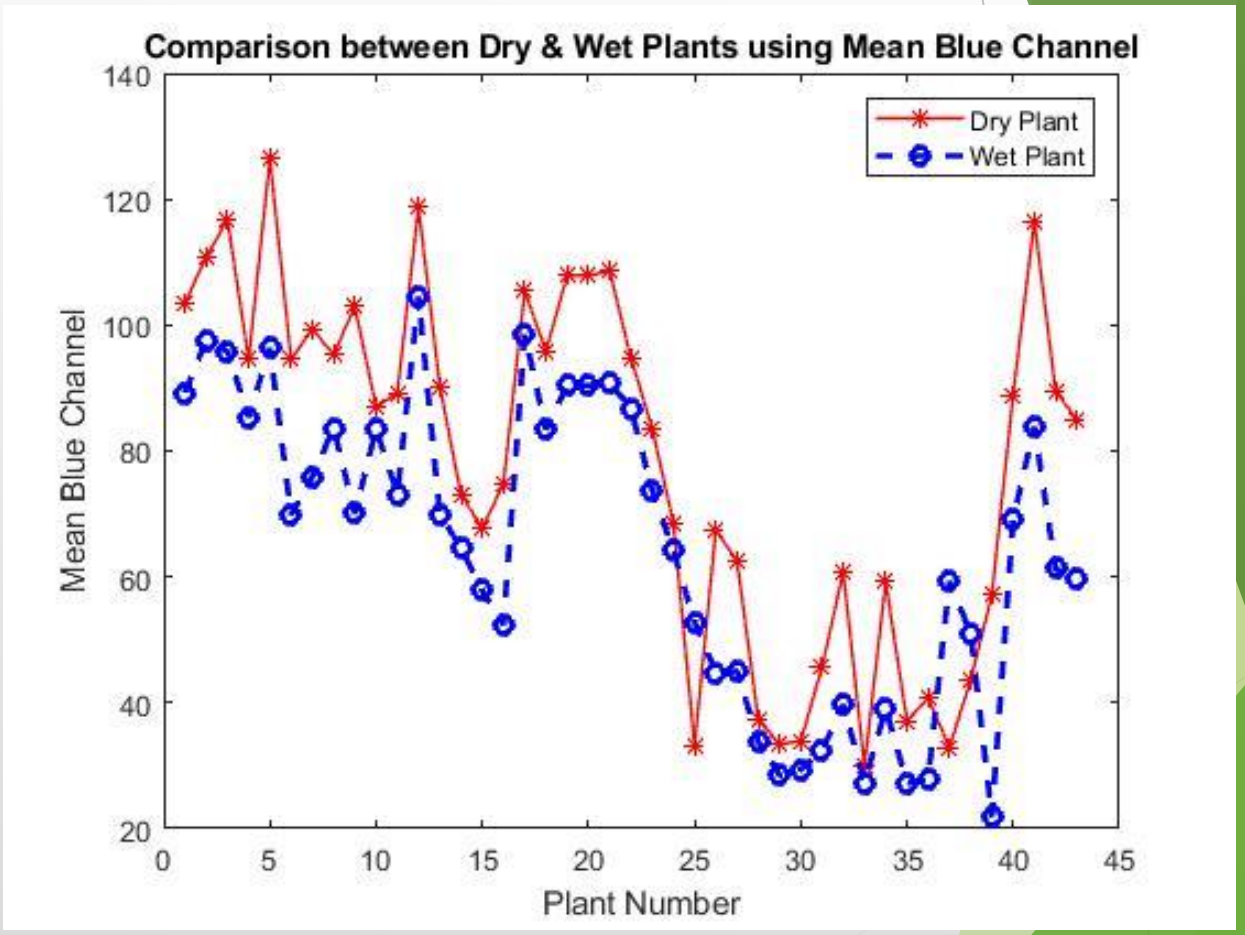


- No constant trend identified

Blue Channel

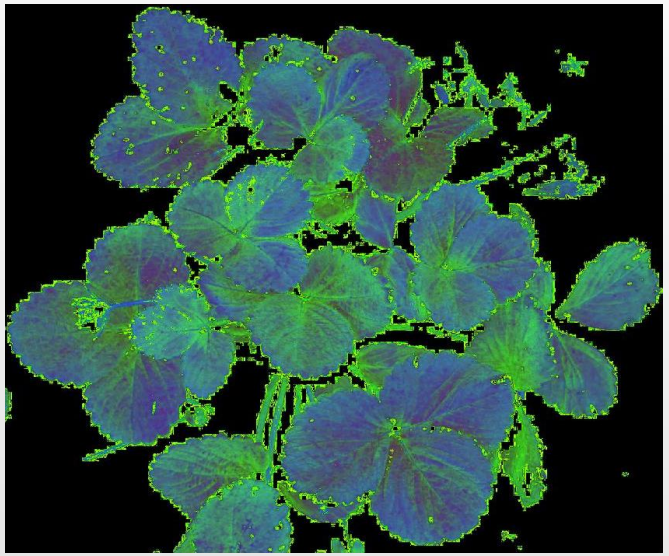
DRY

WET

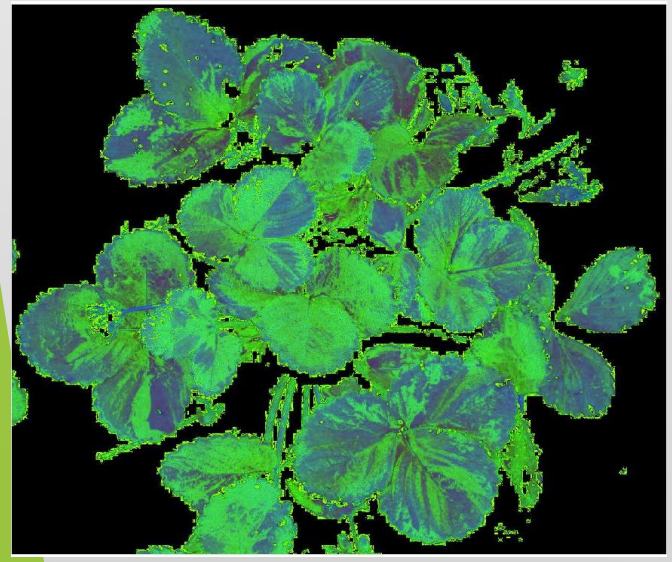


- Wet plants have less blue component than Dry plants

HSV Color Space



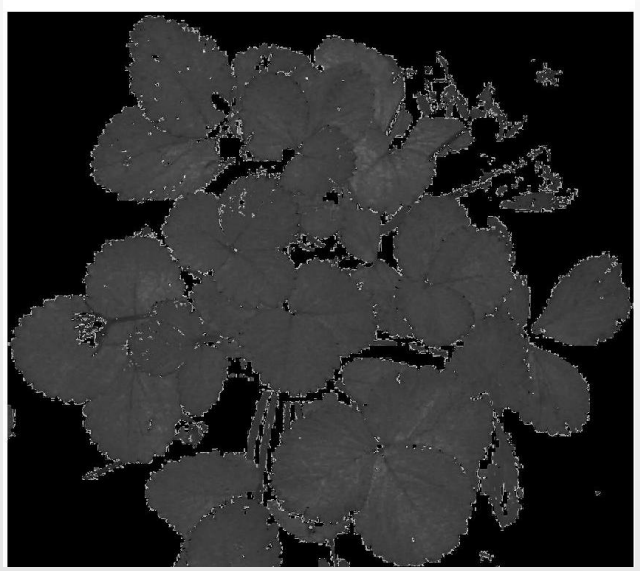
Dry Plant



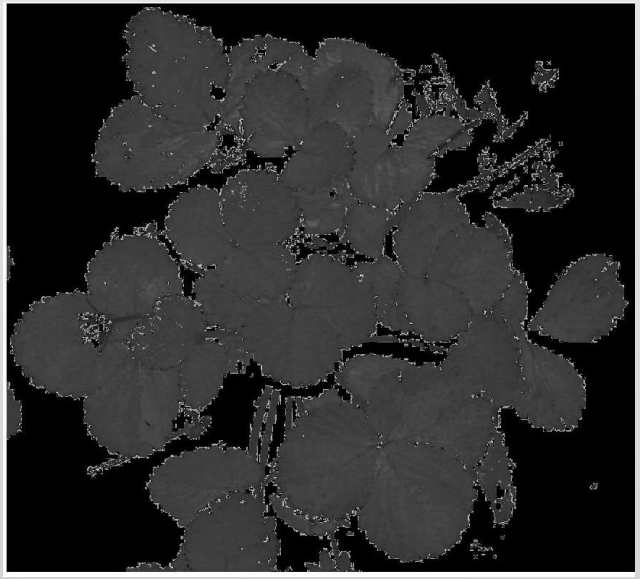
Wet Plant

- HSV Images consists of:
  - Hue Channel : Depicts the actual colors of the image
  - Saturation Channel : Measure of purity of a pixel
  - Value Channel : Brightness or Intensity of the image

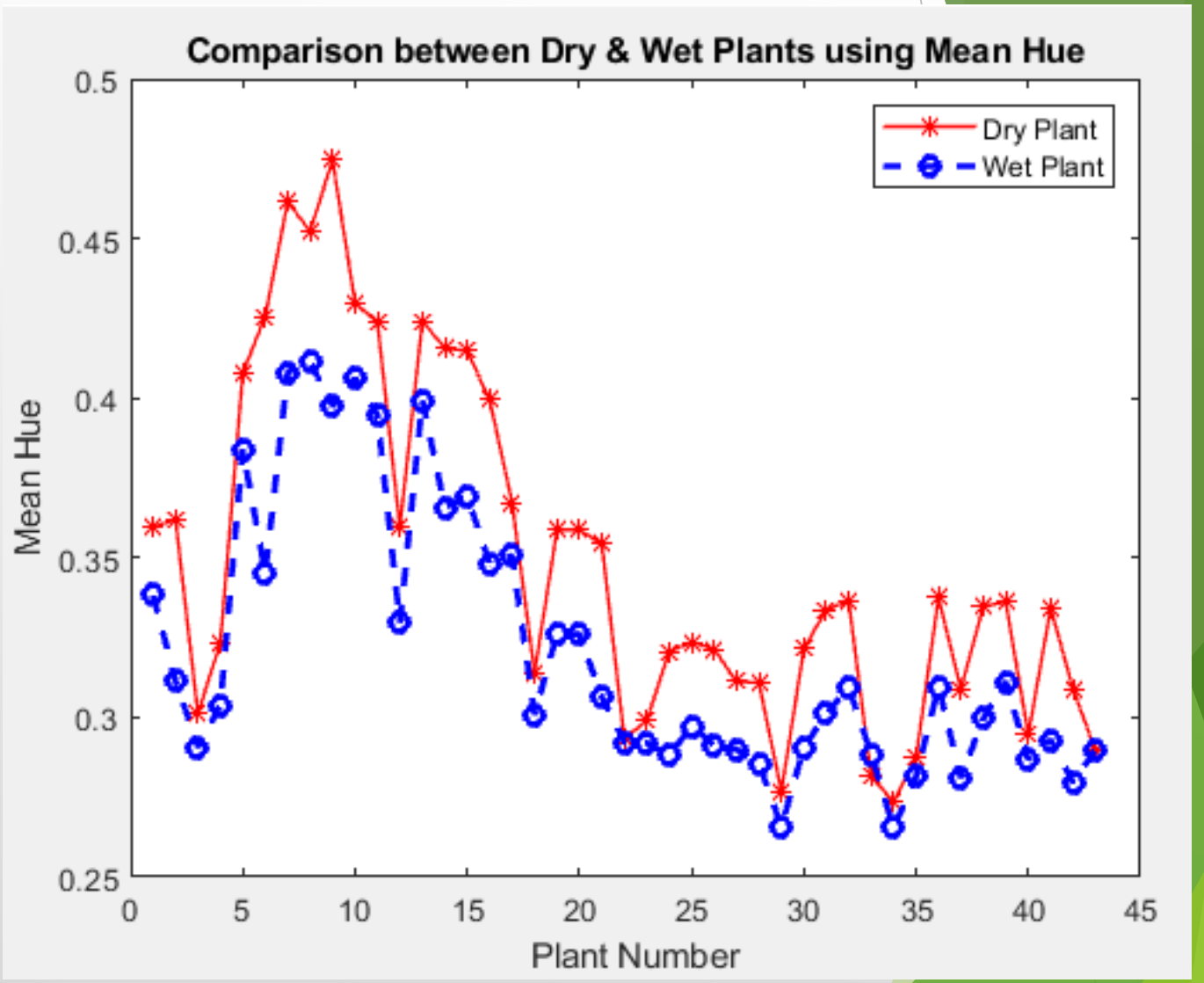
Hue



DRY

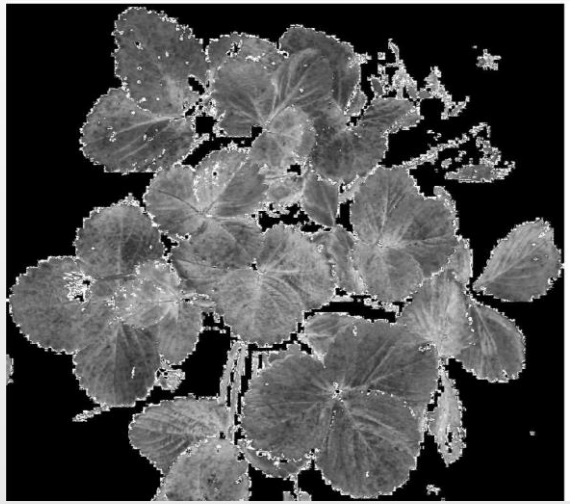


WET



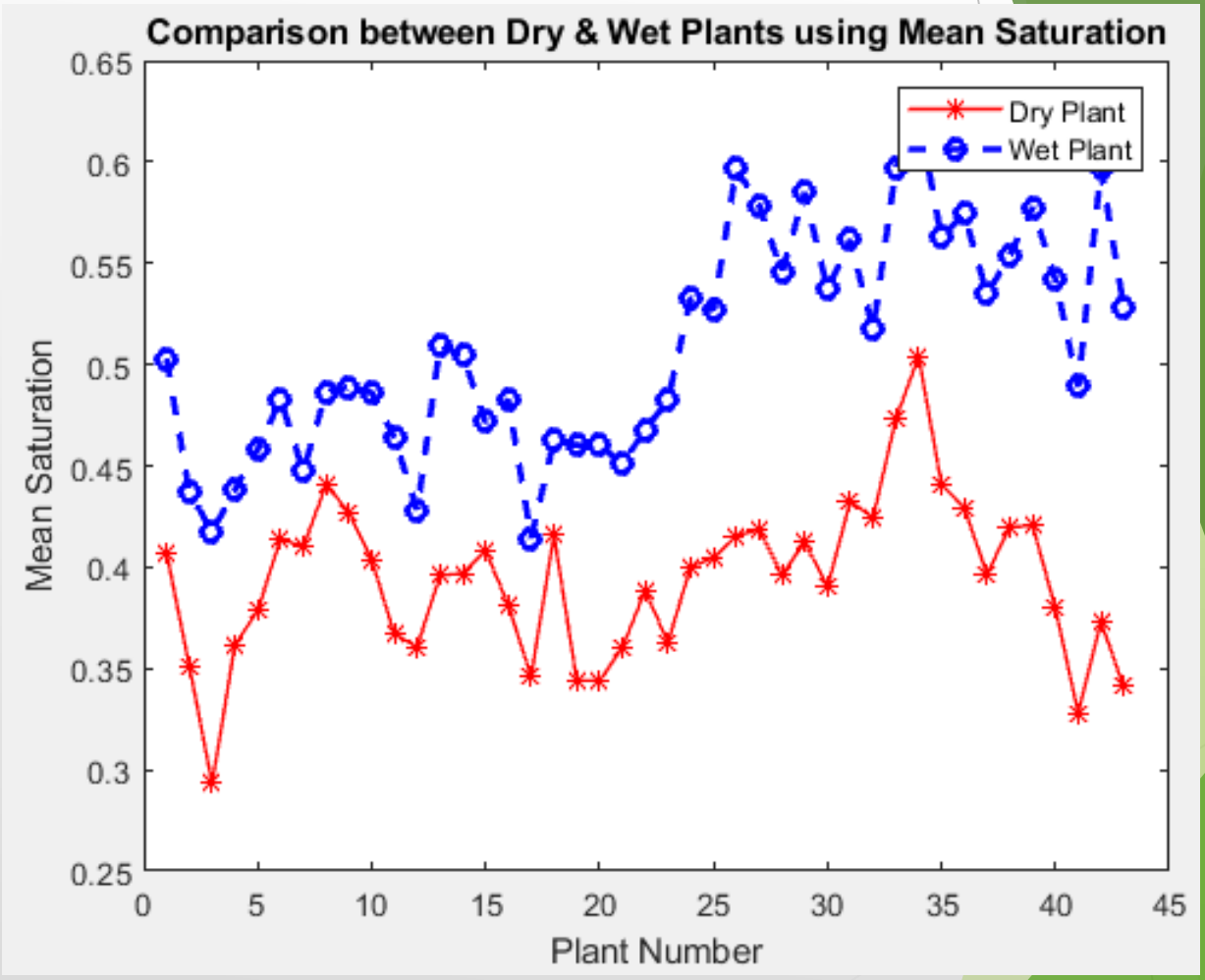
- Wet plants has lower Hue than Dry Plants

Saturation



DRY

WET

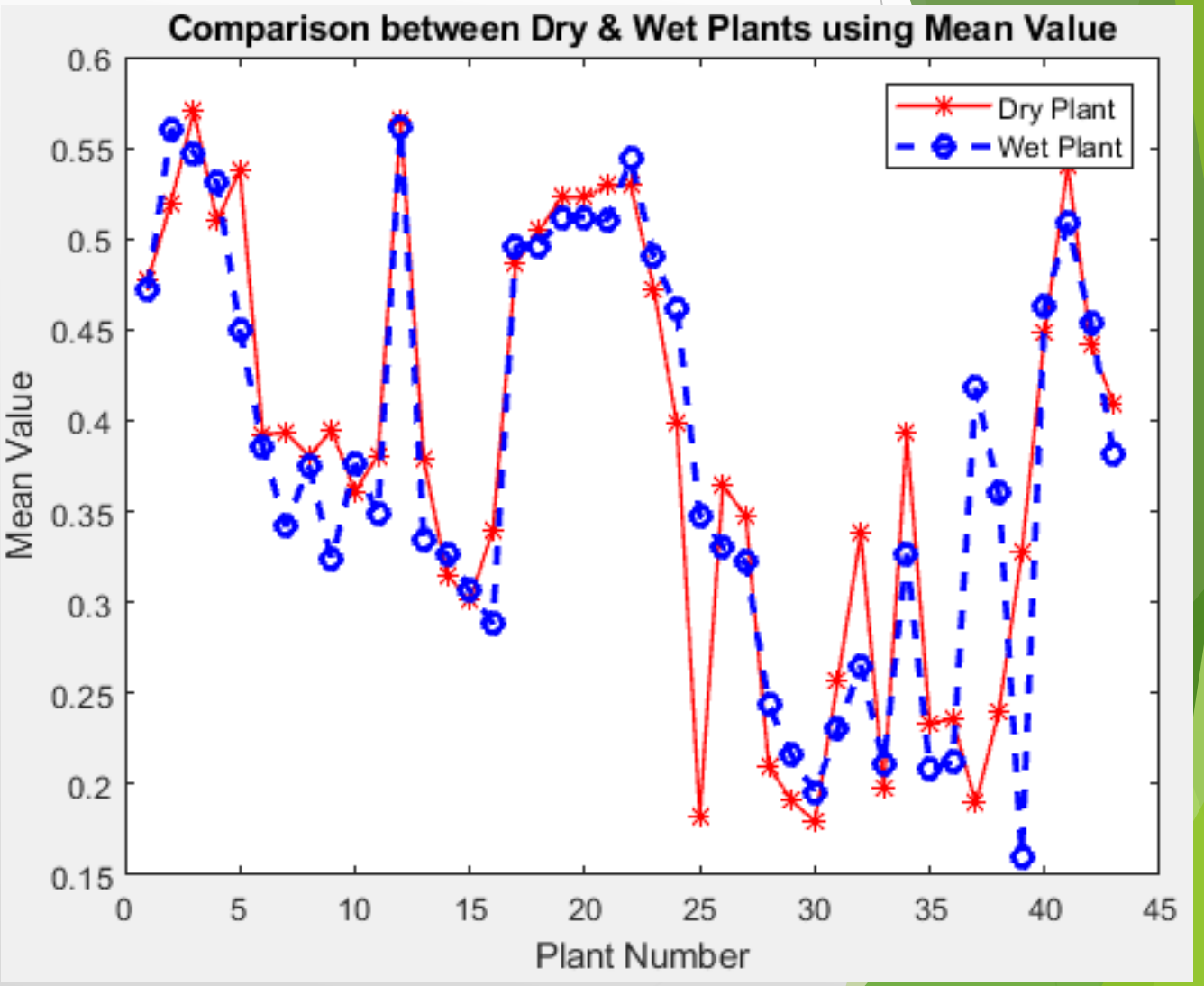


- Wet plants have higher saturation than Dry plants

Value

D
R
Y

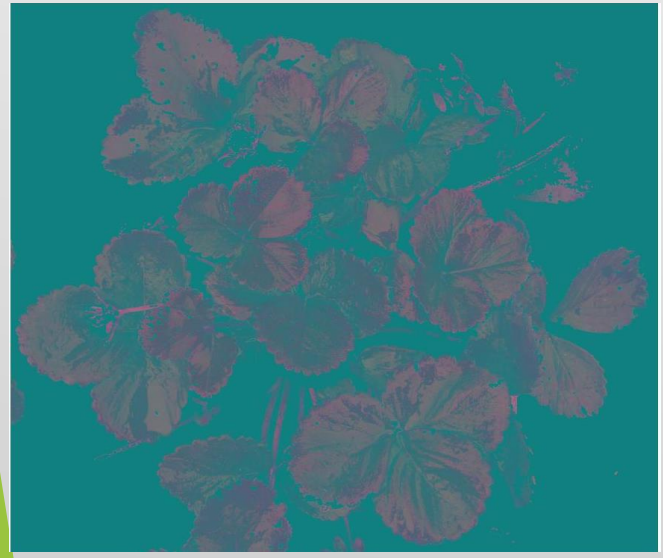
W
E
T



- No constant trend identified

Ycbcr Color Space

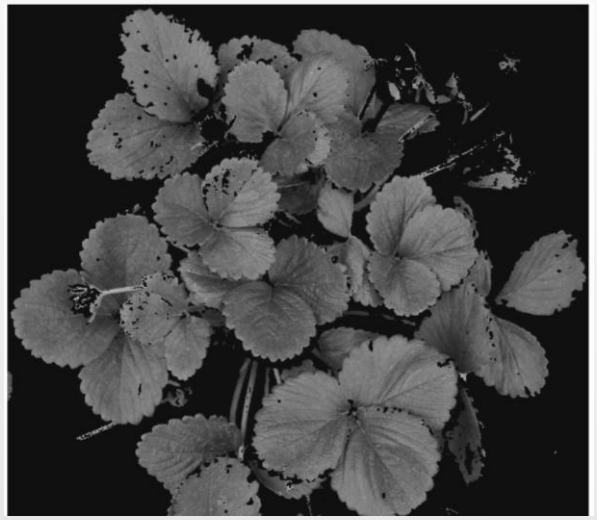
Dry Plant



Wet Plant

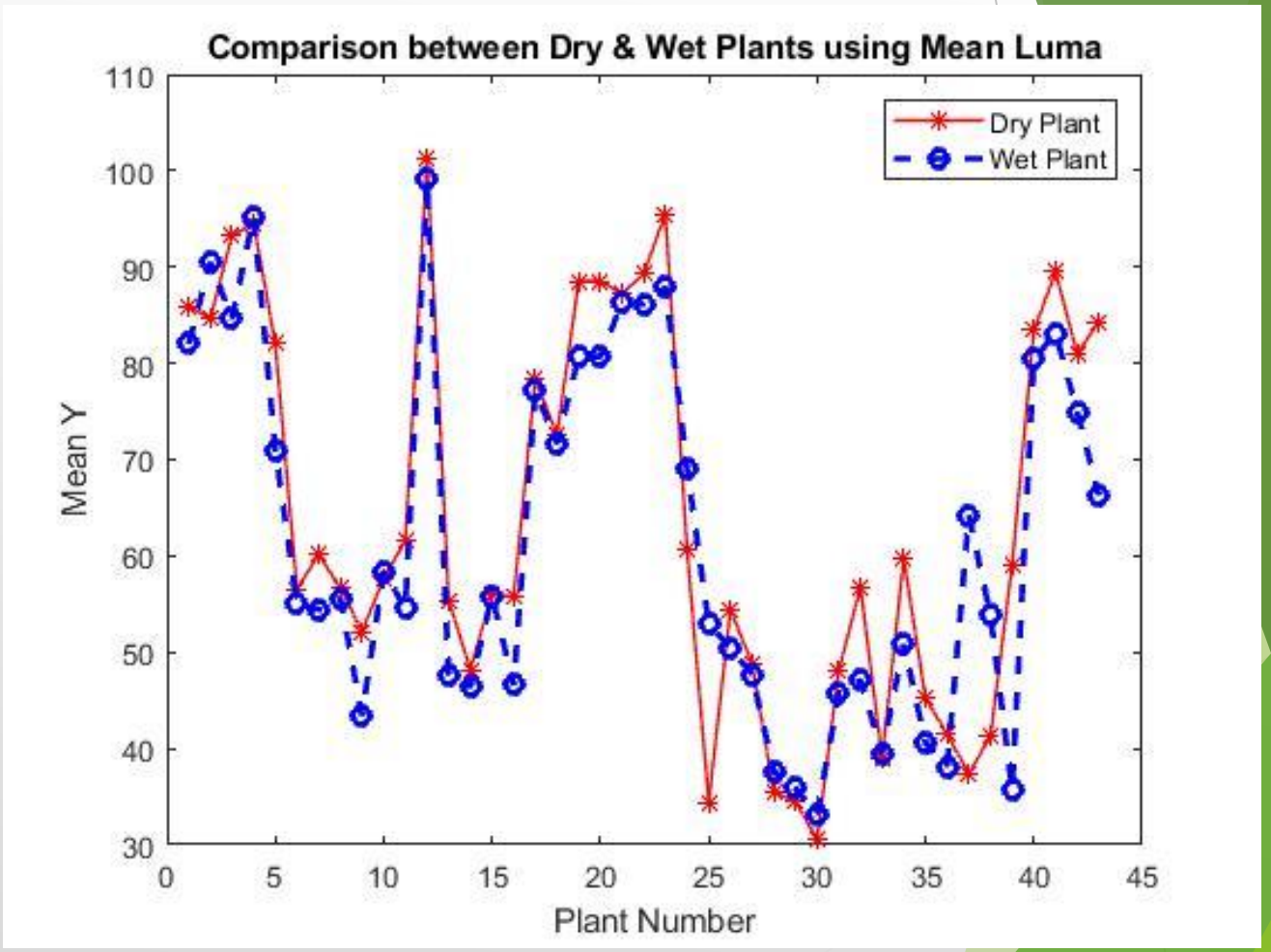
- YCbCr Images consists of:
  - Y - Luma Channel : Depicts the actual colors of the image
  - Cb – Blue Difference Channel : Amount of Blue component relative to Green
  - Cr – Red Difference Channel : Amount of Red component relative to yellow

Luminance (Y) Channel



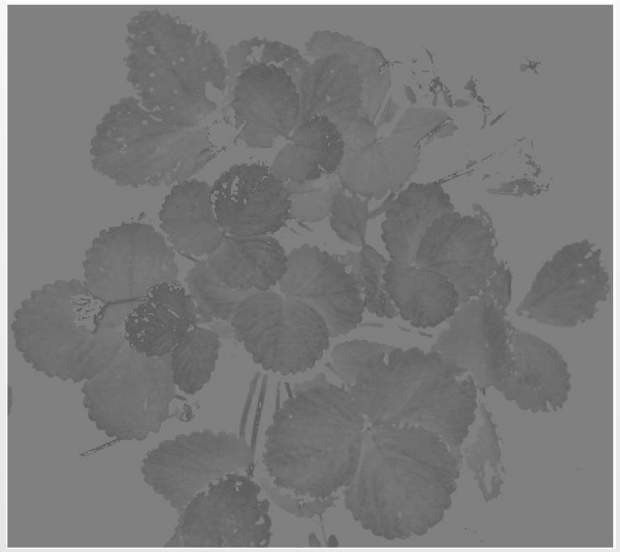
DRY

WET

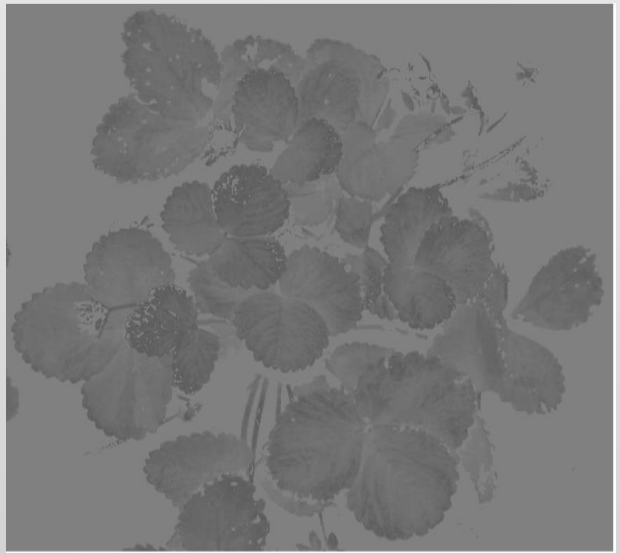


- No constant trend identified

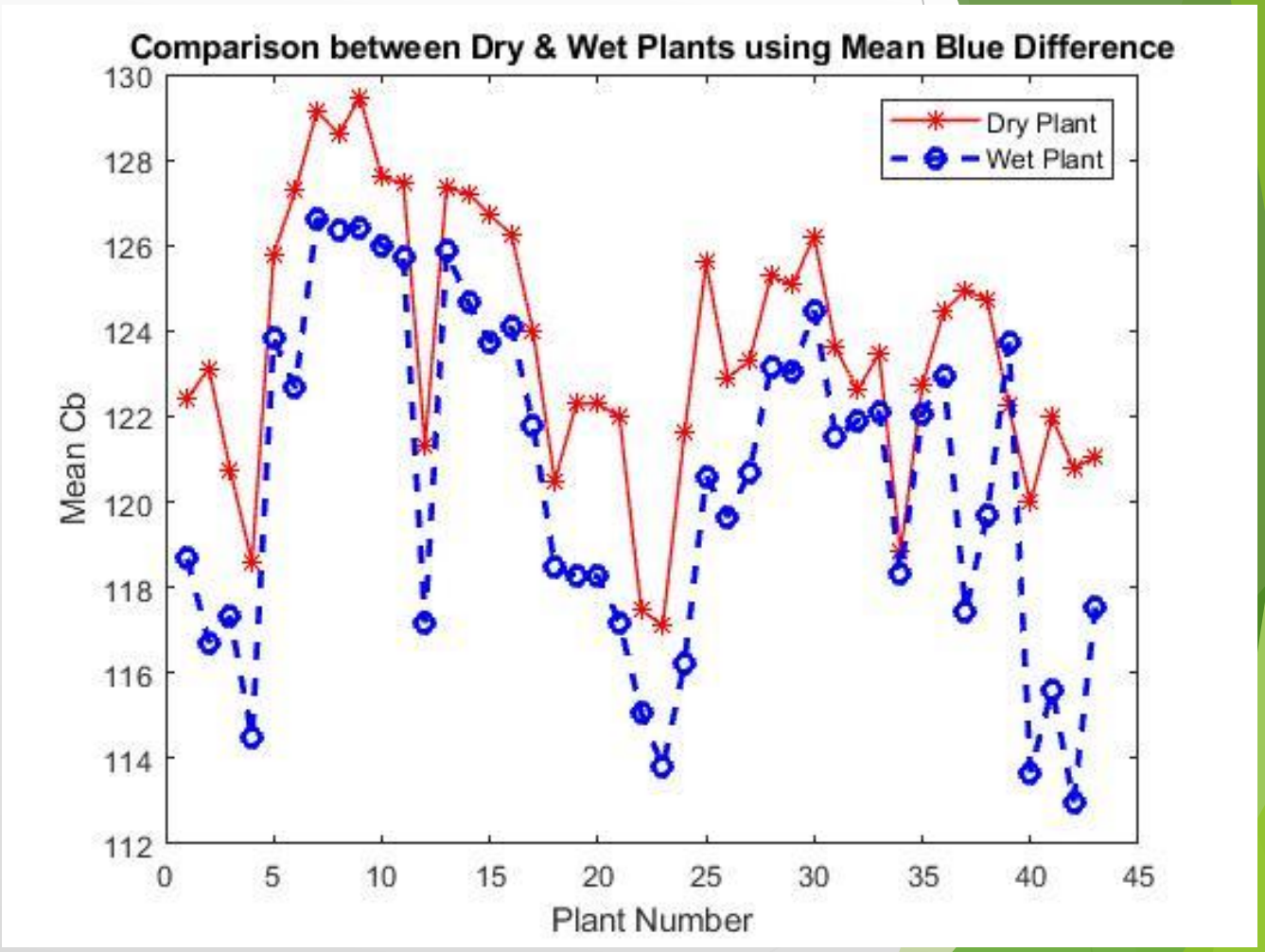
Blue Difference (Cb)



DRY

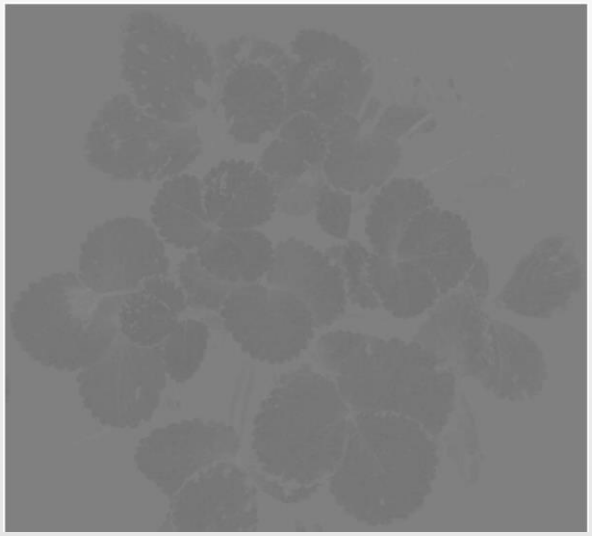


WET

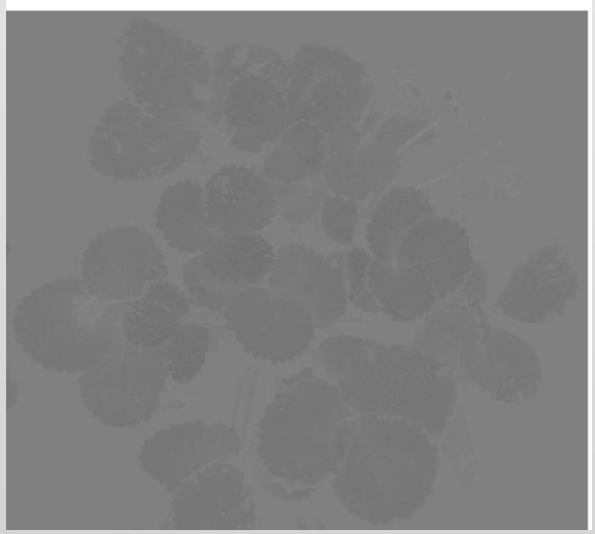


- Wet plants have lower blue component than Dry plants

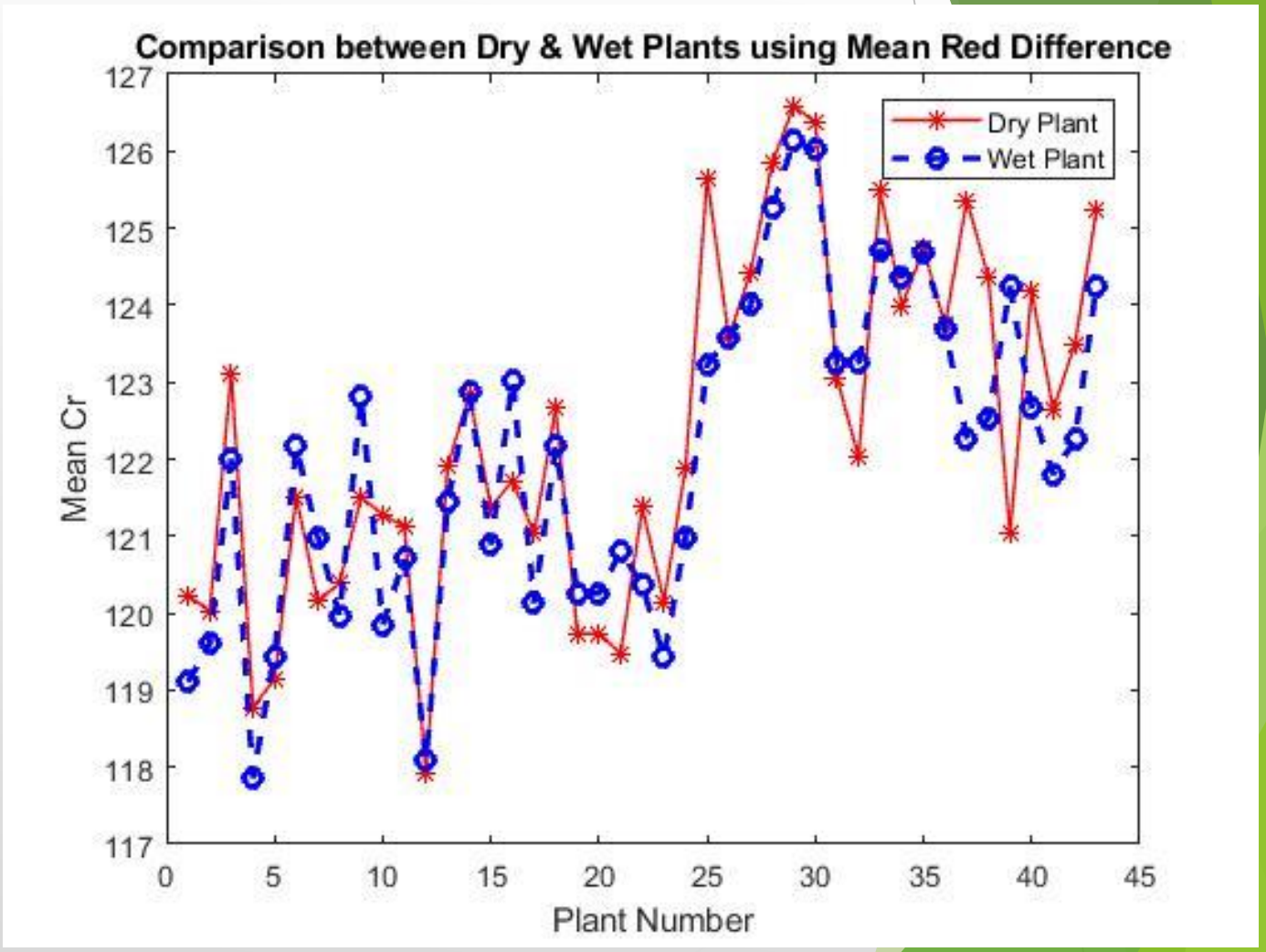
Red Difference (Cr)



D
R
Y



W
E
T



- No constant trend identified

Dry Plant

Wet Plant

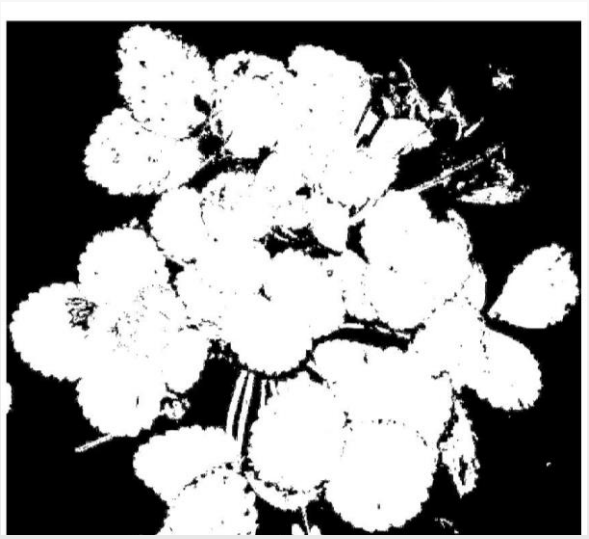
Lab Color Space

- LAB Images consists of:
  - L - Lightness Channel : Depicts intensity of the image
  - a – Red/Green Channel : Amount of Red component relative to Green

    +a = more red
  - b – Blue/Yellow Channel : Amount of Red component relative to yellow

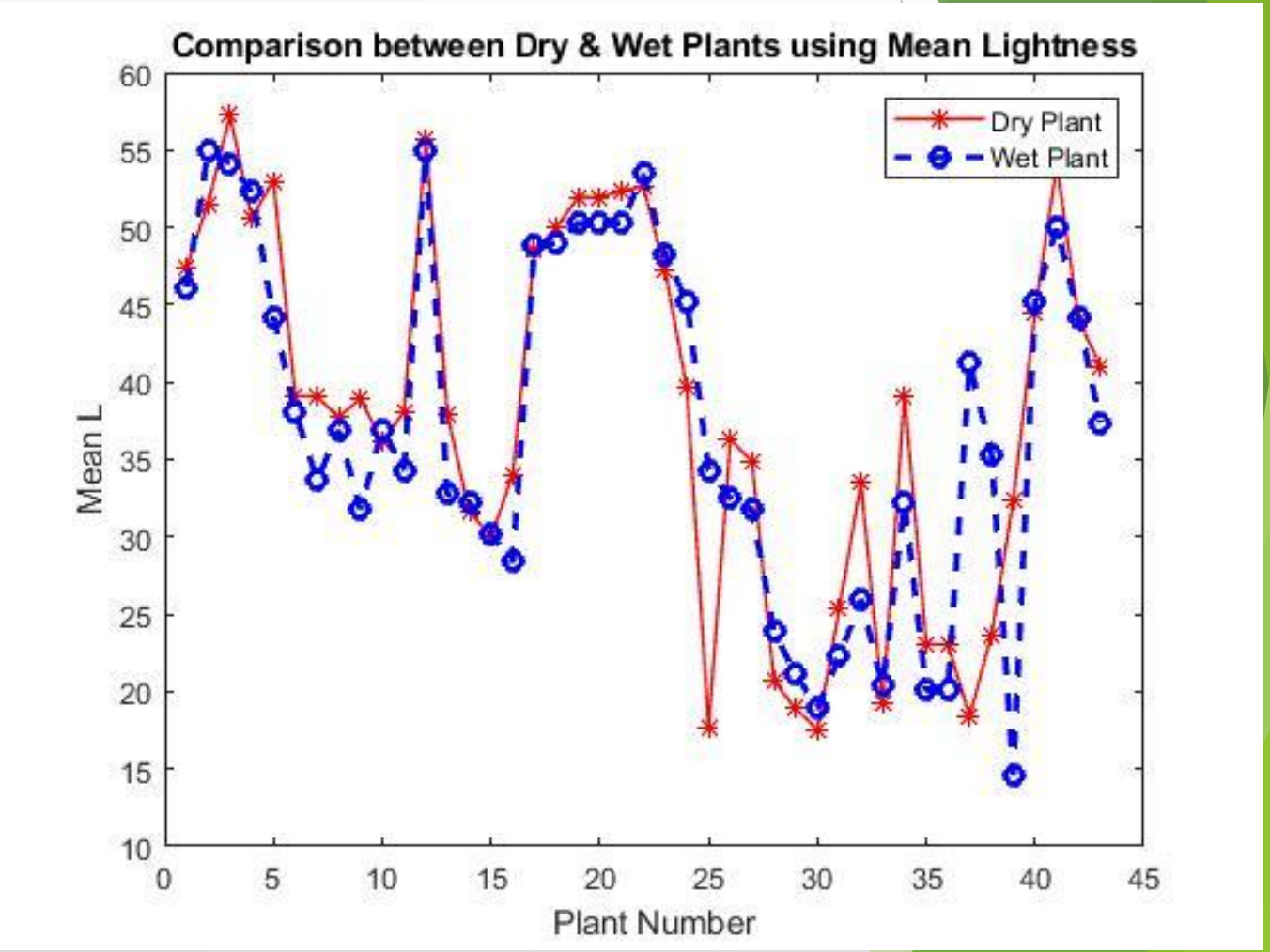
    +b = more yellow

Lightness (L)



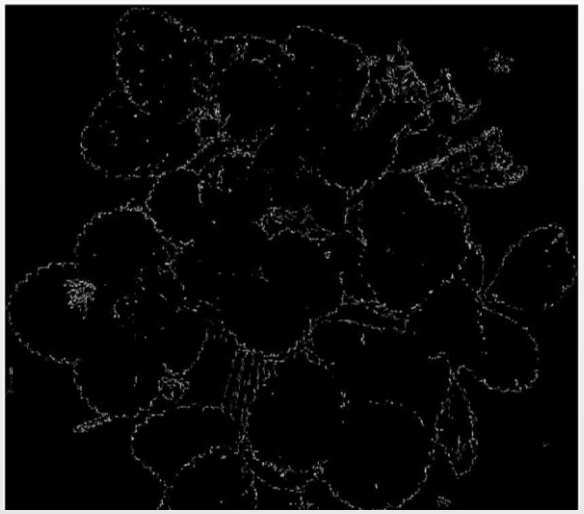
DRY

WET

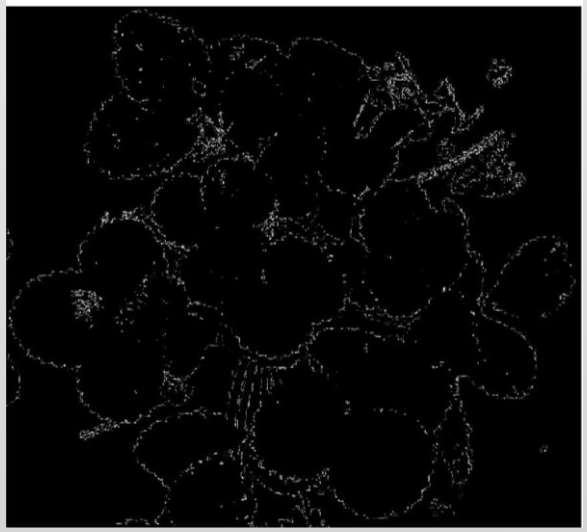


- No constant trend identified

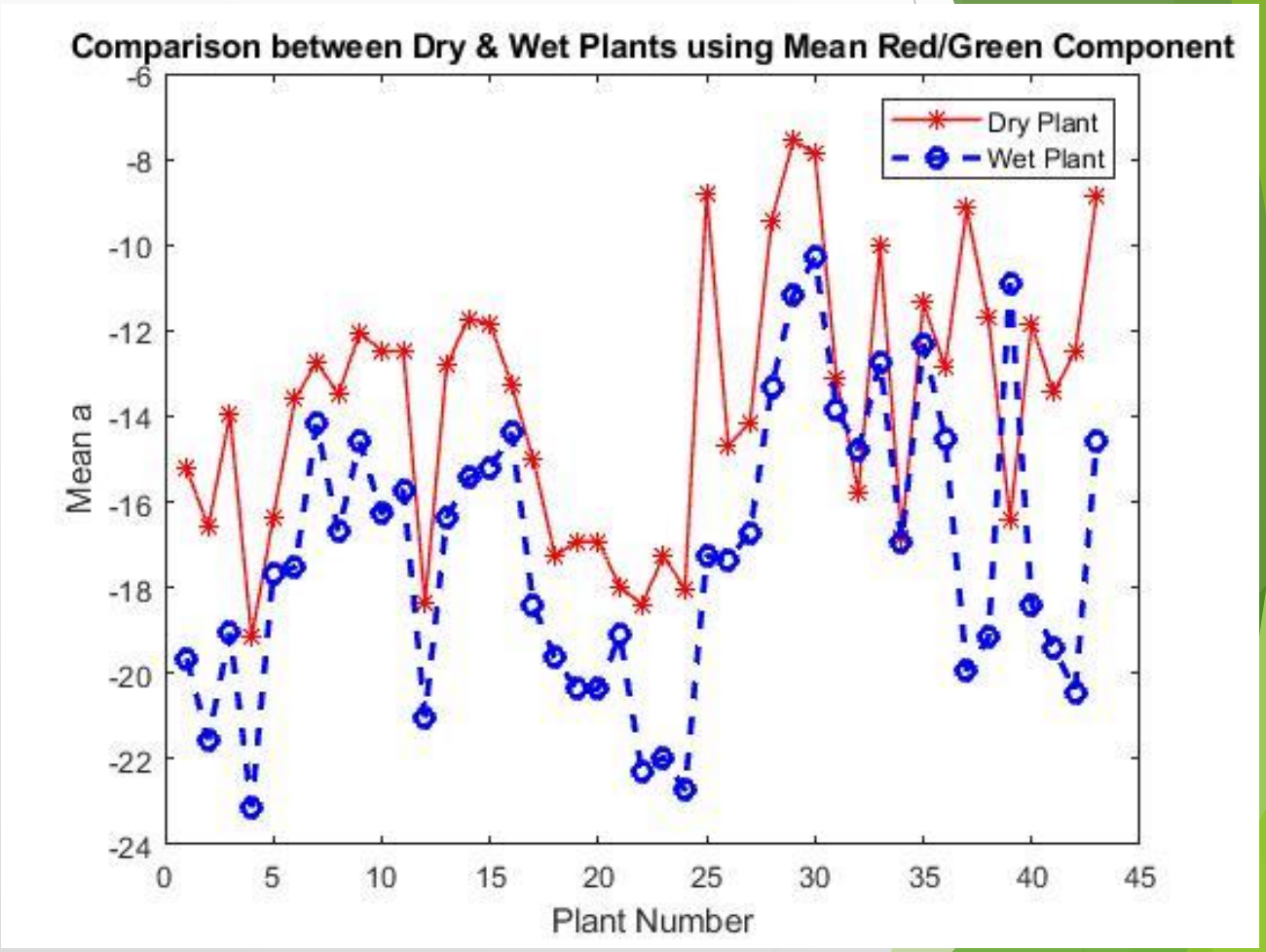
Red/Green Component(a)



D
R
Y

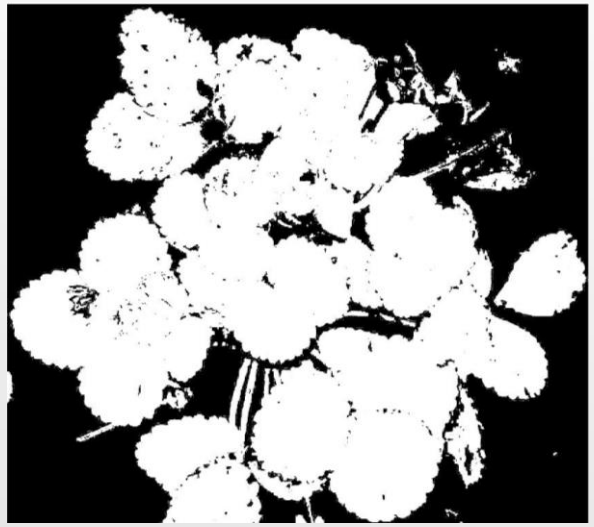


W
E
T



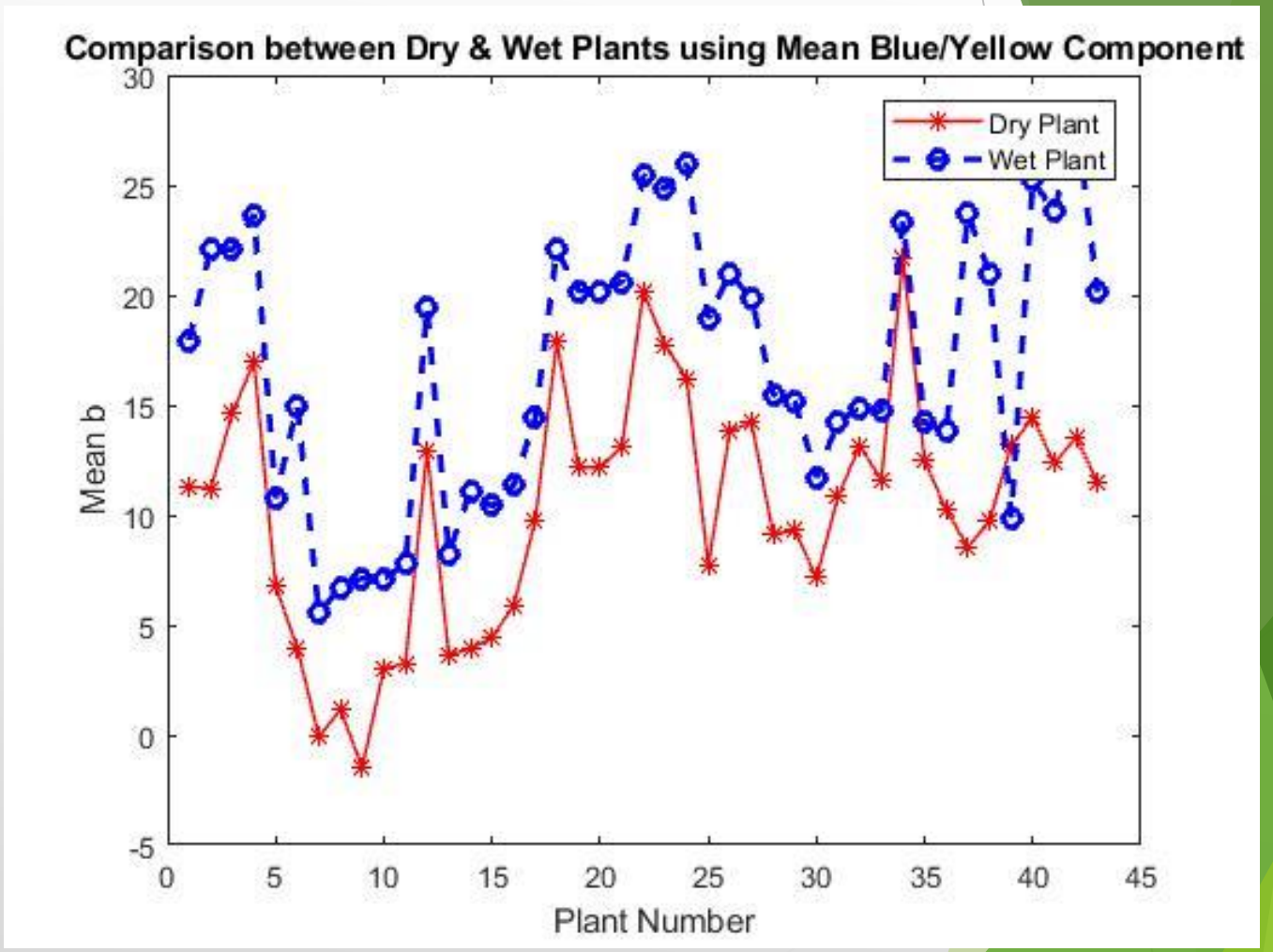
- Wet plants have lower red component than Dry plants

Blue/Yellow Component (b)



DRY

WET



- Wet plants have higher blue component than Dry plants

YIQ Color Space

Dry Plant

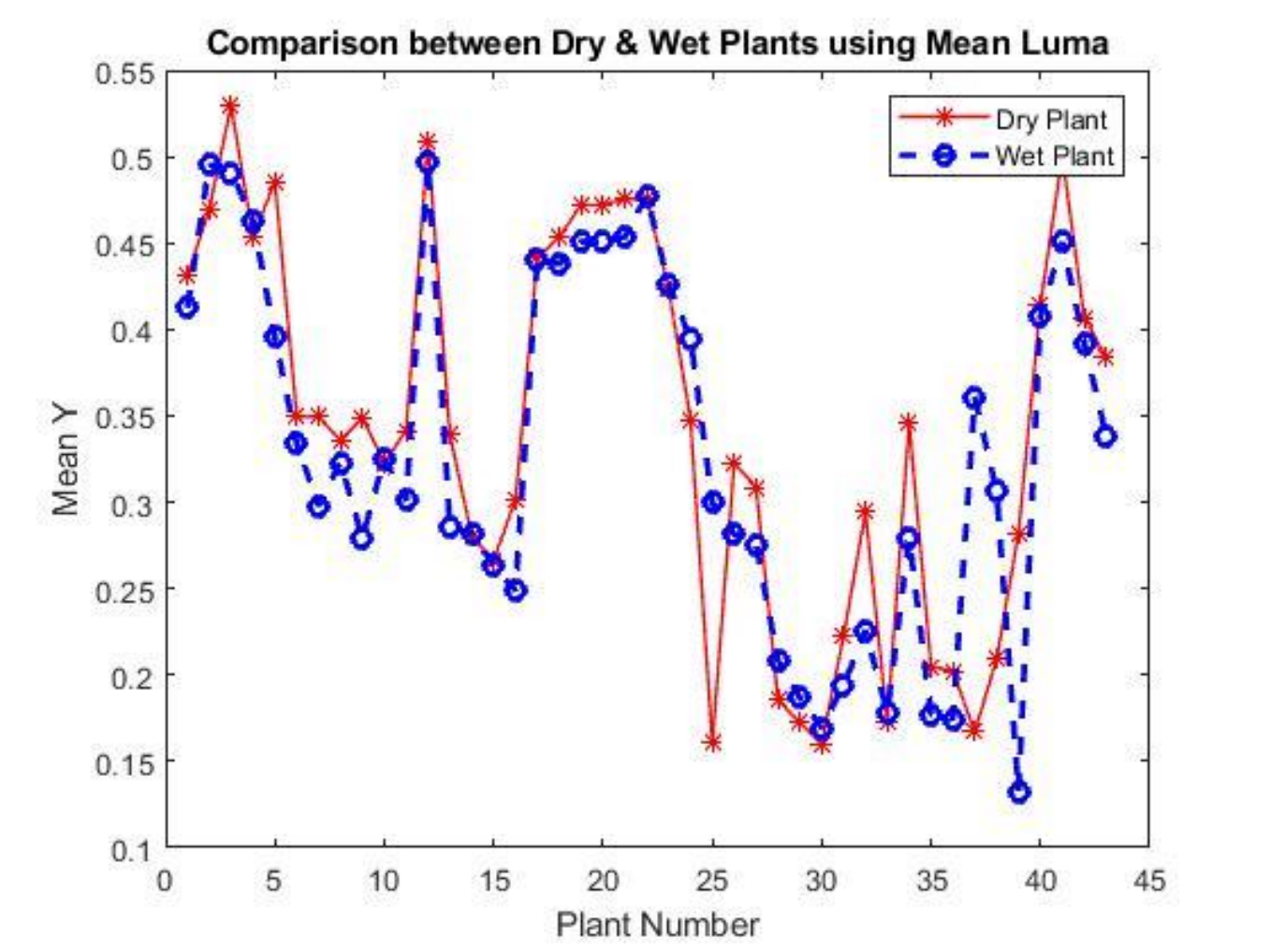
Wet Plant

- YIQ Images consists of:
  - Y - Luma Channel : Depicts intensity of the image
  - I – In-Phase Channel : Contains chrominance Information
  - Q – Quadrature Channel : Contains chrominance Information

Luma (Y)

DRY

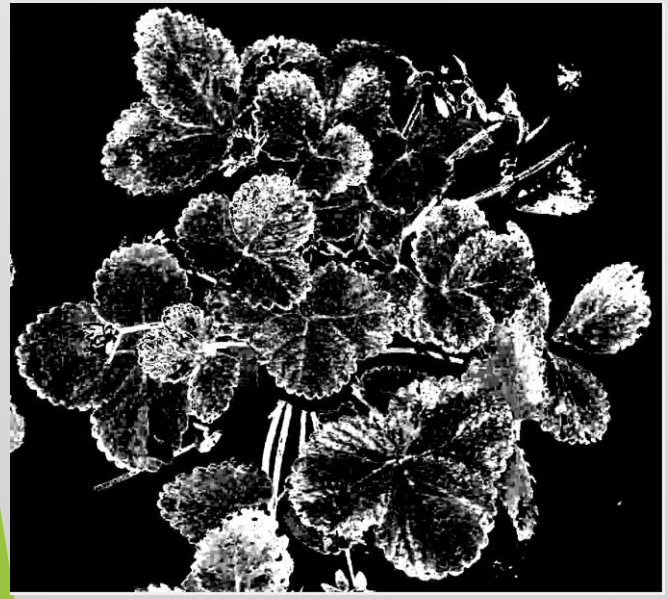
WET



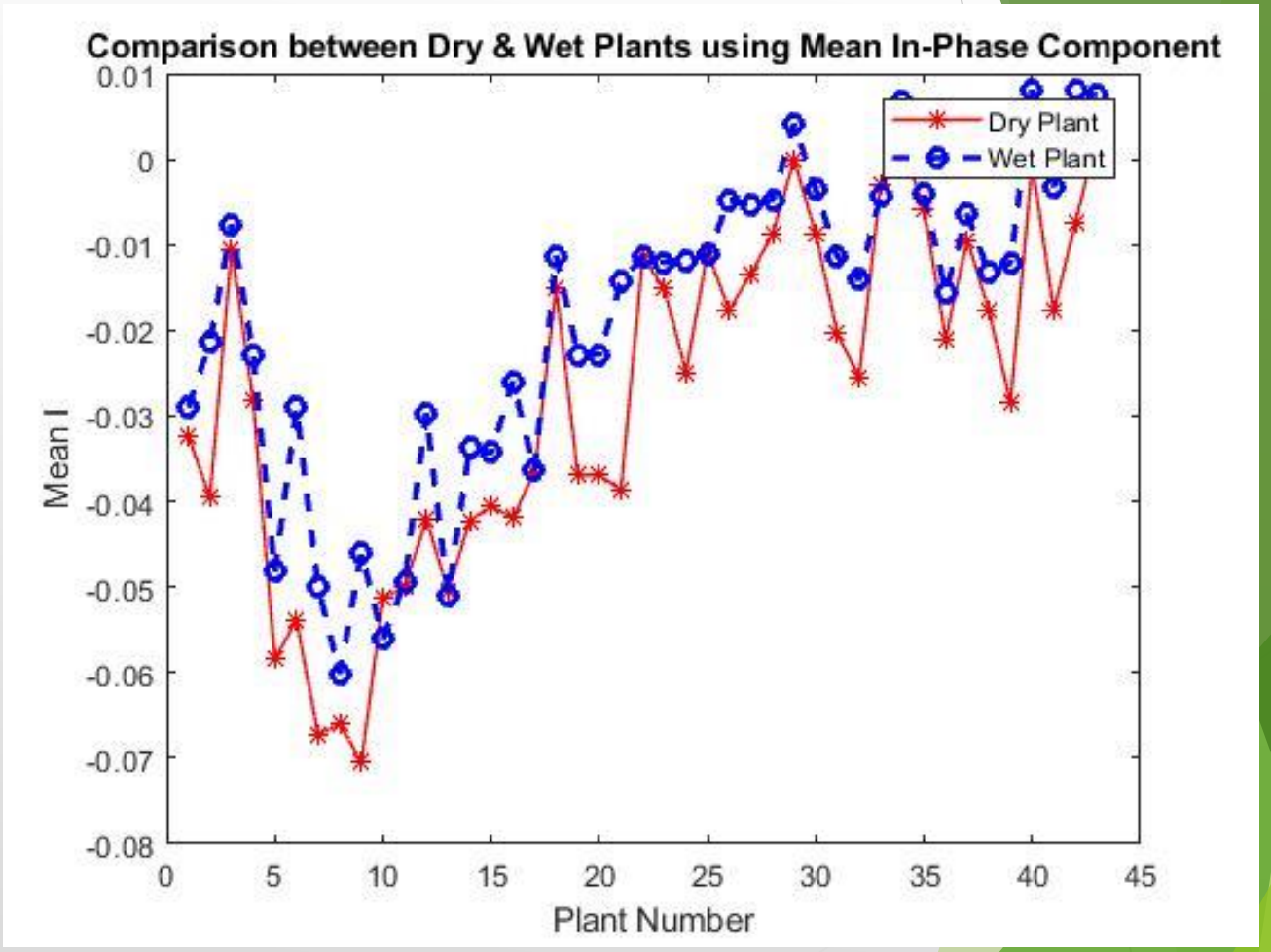
- No constant trend identified

In-Phase (I)

DRY

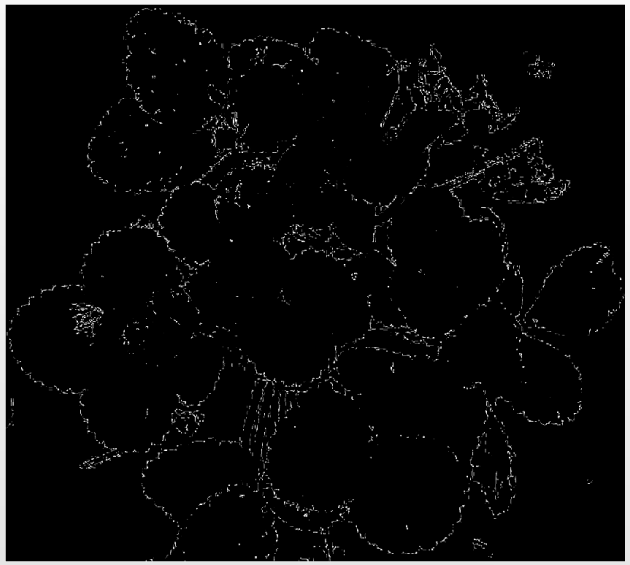


WET

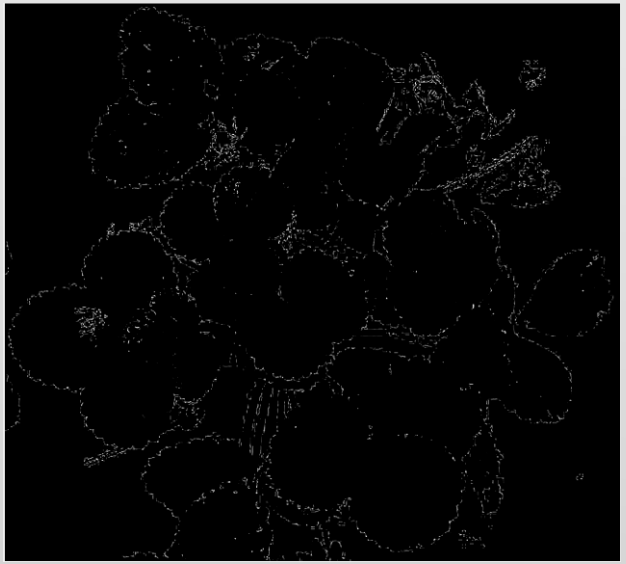


- In-phase component of wet plant is more than the dry plant

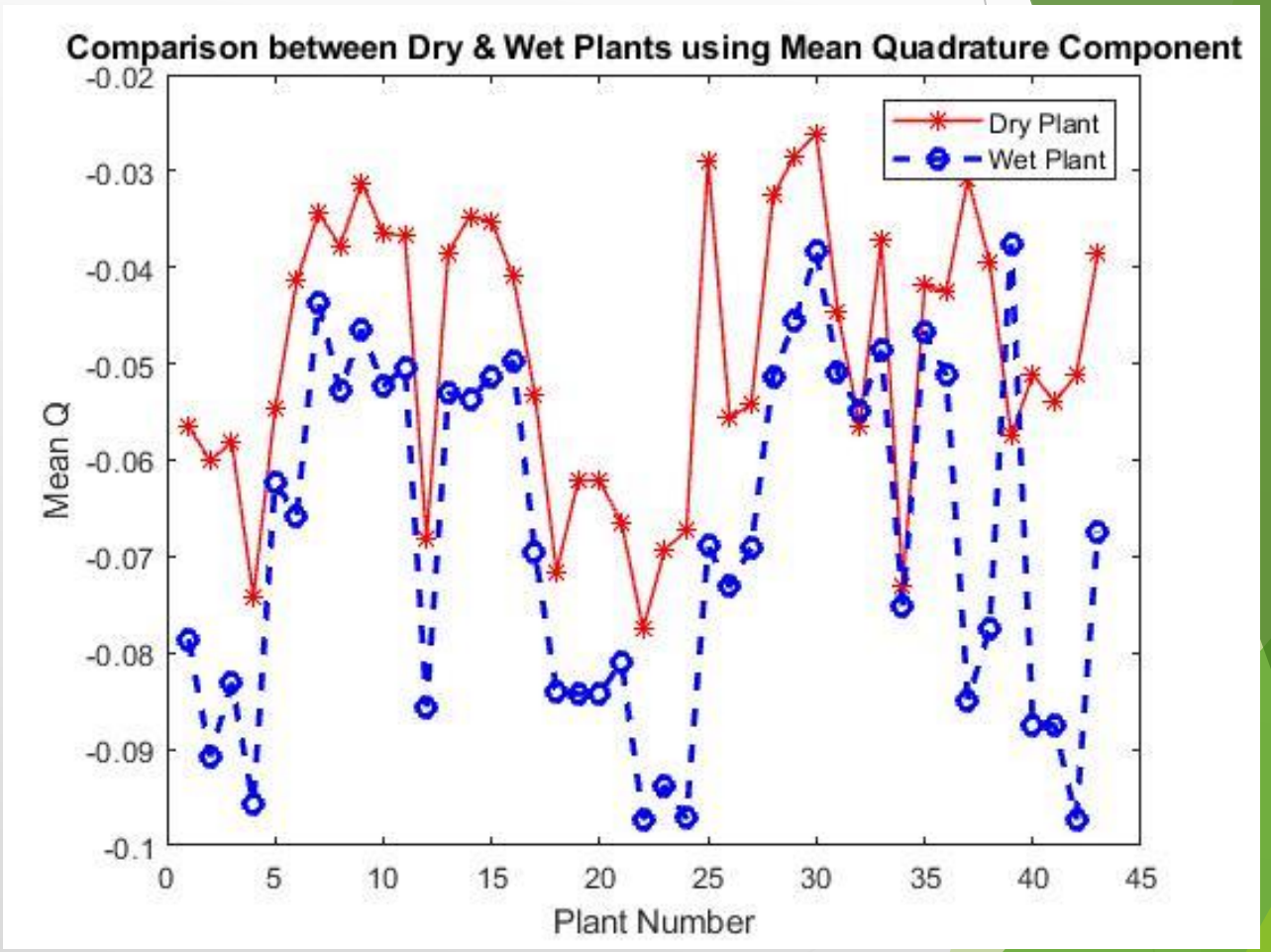
Quadrature (Q)



DRY



WET



- Quadrature component of the dry plant is more than the wet plant

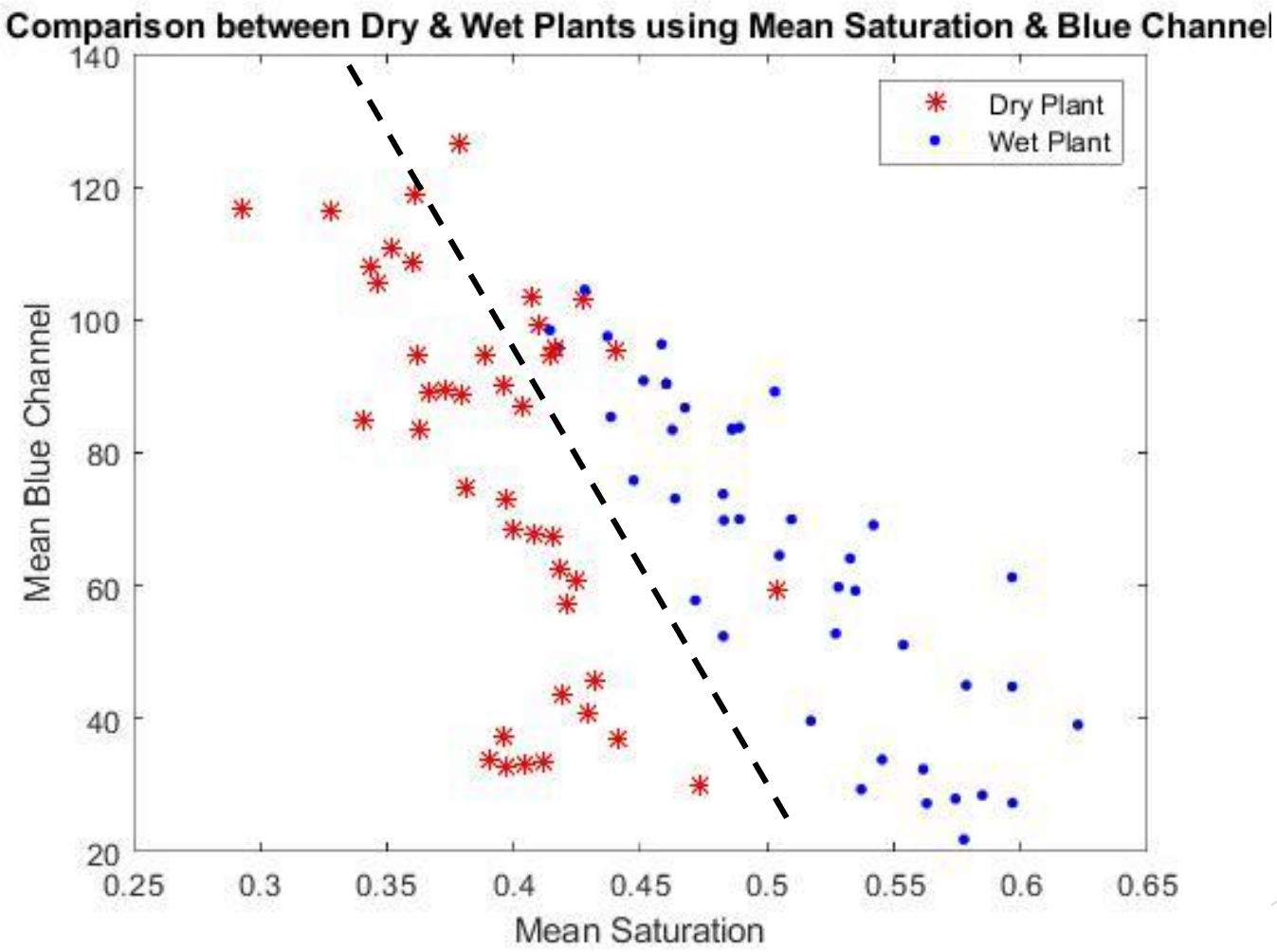
Summary

- List of components which can be most effective in distinguishing between wet and dry plants

Color Component	Minimum Difference between dry and wet plant	Maximum Difference between dry and wet plant	RMSE(%)
Saturation (HSV)	0	0.2	12 *
Blue Channel (RGB)	2.6	35	7.2 *
Hue (HSV)	0	0.1	3 *
Blue/Yellow Component (Lab)	1.6	15.1	2.9
Blue Difference (YCbCr)	0.5	7.8	1.6
Red/Green Component (Lab)	0.1	10.8	1.6
Quadrature (YIQ)	0	0.1	1.6
In-Phase (YIQ)	0	0.03	0.8

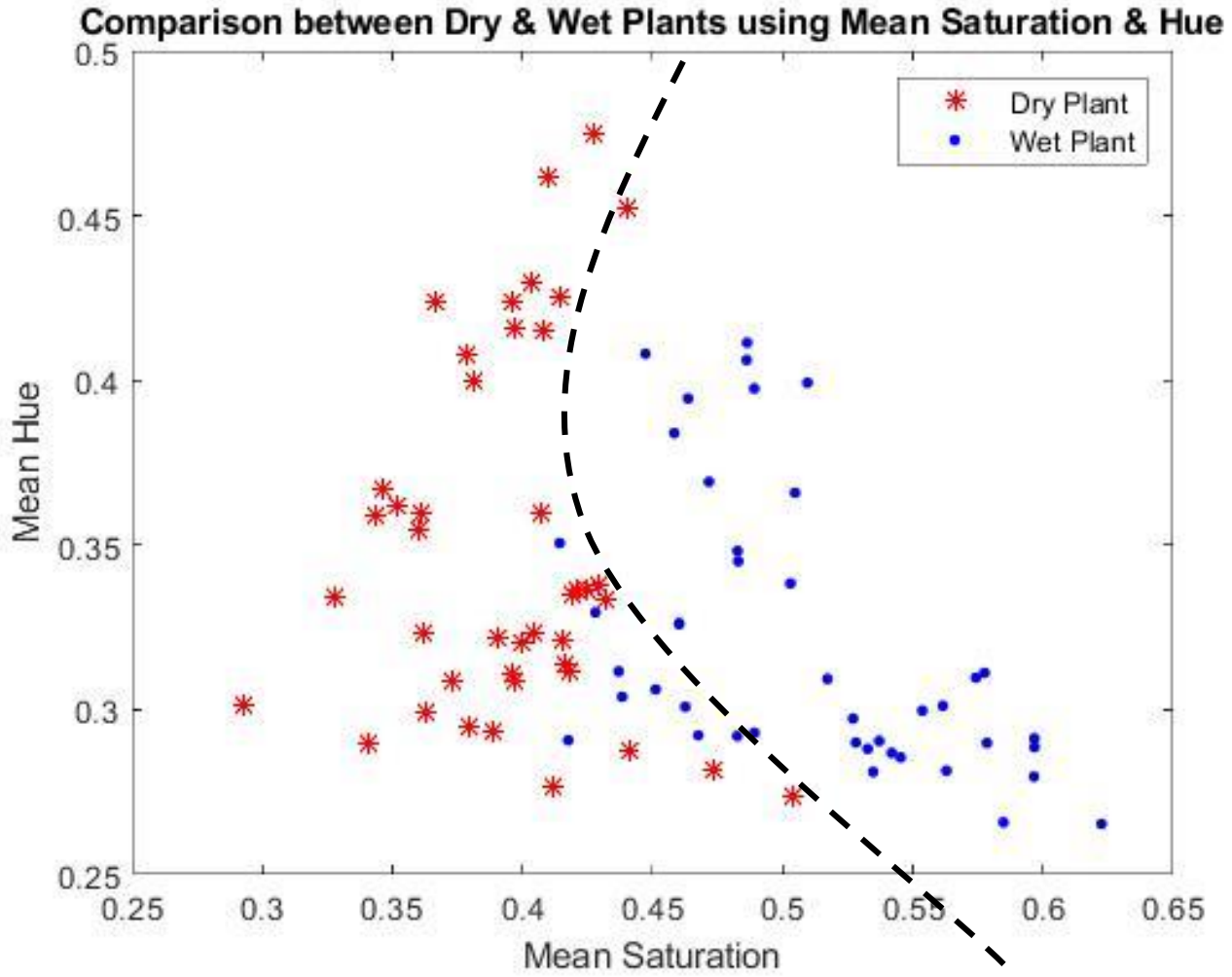
* Top three color components with largest RMSE (difference between wet & dry plants)

Comparison



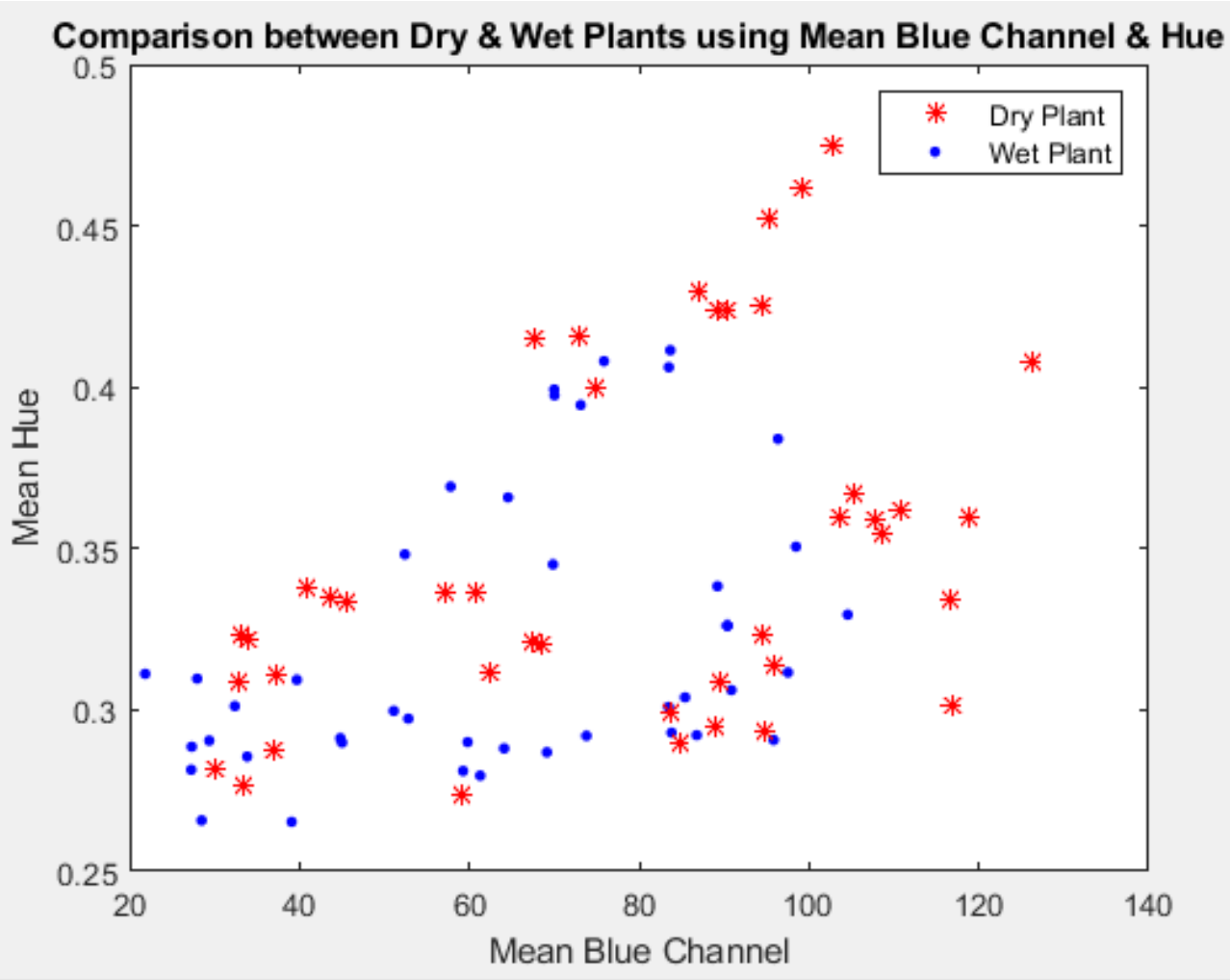
- Mean Hue, Saturation (from HSV) and Blue Channel (from RGB) can be used to differentiate between wet & dry plants

Comparison



- Good distinction between wet and dry region with some outliers

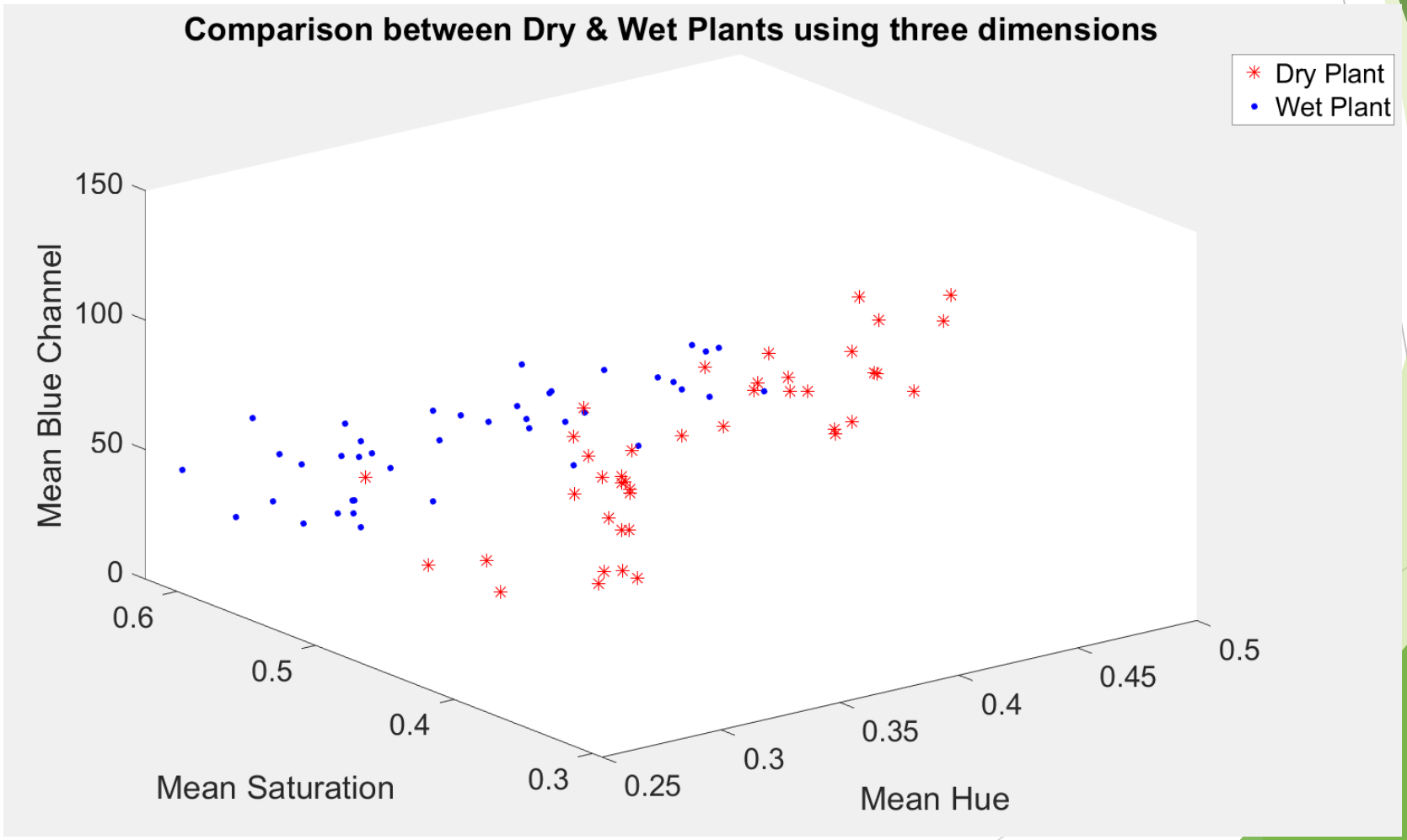
Comparison



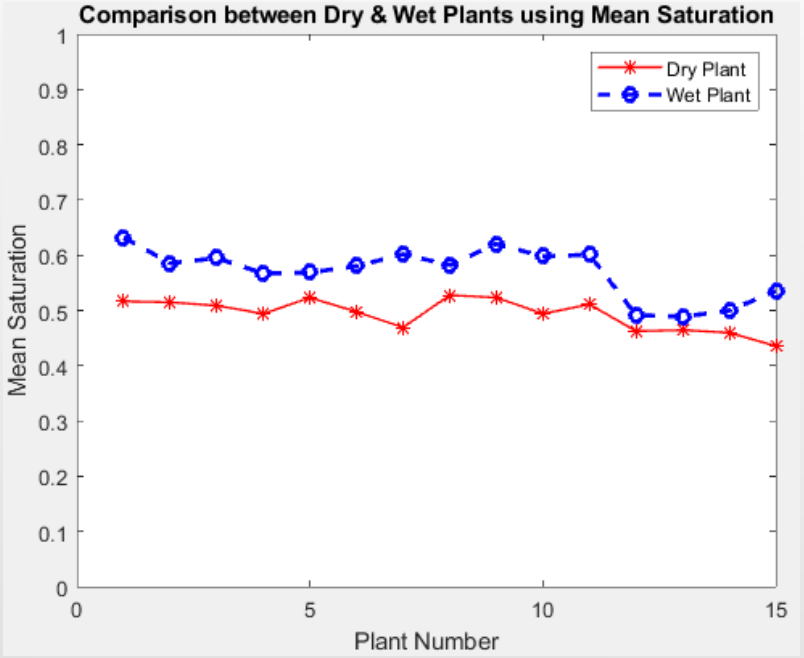
- Poor distinction between wet and dry areas when saturation is not taken into account

Future Work

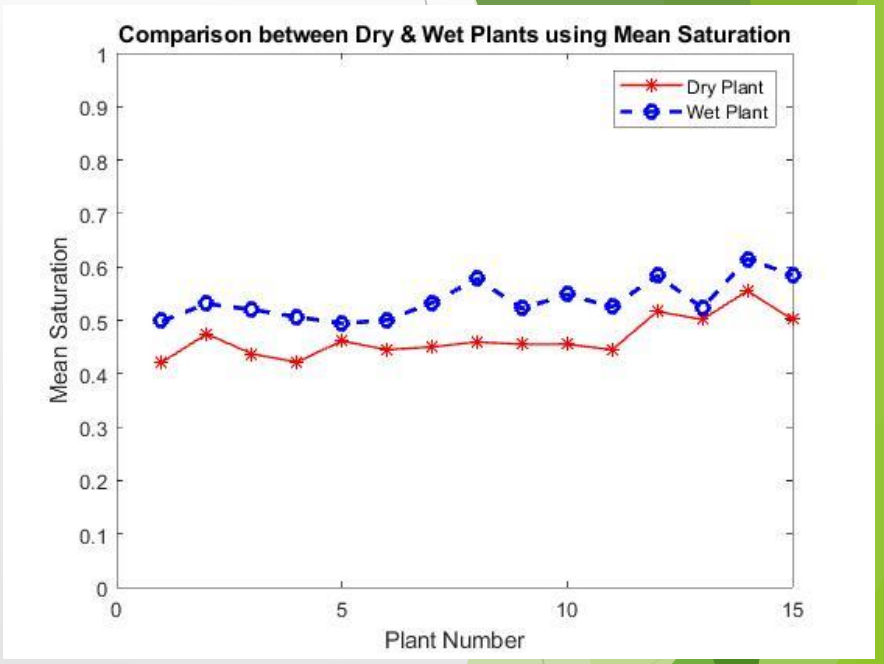
- Optimum threshold for efficient classification of wet and dry plants



Effect of Varying Illumination Conditions



Dry & Wet Plant under Direct Sunlight

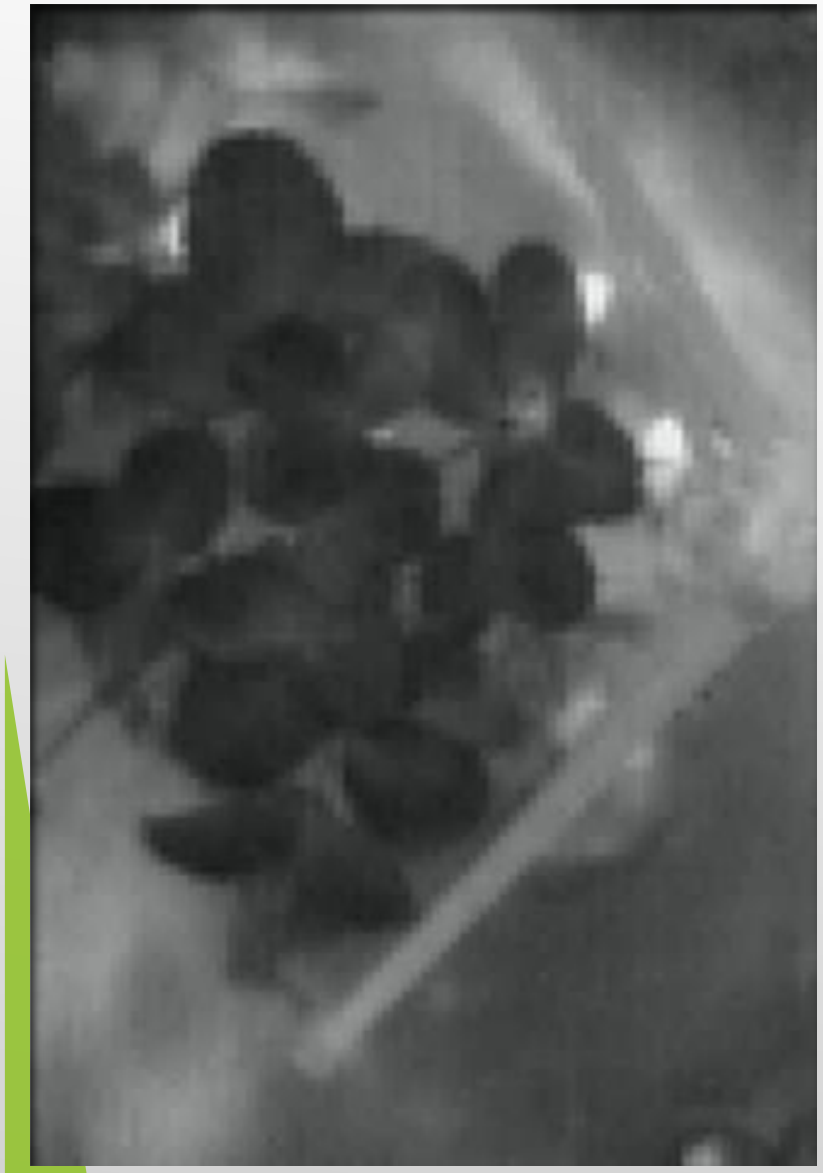


Dry & Wet Plant under Shadow

- Individual values of data points vary with illumination
- Overall both the graphs follow the same trend

Thermal Imaging

Effect of water on plant temperature



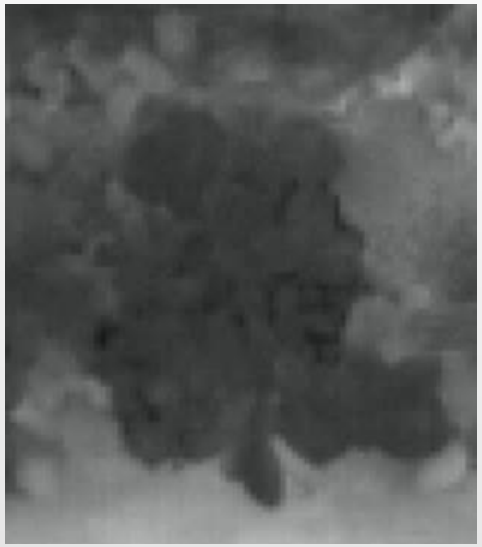
Thermal Image

Lab Setup

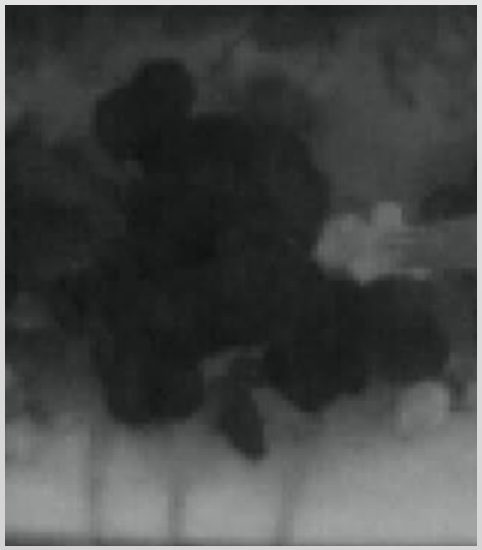
Setup

- **FLIR Duo:**
  - Thermal Imager:
    - Resolution – 160X120
    - Operating Temperature – 0-50 degree Celsius
  - Visible Camera:
    - Resolution – 1920x1080

Test Images



Dry Plant



Wet Plant

- Dataset Information:

  Date: February 19 - March 8

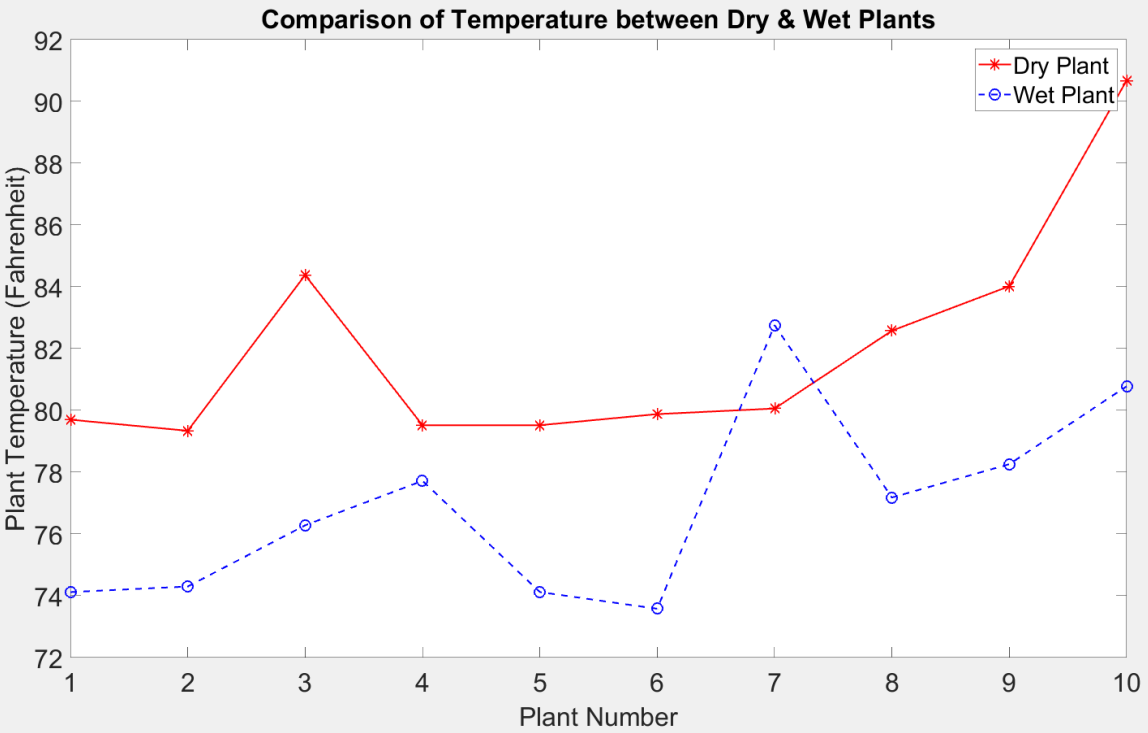
  Weather Conditions:

Date	Avg Wind Speed (mph)	Ambient Temperature (F)	Relative Humidity (%)
2/19/19	2.7	80.96	65.1
2/21/19	0.6	74.3	51.6
2/28/19	0.8	85.64	72.9-85.2
3/8/19	1.3	87.08	50-54.8

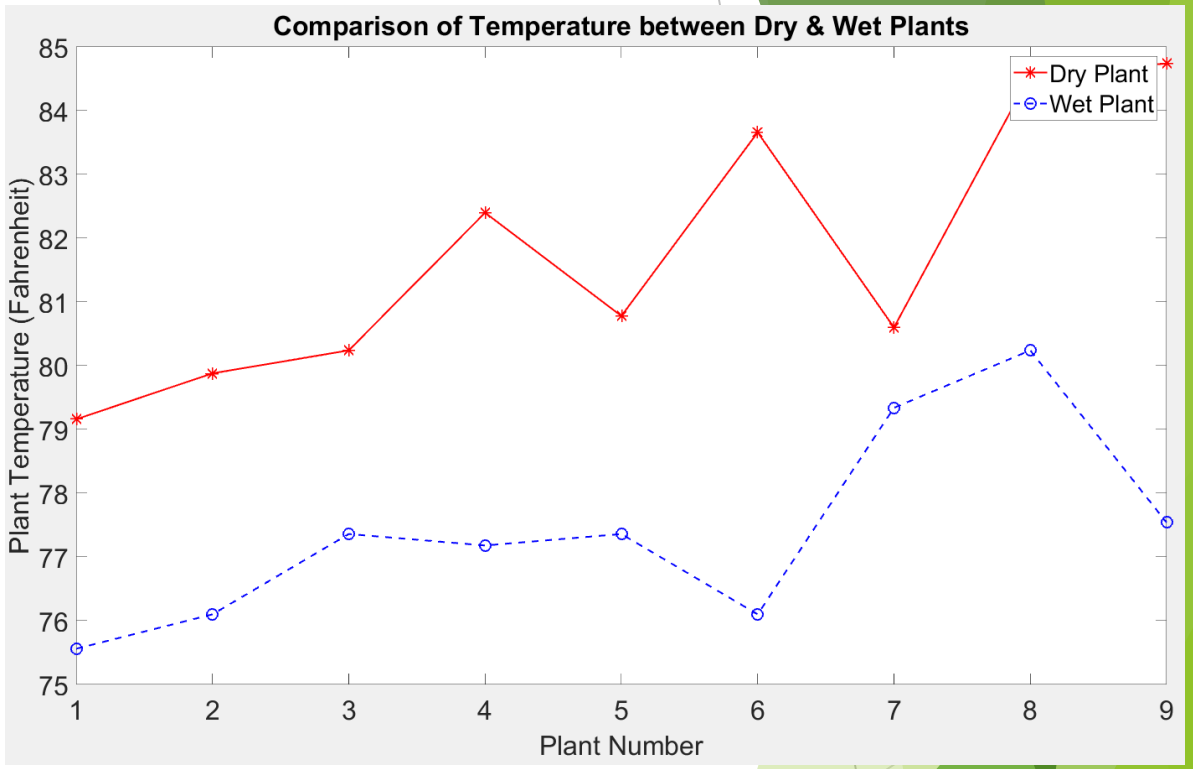
  Number of Images: approximately 20 different plants per dataset

- Sprayed water with a hand pump & waited for 2 minutes before capturing the images of the wet plants so that the evaporation process could start

Analysis of Temperature Variation

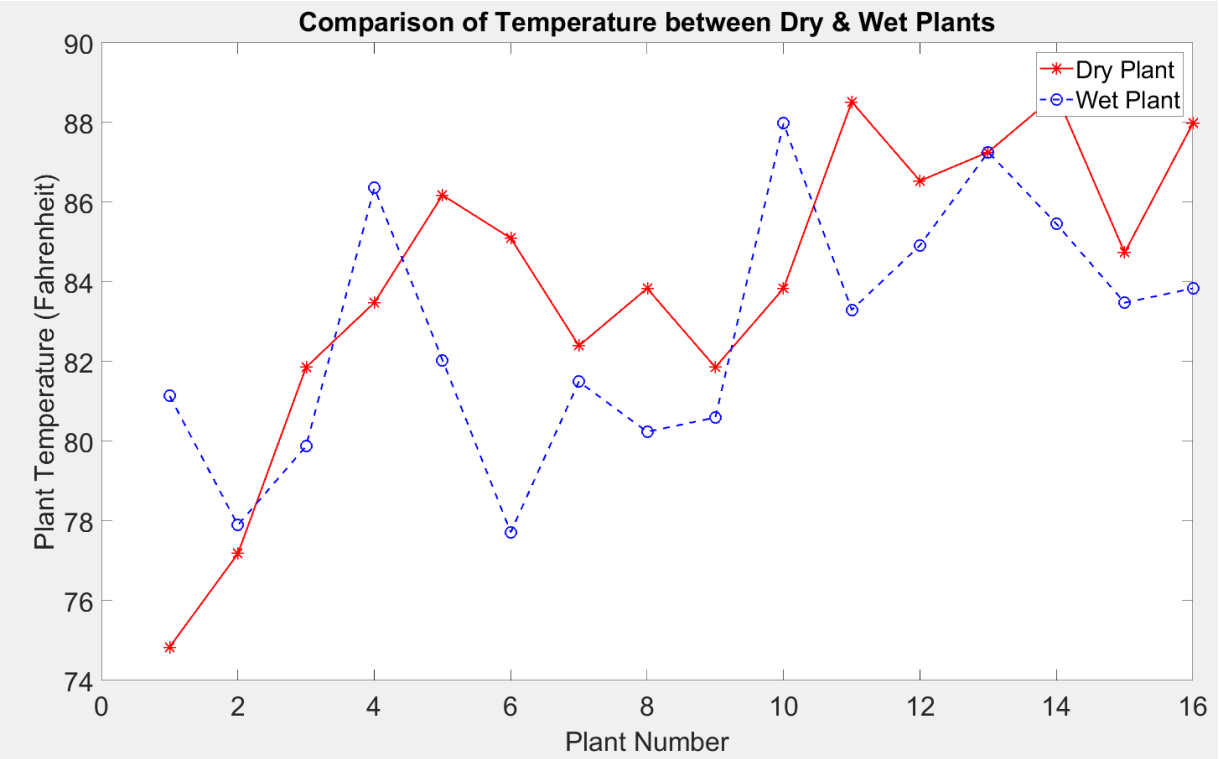


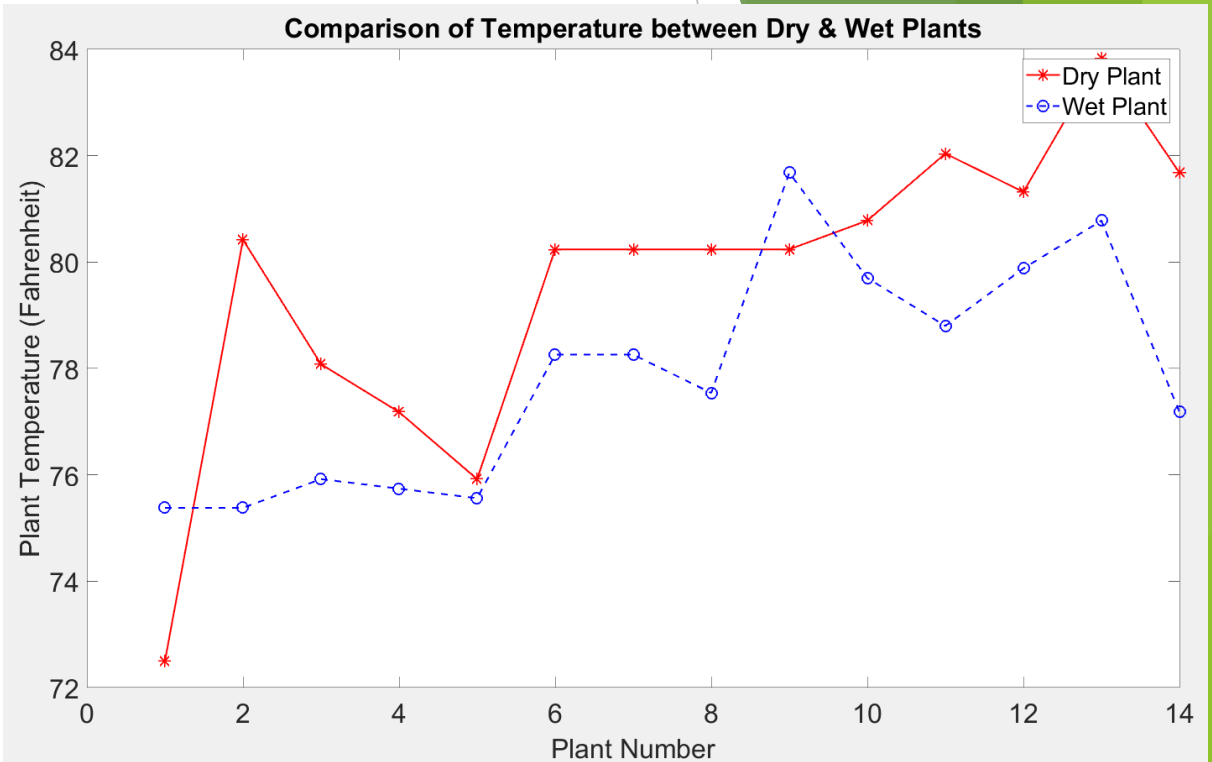
Date: 3/8/19
Weather Conditions:
Average Wind Speed – 1.3mph
Temperature – 87.08 F
Relative Humidity – 50-54.8%
Max Difference - 9.9 F
Min Difference - 1.8 F



Date: 2/28/19
Weather Conditions:
Average Wind Speed – 0.8-1.0mph
Temperature – 85.64 F
Relative Humidity – 72.9-85.2%
Max Difference - 7.5 F
Min Difference - 1.2 F

Analysis of Temperature Variation



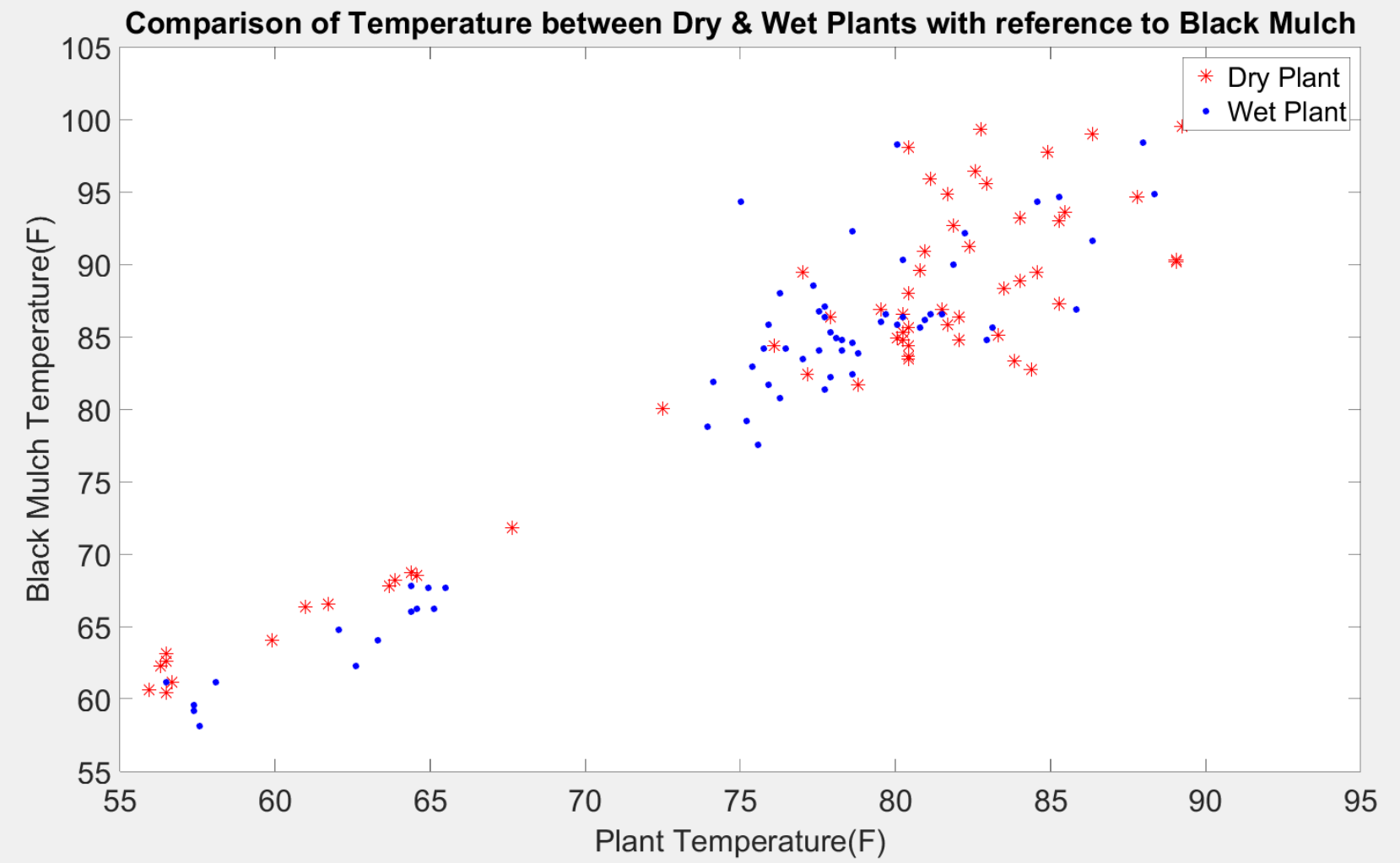


Date: 2/21/19
Weather Conditions:
Average Wind Speed – 0.6-0.8 mph
Temperature – 74.3-86 F
Relative Humidity – 51.6%
Max Difference - 7.3 F
Min Difference - 1 F

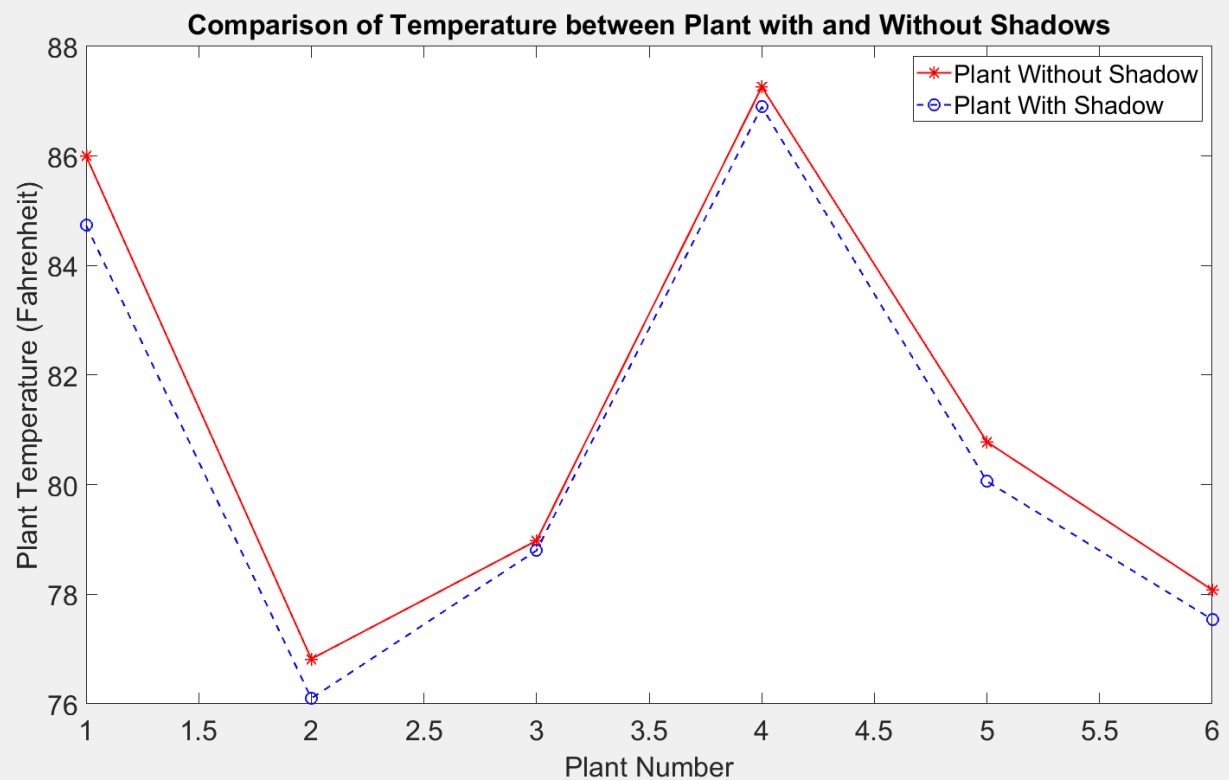
Lower Temperature = More Irregularity

Date: 2/19/19
Weather Conditions:
Average Wind Speed – 1.2-2.7 mph
Temperature – 76.82-80.96 F
Relative Humidity – 62.1-65.2%
Max Difference - 5 F
Min Difference - 0.4 F

Comprehensive Analysis



Effect Of Varying Illumination Conditions



- Negligible difference between temperatures of plants with and without shadow
- Minimum Temperature Difference: 0.3 F
- Maximum Temperature Difference: 1.2 F

Thermal Imaging does not depend on varying illumination conditions!!!

Conclusion

- Spectroscopy is not feasible
  - high cost of spectroscopes
  - point measurements
- Color Imaging provides good distinction
- Thermal Imaging can be used for distinction as well
  - invariant to illumination
  - varies with ambient temperature

Acknowledgements

- Florida Strawberry Growers Association
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Thank you!