Estimation of Stomatal Conductance using Crop Water Stress Index based on the Thermal Image at a Leaf Scale

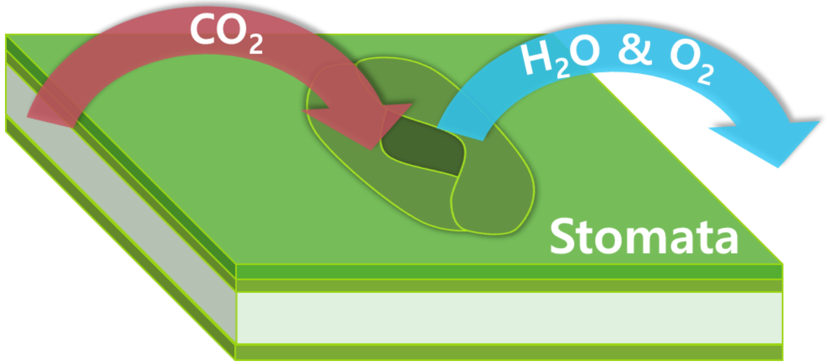
Hoejeong Jeong[1*], Jae-Hyun Ryu[1], Sang-il Na[2], and Jaeil Cho[1]

[1] Department of Applied Plant Science, Chonnam National University, Gwangju, Republic of Korea

[2] Climate Change and Agro-Ecology Division, National Institute of Agricultural Sciences, Rural Development Administration, Wanju, Republic of Korea

[*] contact : 197377@jnu.ac.kr
ghlwjd1022@gmail.com

Introduction

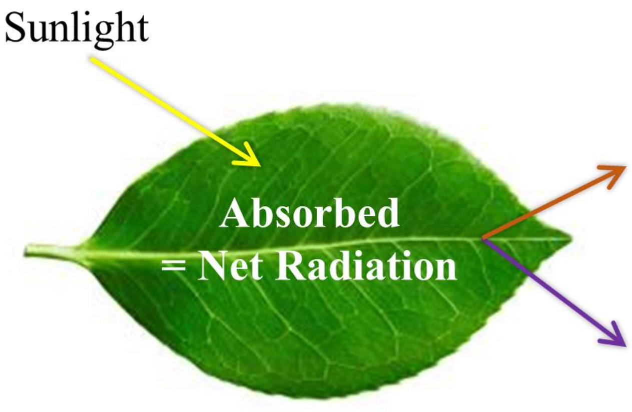


Stomata is a critical organ that regulate the amount of exchange gas between atmosphere and plant.

Stomatal conductance (g_s, mmol m^{-2} s^{-1}) respond to stress sensitively, and it affect to photosynthesis and transpiration.

Understanding of g_s is important to understand the photosynthesis of CO_2 absorption and transpiration of H_2O emission.

However, **observation of g_s continuously is difficult and time consuming**.



Latent heat flux(LE)
= Transpiration

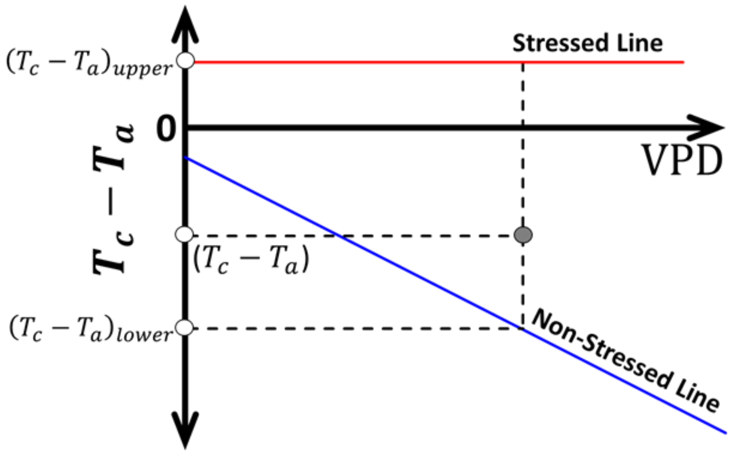
Sensible heat flux(H)
= Leaf temperature

Leaf temperature

Increase → by higher air temperature
strong radiation
stomata close

Decrease → by lower air temperature
weak radiation
stomata open

Introduction



$$\mathbf{CWSI} = \frac{(T_c - T_a) - (T_c - T_a)_{lower}}{(T_c - T_a)_{upper} - (T_c - T_a)_{lower}} = \frac{\Delta T - \Delta T_{wet}}{\Delta T_{dry} - \Delta T_{wet}}$$

In 1980s, Crop Water Stress Index (CWSI) has been suggested by Idso et al. (1981) and Jackson et al. (1981)

CWSI was originally developed to detect the water stress of crops which is based on the leaf energy balance.

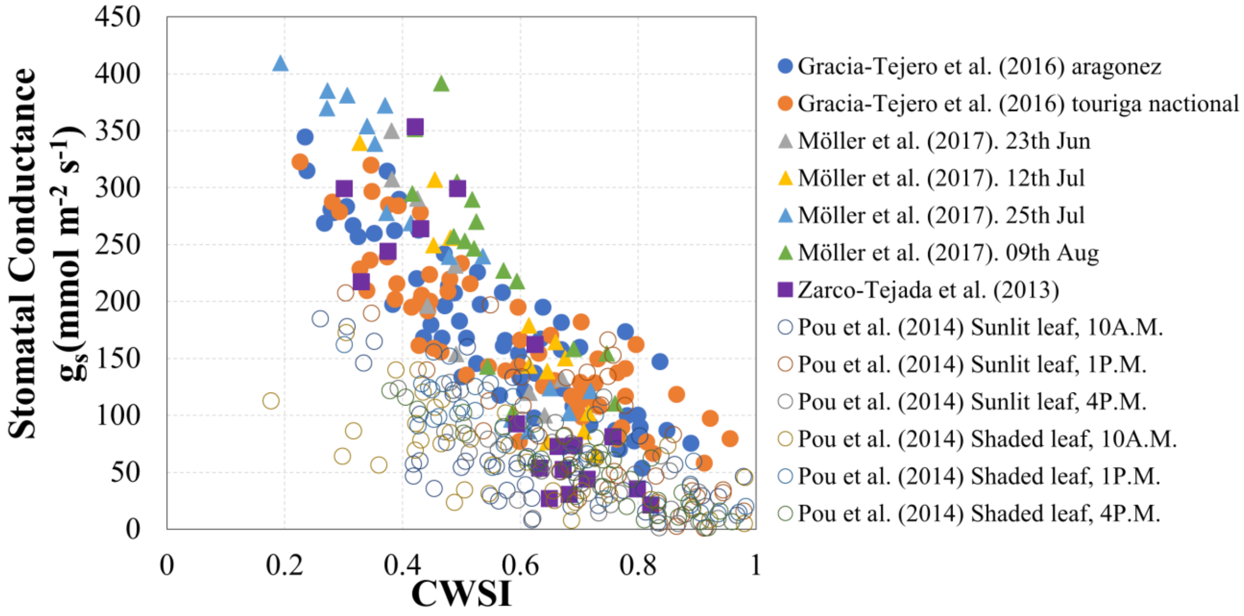
Both g_s and CWSI has a relationship with leaf temperature (i.e., leaf energy balance).

We hypothesized that there is some relation between g_s and CWSI, and this can give a possibility that can estimate the g_s using CWSI.

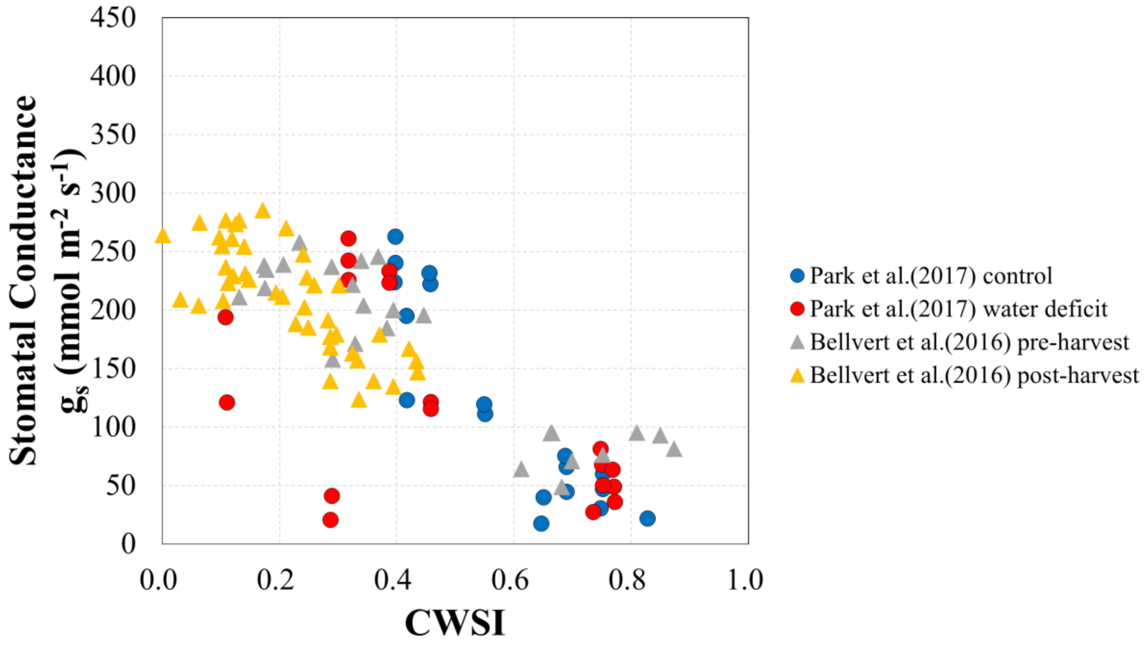
Therefore, in this study we investigate **possibility of estimation of g_s using CWSI which is derived from thermal image**.

Data collected from literatures

First of all, data were collected from previous research paper to **identify the relation between CWSI and g_s**.



grape



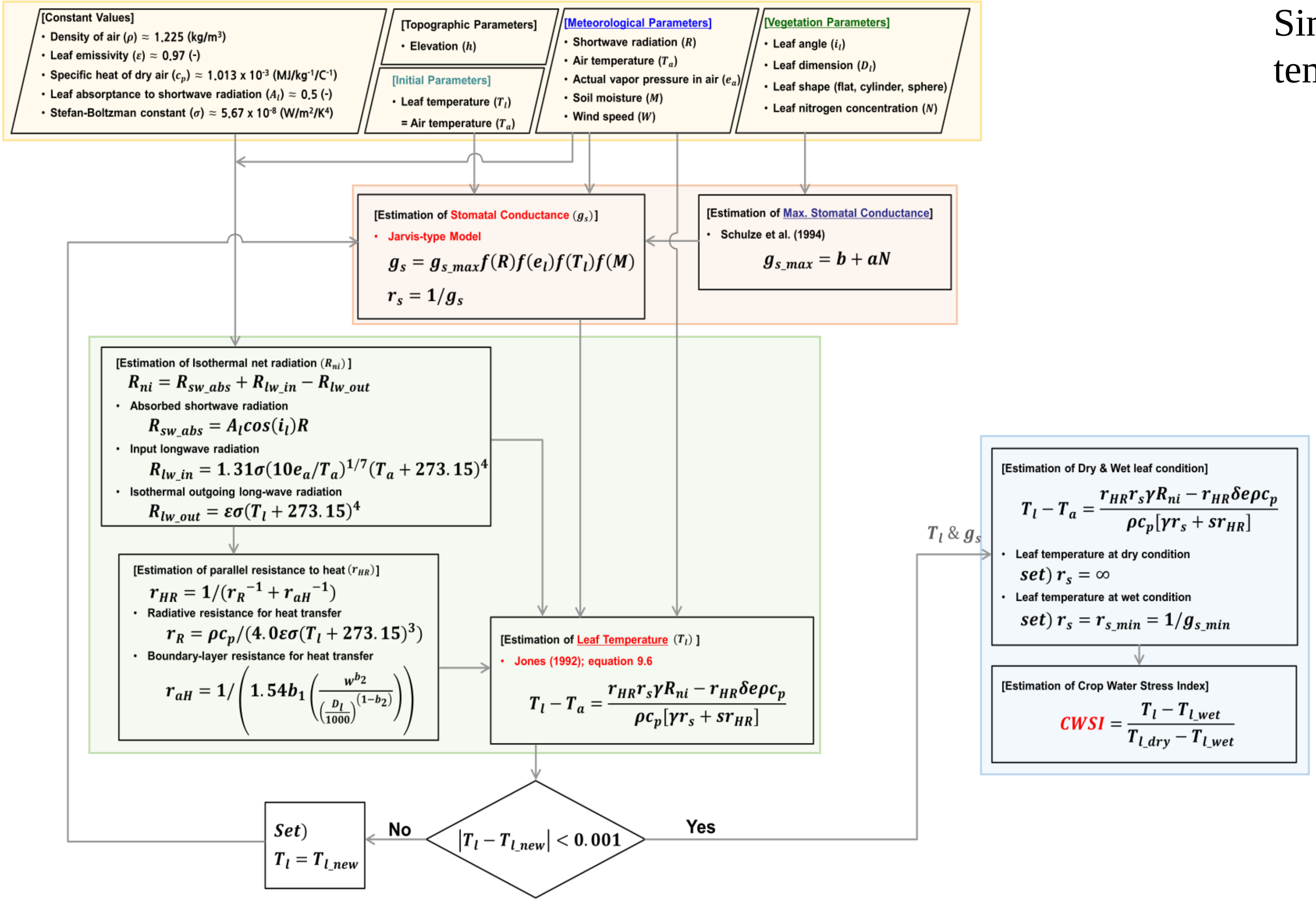
peach

From the collected data, there is **negative relationship** between CWSI and g_s, but it depends on the crops.

Also it depends on the method that calculate the CWSI.

EGU General Assembly 2020 / Online / 08.May.2020

Simulation – Algorithm



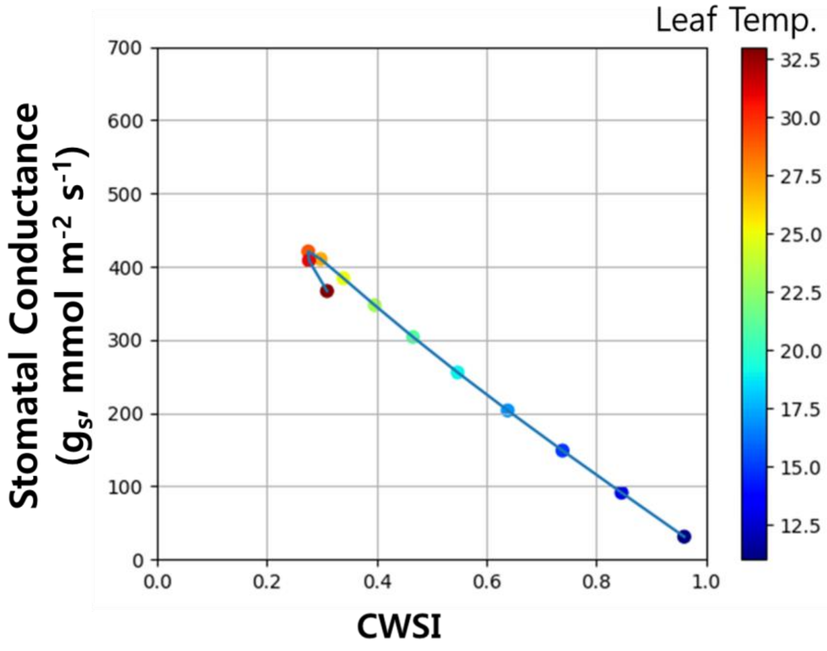
Simulation was conducted based on leaf temperature

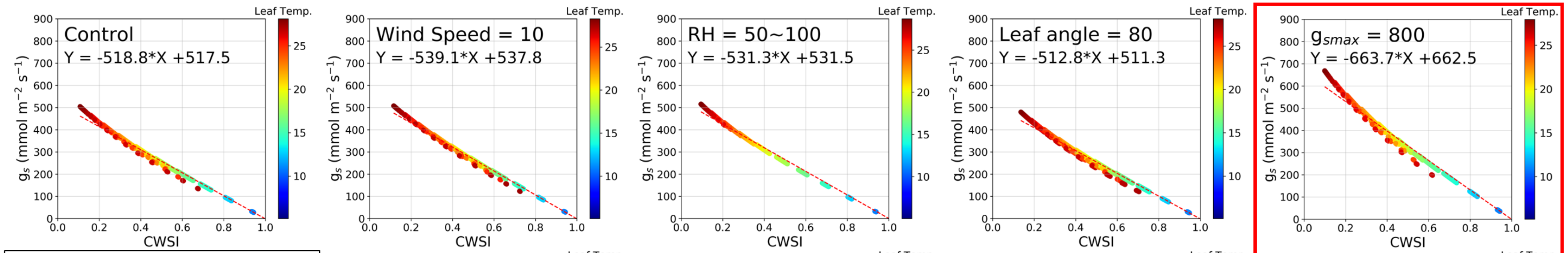
- Input data
  (e.g., meteological parameters, vegetation parameters, constants, etc..)
- Estimation of g_s
  → Jarvis-type model
- Estimation of leaf temperature
  → Jones (1992) leaf energy balance equation
- Calculation of CWSI
  → Jones (1992)

Simulation – Result

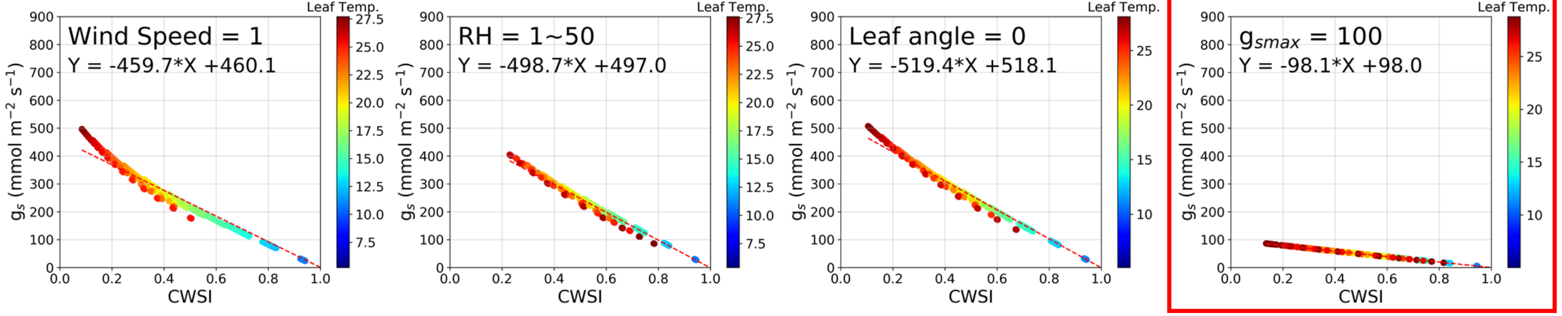
As the results of simulation, we found that there is **some negative linear relation between CWSI and g_s**.

The slope of CWSI and g_s is changed by **maximum stomatal conductance (g_{s_max})**.

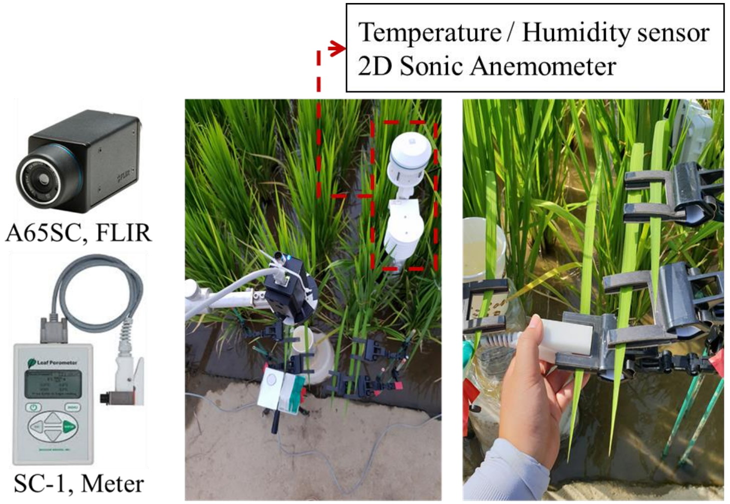


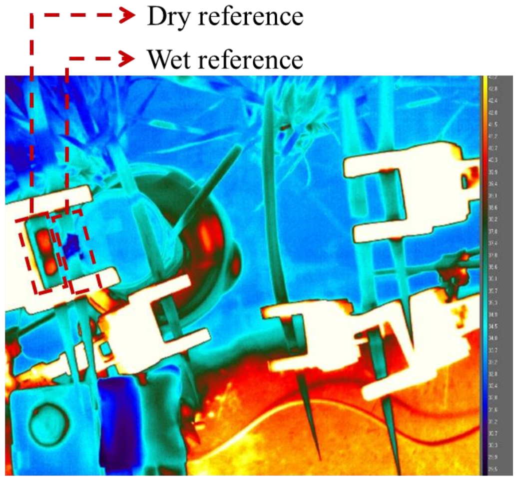


Elevation : 10m
Wind Speed : 10 m^{-1} s
Leaf angle : 45°
Leaf dimension : 100mm
Leaf shape : flat
Soil moisture : 100 %
g_{s_max} : 600 mmol m^{-2} s^{-1}
Chlorophyll concentration : 5 mg dm^{-2}
Short wave radiation : 800 W m^{-2}
Leaf temperature : 5~30 °C
RH : 10~90 %



Field measurement (leaf scale) – Methodology





To verify the hypothesis and the results of previous 2 studies, field measurement has been conducted on garlic field at Muan, Korea in 2018 to 2019.

Thermal images were taken with infrared thermal camera (A65SC, FLIR)

g_s measurement demonstrated using stomatal conductance porometer (SC-1, Meter)

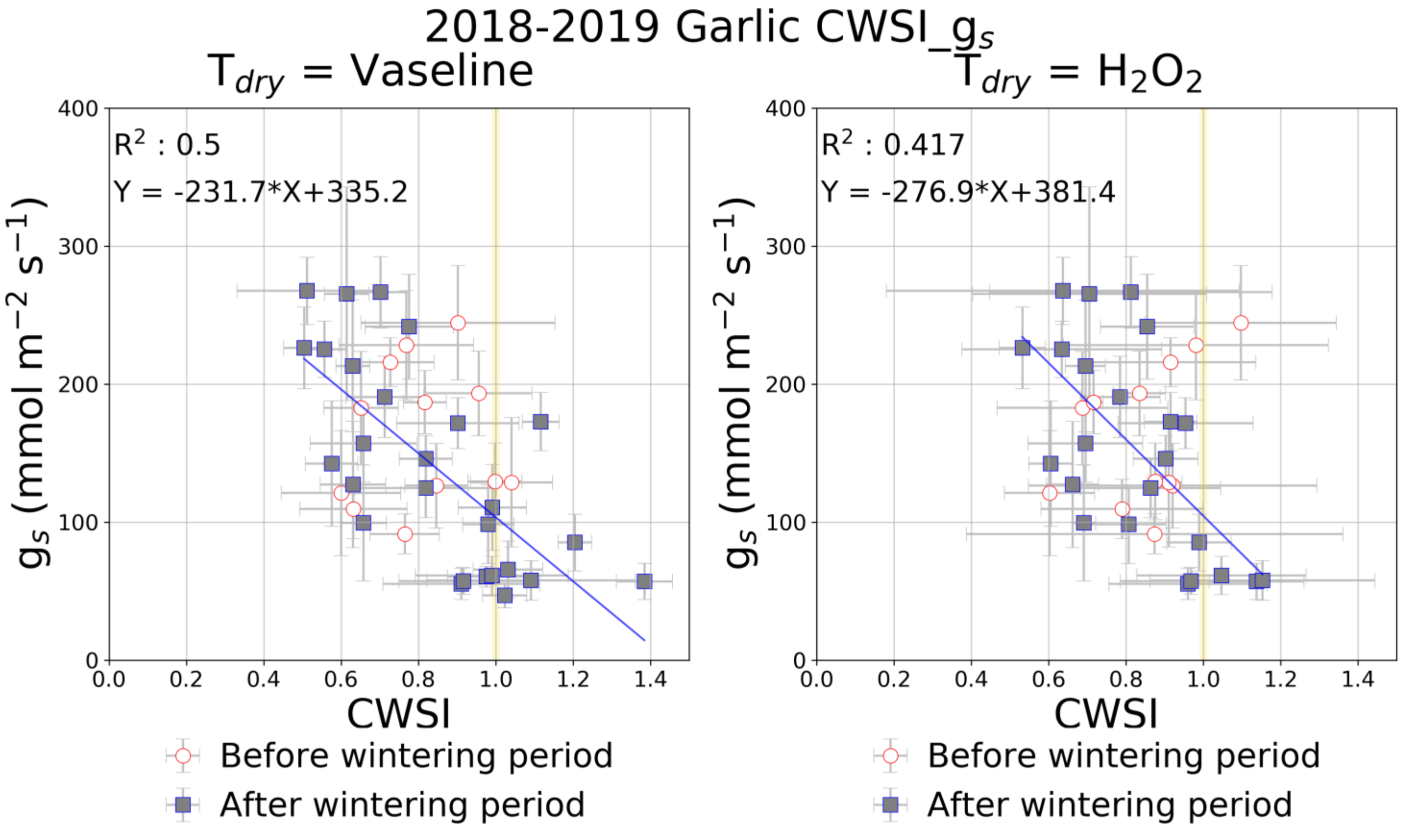
In this measurement we followed Jones (1992) method, Vaseline and water-spray was used for the dry reference and wet reference, respectively.

Also tried a new dry reference (H_2O_2) and compared it to the Vaseline dry reference.

Furthermore, leaf fixed by ‘ㄷ’ shape clip can get the same amount of solar energy.

Calculation of CWSI is following Jones (1992) method which use the reference and leaf temperature.

Field measurement (leaf scale) – Results



It shows correlation between CWSI and g_s at whole growing season in garlic.

There was no significant correlation at before wintering period.

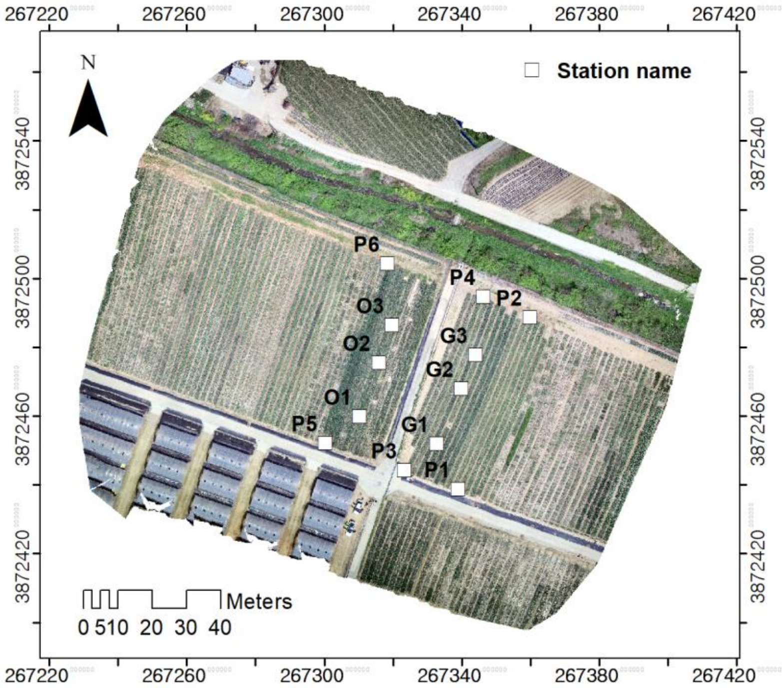
After wintering period, it shows **negative linear correlation**.

Comparison of Vaseline and H_2O_2 (dry reference), Vaseline seems more effective to identify the relation between CWSI and g_s

Field measurement (field scale) – Methodology

Duo Pro R, FLIR

RedEdge, MicaSense



Field measurement were conducted to see if CWSI calculation results similar to measurement at the leaf scale can be observed at the field scale.

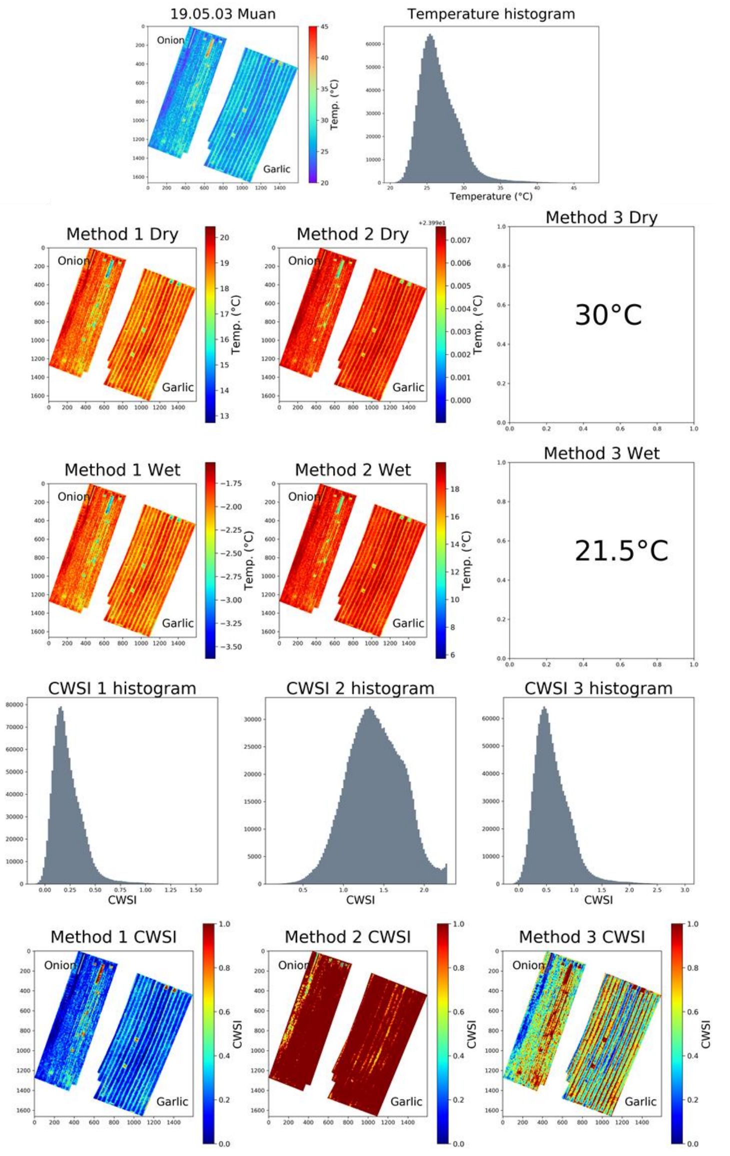
In this study, 3rd, May, 2019 data was used which is observed at solar noon time in garlic field at Muan, Korea.

Thermal imaging camera (Duo Pro R, FLIR) and multispectral sensor(RedEdge, MicaSense) were mounted on the drone.

Based on the observed thermal image, CWSI was calculated through 3 methods.

Field measurement (field scale) – Result

Method		reference
Method 1 Jackson et al. (1986)		Physical equation based on leaf surface energy balance when the stomatal resistance is 0 and ∞
	Dry	$T_{dry} = r_a R_n / pC_a$
	Wet	$T_{wet} = \frac{r_a R_n}{pC_a} \bullet \frac{\gamma}{\Delta+\gamma} - \frac{VPD}{\Delta+\gamma}$
Method 2 Jackson et al. (1986)		CWSI calculated by putting the maximum and minimum values of realistic gs inferred through field observation to Method 1
	Dry	$T_{dry} = \frac{r_a R_n}{pC_a} \bullet \frac{\gamma(1+r_c/r_a)}{\Delta+\gamma(1+r_c/r_a)} - \frac{VPD}{\Delta+\gamma(1+r_c/r_a)}$ $r_c = 1/g_s,\ g_s = 30\ mmol\,m^{-2}s^{-1}$
	Wet	$T_{wet} = \frac{r_a R_n}{pC_a} \bullet \frac{\gamma(1+r_c/r_a)}{\Delta+\gamma(1+r_c/r_a)} - \frac{VPD}{\Delta+\gamma(1+r_c/r_a)}$ $r_c = 1/g_s,\ g_s = 200\ mmol\,m^{-2}s^{-1}$
Method 3 Jones (1992)		Using the temperature of the dry and wet reference form the field observation (temperature of the dry reference was used that of H_2O_2)
	Dry	Dry reference temperature from field observation
	Wet	Wet reference temperature from field observation



Also as you can see, 3 types of thermal image simulation has been conducted using references above.

Each method shows a similar distribution of CWSI but the range of CWSI value is only well fits on Method 3.

Results

◌ We found that CWSI and g_s are negative linear correlation.

- The collected data from literatures found that there is linear pattern between CWSI and g_s.
- Our simulation experiment shows that the linear slope between CWSI and g_s is depend on the g_{s_max} of leaf.

◌ Field observation were conducted to test how to estimate g_s using the relationship between CWSI and g_s.

- **We found the possibility that g_s can be estimated by accurately calculated CWSI using a empirical correlation between CWSI and g_s.**
- The further study has to focus on not only the g_s estimation method from CWSI but also the measurement method of CWSI (e.g., dry & wet reference).

◌ Our results will contribute to not only monitoring of crop water stress for irrigation in smart-farm system but also calculating evapotranspiration, photosynthesis, and crop yield through the estimated g_s.