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Microclimate Condition in the Natural Ventilated Greenhouse

Iklim Mikro di Rumah Kaca Berventilasi Alami

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Abstract. A Greenhouse has a different microclimate compared to the outside field. Climate parameters such as solar radiation and air temperature are important parameters that affect plant growth and productivity. This research aims to understand the relation of climate factors in the inside and outside Greenhouse, the effect of microclimate on evapotranspiration and to predict the amount og evapotranspiration inside the Greenhouse. Microclimate analysis was held in two stages, the first stage was from February 5 to March 21, 2018 and the second stage from March 19 to April 29, 2019 at the Department of Civil and Environmental Engineering, IPB University. Primary data was measured by the Decagon sensor. Solar radiation was collected using the Decagon PYR Pyranometer sensor and air temperature using the Decagon VP-4 sensor. Based on the result, the daily air temperature inside the Greenhouse was higher than that of the outside. The inside solar radiation was lower than that of outside the Greenhouse. The relative humidity fluctuated, and the air pressure was higher inside the Greenhouse. Evapotranspiration inside the Greenhouse was lower than outside and solar radiation was the most determining factor of evapotranspiration.

Abstrak. Rumah kaca memiliki iklim yang berbeda dengan lahan terbuka yang disebut dengan iklim mikro. Parameter iklim seperti radiasi matahari dan suhu udara adalah parameter penting yang mempengaruhi pertumbuhan dan produktivitas tanaman. Penelitian ini bertujuan untuk memahami hubungan faktor iklim di dalam dan luar rumah kaca, pengaruh iklim mikro terhadap evapotranspirasi dan model untuk memprediksi evapotranspirasi di dalam rumah kaca. Analisis iklim mikro dilaksanakan dalam dua tahap, tahap pertama dari 5 Februari sampai 21 Maret 2018 dan tahap kedua dari 29 Maret sampai 29 April 2019, di Rumah kaca Departemen Teknik Sipil dan Lingkungan, Institut Pertanian Bogor. Data primer diukur dengan sensor Decagon. Radiasi matahari diukur menggunakan sensor Pyranometer Decagon PYR dan suhu udara menggunakan sensor Decagon VP-4. Berdasarkan hasil penelitian, suhu udara harian di dalam lebih tinggi daripada di luar rumah kaca. Radiasi matahari di dalam rumah kaca lebih rendah dibandingkan di luar rumah kaca. Perubahan kelembaban relatif relatif dan tekanan air lebih tinggi di dalam rumah kaca. Evapotranspirasi di dalam rumah kaca lebih rendah daripada di luar, dan radiasi matahari merupakan faktor yang paling menentukan evapotranspirasi.

Pendahuluan

A greenhouse can have a different climate compared to the field. It is called a microclimate. The microclimate is influenced by several factors, such as wind speed, humidity, irrigation, climate factor, etc. (Ebrahimabadi *et al*. 2015). Climate factors that greatly affect plant growth are solar radiation, air temperature, wind speed, and rainfall (Hatfield *et al*. 2015). Microclimate also affects from the Greenhouse design and cover material properties that strongly impact greenhouse energy. The Greenhouse will have a direct impact on plant growth and climate needs (Boulard *et al*. 2017).

Temperature and solar radiation have an important role in plant growth (Alsadon *et al*. 2016). Solar radiation determines the photosynthesis. The temperature will affect the respiration process in the plant (Mobtaker *et al*. 2016). Solar radiation inside the Greenhouse depends on the screen used in the Greenhouse design. The type of material used as a screen will reduce light transmission. These climate parameters will have an impact on the evapotranspiration process (Teitel 2007).

Evapotranspiration process related to the water demand of the plant. Evapotranspiration (ET) is the total loss of water to the atmosphere through evaporation and transpiration. Transpiration is a loss of water from the plant (Zhang *et al*. 2010). Through the different climate between inside and outside the Greenhouse, the evapotranspiration value follows the climate condition. This research aims to understand the relation of climate

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factors in the inside and outside Greenhouse, the effect of microclimate for evapotranspiration and model to predict evapotranspiration inside the Greenhouse.

Materials and Method

The research was conducted at the organic vegetable greenhouse with natural ventilation, located at the Department of Civil and Environmental Engineering, Bogor Agricultural University. The research was held in 2 stages, the first stage from February 5 to March 21, 2018 and the second stage from March 19 to April 29, 2019. The greenhouse has a length of 9 m and a width of 3 m, with a height of 4 m covered by net wall. A greenhouse covers a floor area 27 m^2 with polycarbonate roff 90% transparency and the slope was 30^o. The research location was S 6.55635°; E 106.72914° with altitude was 950 m above sea level.

Solar radiation was collected using the Decagon PYR Pyranometer sensor and air temperature using a Decagon VP-4 (Temperature, Humidity, and Pressure Sensor) sensor. The data were collected every 15 minutes during the study.

Potential evapotranspiration is generally identified as ETo. Potential evapotranspiration values can be estimated using several models. In this study, the meteorological data were not obtained completely using the measurement sensors used, so the calculation of potential evapotranspiration in the study using the Hargreaves model suggested by Allen *et al.* (2006). The Hargreaves equation requires meteorological data consisting of air temperature data and solar radiation shown in Equation 1.

$$ETo = \frac{C_o}{K_r} R_s \left(T_{mean} + 17.8\right) \qquad (1)$$

which *ETo* is potential evapotranspiration (mm d^{-1}), C_o/K_r is adjustment coefficient (0.0135), T_{max} is the maximum temperature (^{o}C), T_{min} is minimum temperature (^{o}C), T_{mean} is average temperature (^{o}C) and R_s is solar radiation (Langleys/day). Solar radiation was convert to MJ m^{-2} d^{-1} to make easy the analysis. Then, the potential evapotranspiration equation shown in Equation 2.

$$ETo = \frac{C_o}{K_r} R_s \left(T_{mean} + 17.8\right) \frac{238.8}{595.5 - 0.55T_{mean}} \qquad (2)$$

The correlation between potential evapotranspiration (*ETo*) with crop evapotrapiration (*ETc*) was describe in Equation 3.

$$ETc = Kc \times ETo \qquad (3)$$

which *Kc* was crop coefficients that have different value every crop and stage of plant growth. Based on crop in this research, the initial stage (on 0th – 6th day after planting) was 0.7, at the middle session stage (on 17th – 23th day after planting) was 1 , and at the end of the late season stage (on 30th – 36th day after planting) was 0.95 (Allen *et al.* 2006).

Result and Discussions

Climates

The first and second stage was held 42 days per stage. Based on the primary data, the statistics of climate parameters were shown in Table 1. The climate inside the

Table 1. Statistics of climates data

Tabel 1. Statistik data iklim

Data	1st Stage			2nd Stage		
	Max	Min	Mean	Max	Min	Mean
Solar radiation outside (RSo)	41.91	5.70	20.41	32.51	9.81	23.69
Solar radiation inside (RSin)	20.64	3.48	9.89	5.18	1.19	3.59
Air temperature minimum outside (Tmino)	24.10	21.00	22.97	24.80	22.60	23.64
Air temperature maximum outside (Tmaxo)	37.90	26.30	32.92	36.30	29.70	33.85
Air temperature average outside (Taveo)	28.88	24.27	26.43	28.56	25.70	27.03
Air temperature minimum inside (Tmini)	23.90	20.70	22.70	24.50	22.20	23.20
Air temperature maximum inside (Tmaxi)	36.00	25.10	31.60	36.30	29.70	33.96
Air temperature average inside (Tavei)	28.25	23.69	25.88	28.46	24.75	26.74
Relative humidity outside (RHout)	0.99	0.74	0.89	0.92	0.76	0.83
Relative humidity inside (RHin)	0.97	0.72	0.87	0.90	0.78	0.83
Air pressure outside (Pout)	99.31	98.76	98.97	99.10	98.63	98.88
Air pressure inside (Pin)	99.35	98.81	99.02	99.35	98.81	99.02

Greenhouse was significantly different than in the outside.

The solar radiation on the inside ranged from 37% to 66% than the outside during 42 days of cultivation. The daily solar radiation inside the Greenhouse ranged from 3.48 until 20.64 MJ m^{-2} d^{-1} while in the outside ranged from 5.70-41.91 MJ m^{-2} d^{-1}. The correlation between solar radiation for the first and second stage was drawn in Figure 1-2.

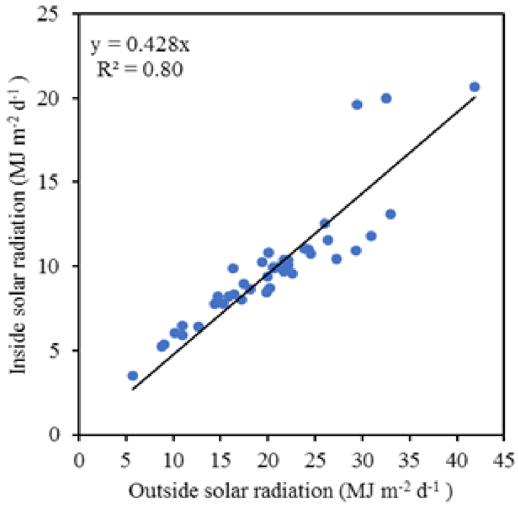

Figure 1. Correlation of inside and outside solar radiation in the first stage of February 5 to March 21, 2018

Gambar 1. Korelasi radiasi matahari di dalam dan luar pada tahap pertama 5 Februari hingga 21 Maret 2018

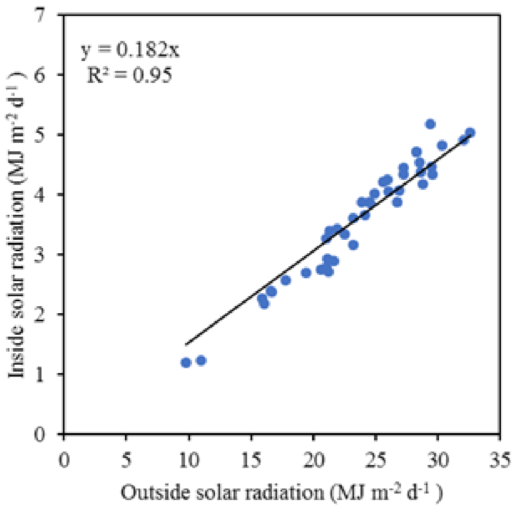

Figure 2. Correlation of inside and outside solar radiation in the second stage of March 19 to April 29, 2019

Gambar 2. Korelasi radiasi matahari di dalam dan luar pada tahap kedua 19 Maret hingga 29 April 2019

In some conditions, the daily temperature inside Greenhouse is relatively higher than that in the outside in both stages this condition caused by the greenhouse effect (Lamnatou dan Chemisana 2013). Shortwave radiation that enters inside the greenhouse transformed into a long wave as it passes cover material (roof and walls) and reflected by the floor and the greenhouse construction (Suhardiyanto 2009). This greenhouse effect trap causes the temperature inside the Greenhouse higher. The average air temperature inside the Greenhouse was 25.88 ^{o}C, and the outside was 28.56 ^{o}C.

The average daily temperature requirement for Kailan vegetable growth is 25-35 ^{o}C (Suharyanto and Sulistiawati 2012). At low temperatures, the plants will show symptoms of leaf tissue death, and eventually, the plants die. At high temperatures, the plants will die because the evaporation process is too large (William *et al.* 2017).

Air temperature data used in the further analysis, such as calculation of evapotranspiration and air temperature modelling. Relative humidity in the Greenhouse was 96-99% from outside. The value of average relative humidity was 0.87 for inside and 0.89 for outside the Greenhouse. The air pressure inside Greenhouse was higher compare to outside. It is consistent with the air temperature.

Crop Evapotranspiration

Based on the calculation crop evapotranspiration (*ETc*) using Hargreaves, the correlation between crop evapotranspiration inside and outside the Greenhouses in both stages shown in Figure 3-4. The average evapotranspiration in the first stage during the cultivation was 2.30 mm for inside Greenhouse and 4.84 in the outside. The crop evapotranspiration inside Greenhouse was below from outside. It is caused by solar radiation outside was higher.

The result of crop evapotranspiration in the second stage was lower than the first stage. It is caused the microclimate that happens in the Greenhouse was changed. The value of crop evapotranspiration for the second stage in the inside Greenhouse was 0.34 mm day^{-1}, and the outside was 5.59 mm day^{-1} (*Kc* from reference).

The determination coefficient in the second stage was higher than the first stage. This function can be used to predict the correlation between reference evapotranspiration (*ETo*) inside and outside the Greenhouse. Based on the linear regression method, to obtain evapotranspiration inside the Greenhouse based on the outside the Greenhouse data was used Equation 4.

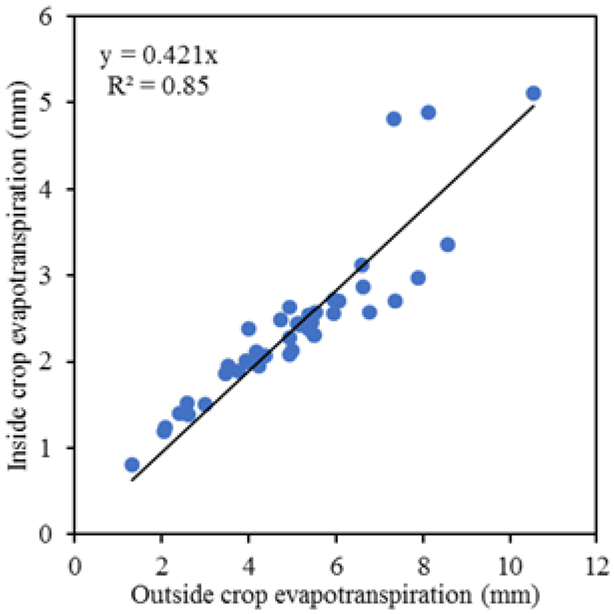

Figure 3. Correlation of inside and outside crop evapotranspiration (first stage, February 5 to March 21, 2018)

Gambar 3. Korelasi evapotranspirasi tanaman di dalam dan luar pada (tahap pertama, 5 Februari hingga 21 Maret 2018)

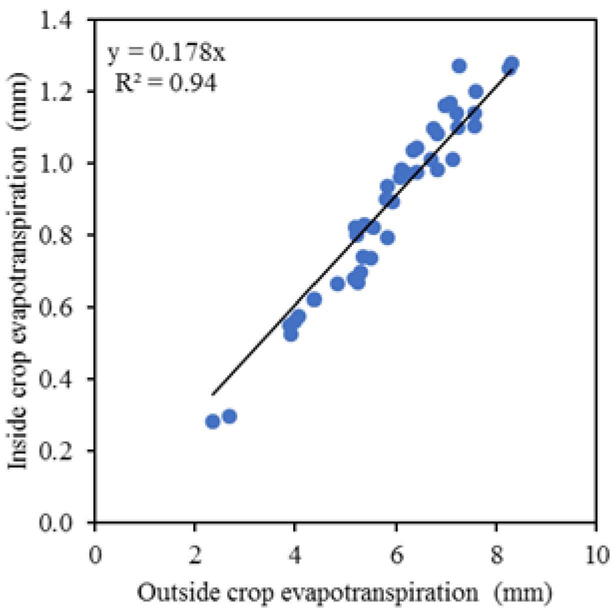

Figure 4. Correlation of inside and outside crop evapotranspiration (second stage, March 19 to April 29, 2019)

Gambar 4. Korelasi evapotranspirasi tanaman di dalam dan luar (tahap kedua, 19 Maret hingga 29 April 2019)

$$y = 0.178x \quad (4)$$

$$y = 0.178\, R_{so}\, (T_{meano} + 17.8) \frac{238.8}{595.5 - 0.55 T_{meano}}$$

Which y is reference evapotranspiration inside the Greenhouse (mm), and x is reference evapotranspiration outside the Greenhouse (mm). R_{so} is solar radiation outside the Greenhouse (MJ m^{-2} d^{-1}) and T_{meano} is average temperature outside the Greenhouse (^{o}C). The result of y multiplied by a crop coefficient (*Kc*) is crop evapotranspiration (*ETc*). This equation can be used to predict evapotranspiration inside the Greenhouse. The accuracy of the results is based on the Greenhouse design and climate type at the Greenhouse location. In this research, the type of Greenhouse is natural ventilation with the polycarbonate roof and net wall.

Influential Parameter of Crop Evapotranspiration

Based on the Hargreaves Model that used in this research, temperature and solar radiation is the main parameter that affects crop evapotranspiration. Figure 5-8 show the correlation between both of the parameters with crop evapotranspiration inside the greenhouse. Based on the determination coefficient, in the first and second stage, the main parameter that has strong effect on crop evapotranspiration was solar radiation with the R^2 = 0.99.

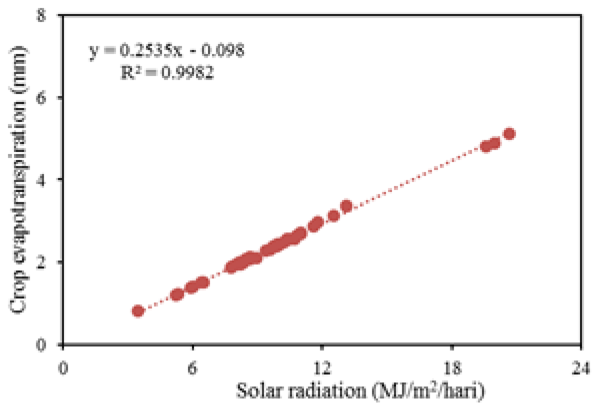

Figure 5. Correlation inside crop evapotranspiration and solar radiation (first stage, February 5 to March 21, 2018)

Gambar 5. Korelasi evapotranspirasi tanaman di dalam dan radiasi matahari (tahap pertama, 5 Februari hingga 21 Maret 2018)

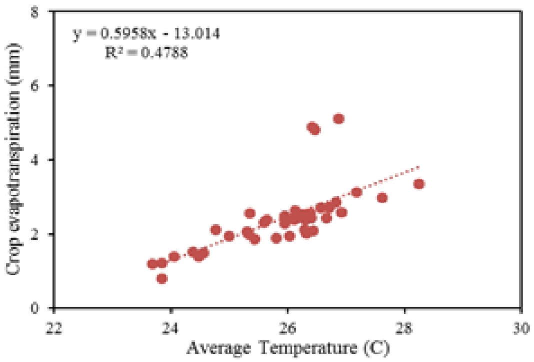

Figure 6. Correlation inside crop evapotranspiration and average temperature (first stage, February 5 to March 21, 2018)

Gambar 6. Korelasi evapotranspirasi tanaman di dalam dan suhu rata-rata (tahap pertama, 5 Februari hingga 21 Maret 2018)

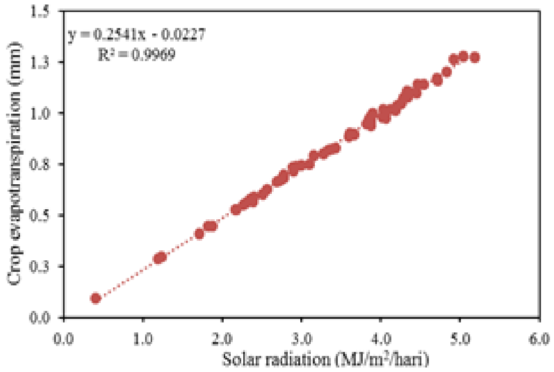

Figure 7. Correlation inside crop evapotranspiration and solar radiation (second stage, March 19 to April 29, 2019)

Gambar 7. Korelasi evapotranspirasi tanaman di dalam dan radiasi matahari (tahap kedua, 19 Maret hingga 29 April 2019)

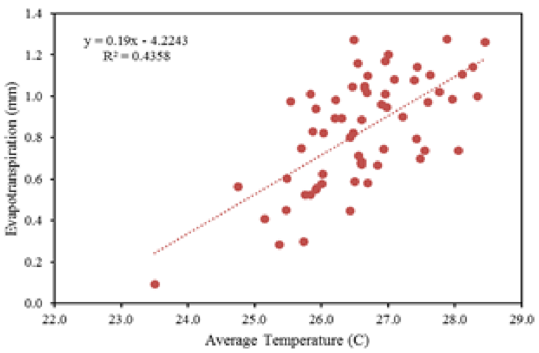

Figure 8. Correlation inside crop evapotranspiration and average temperature (second stage, March 19 to April 29, 2019)

Gambar 8. Korelasi evapotranspirasi tanaman di dalam dan suhu rata-rata (tahap kedua, 19 Maret hingga 29 April 2019)

Askari *et al.* (2015) explain the graphical and partial derivatives approaches were used to analyze the sensitivity of variables for the variable of evapotranspiration models. Sensitivity analysis was performed to investigate the effect of the climate parameter to the evapotranspiration. Based on the sensitivity analysis, solar radiation was the most sensitive variable in the Hargreaves model.

Implications in the Agricultural Sector

Based on the result, the climates parameter will directly influence the agricultural sector, specifically plant growth. Crop evapotranspiration will affect water demand. One of the most influential factors is solar radiation. This must be considered when selecting the kind roof of a Greenhouse. Solar radiation transmissivity greatly influences the evapotranspiration process and the water needs of plants in Greenhouses that are smaller than open land. Besides, the temperature will be affected by the selection of the Greenhouse wall. Knowing the parameters that most influence on evapotranspiration will make it easier to plan Greenhouses according to crop needs.

Conclusions

The daily air temperature inside the Greenhouse was higher than that of the outside of the Greenhouse. The solar radiation inside was lower than the outside. The relative humidity fluctuated, and the air pressure was higher inside the Greenhouse. Evapotranspiration inside the Greenhouses was lower than outside. Based on the linear regression the amount of evapotranspiration inside the Greenhouse can be calculated by $y = 0.178\, R_{so}\, (T_{meano} + 17.8)\frac{238.8}{595.5 - 0.55 T_{meano}}$, with the R^2 of 0.95; where R_{so} is outside solar radiation, and T_{meano} is average temperature outside the Greenhouse. The parameter that influences the crop evapotranspiration the most was solar radiation. This results provide an estimate of how much water should be supplied for a Greenhouse experiment or production systems.

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