Running title: Light Intensity Affects Stress Characteristic of Tatsoi’s Plant

# **Light Intensity Affects Stress Characteristic of Tatsoi (*Brassica rapa subsp. narinosa*) Plant Cultivated under Water Deficiency**

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# **Novelty statement**

Stress characteristics of the Tatsoi plant grown under multiple stress conditions have rarely been observed, primarily that is cultivated inside a greenhouse in tropical regions such as Indonesia. These results show that the extreme reduction of sunlight intensity substantially affects the growth of the Tatsoi plant under water stress. We also found that leaf temperature is highly related to plant water consumption, which primarily affects plant morphology and physiology.

# **Abstract**

According to preliminary studies, it is important to maintain production in order to fulfill the new growing market demand for Tatsoi (*Brassica rapa subsp. narinosa*) plant. Therefore, this research investigated the stress characteristics of the Tatsoi plant cultivated in a tropical greenhouse using a nutrient film technique (NFT) hydroponic module. Tatsoi plant was treated at various sunlight intensities (A, B, C) under different watering durations (24-hour, 12-hour, and 6-hour). The parameters observed during the growth period and at harvest (27 days after plantation) were plant morphology and physiology. The water level of the nutrient solution inside the container was also measured to determine daily plant water consumption. The microclimate parameters inside the greenhouse were collected automatically using sensors connected to the Arduino microcontroller. The results showed that under extreme sunlight deficiency (-98.78%), the Tatsoi plant experienced a decrease in leaves number (-79.17%), canopy (-99.17%), plant height (-72.3%), root length (-97.52%), and plant weight (-99.62%) compared to conditions of extreme water deficiency. Moreover, Tatsoi plant transpiration rate (-91.45%) was more impacted than the photosynthesis (-20%). This phenomenon was indicated by the decreasing plant water consumption (-15.48%) and water level reduction (-22.95%) that were negatively related to leaves-air temperature difference. These similar stress characteristics were found to be consistent at different watering durations. Finally, the correlation analysis showed that sunlight intensity has a high positive correlation value ( > 0.9 ) with Tatsoi plant morphology and physiology.

**Keywords**: Stress characteristic; Sunlight deficiency; Tatsoi plant; Water deficiency

# **Introduction**

Tatsoi plant, which originated from China is one of the horticultural plants belonging to the *Brassica* family. This plant has spoon-shaped, dark green, and waxy leaves with a short green petiole (2–9 cm) on leavestalk (Tomás-Callejas *et al.*, 2012). In its native area, this plant usually cultivates in the spring or fall and is known to have high economic value, with the highest vitamin A, vitamin C, and calcium content from Tatsoi compared to other *Brassica* plants, such as green mustard, chicory, and pak choi (*Andra Farm - Go Green*, 2019). Recently, Tatsoi has gained considerable attention in the Indonesian market, with a selling price range of approximately Rp 50,000 per kilogram, a figure significantly higher than that of other *Brassica* families (Rahmawati, 2023).

There is a growing demand for Tatsoi plant consumption in urban areas, yet the availability is still limited, specifically in tropical climate regions such as Indonesia. According to Nugroho & Widyawati (2022), the traditional cultivation methods used for Brassica plant contribute to the low quantity and quality of these crops. This condition presents an opportunity for the development of Tatsoi, particularly in urban areas with a higher middle-class population. Given the constraints of limited productive agricultural land in urban areas, it is advisable to explore alternative methods of plant cultivation, such as soil-less media using hydroponic method. Among hydroponic methods, nutrient film technique (NFT) stands out as widely adopted for horticultural crop cultivation. This method is known for its superiority in maximizing water-use efficiency by recycling all water and nutrient that are not absorbed by plant (Putra & Yuliando, 2015).

Tatsoi plant exhibits sensitivity to external factors, including fluctuations in temperature and water availability. Without a proper strategy, rising temperatures will affect most vegetable crops in terms of productivity, especially in the tropics (Scheselbeek *et al.*, 2018). Therefore, it is important to implement a proper strategy, as rising temperatures have the potential to significantly impact the productivity of most vegetable crops, particularly in tropical regions.

Recently, more farmer cultivated plant inside greenhouse. Plant cultivated in greenhouse still get sunlight as an energy source for photosynthesis, yet more protected from extreme conditions, such as high rainfall and strong winds, and minimize pests and diseases. However, microclimate condition inside the greenhouse are highly depend on the weather outside the greenhouse. Cultivated plants inside the greenhouse exposed to suboptimal microclimatic conditions tend to encounter various stress factors, often referred to as multiple stressors, and these can detrimentally affect their growth and yield.

During growth phase, plant that are stressed due to prolonged water shortages tend to exhibit higher leaves surface temperatures compared to unstressed ones (Gräf *et al.*, 2021; Shahenshah & Isoda, 2010). Additionally, when plant are stressed due to excessively high light intensity and temperature, their leaves may display signs of burning and necrosis (Dongsansuk *et al.*, 2020). Conversely, exposure to low light intensity can lead to a change in leaves color from green to yellowish (Rezai *et al.*, 2018).

Research on stress characteristics of Tatsoi plant cultivated in urban tropical climates has not been widely conducted. Therefore, this research aims to investigate stress characteristics of Tatsoi plant cultivated using NFT hydroponic within tropical greenhouse environment exposed to various sunlight intensity and watering duration. The results are expected to be initial reference for farmers, specifically in urban areas, to obtain optimum plant yield and fulfill the market demand.

# **Materials and methods**

## **Experimental details and treatments**

**Experimental site and schedule:** The research was conducted within greenhouse located in the Faculty of Agriculture, Gadjah Mada University (7°46'06" S, 110°22'54" E). Totally, 9 m x 1 m hydroponic module used in this experiment was positioned at the center of greenhouse. This study was conducted from August to September 2022 during the dry season.

**Experimental treatments:** The subjects of the research were Tatsoi plant, aged ten days after sowing (DAS), cultivated in NFT hydroponic module. As shown in Figure 1, the Tatsoi plant was subjected to various shading treatments, *i.e.* without shading (A, 0% shade), one sheet of paranet for shading (B, 90% shade), and two sheets of paranet for shading (C, 99% shade).

The duration of nutrient solution watering was varied for each treatment, specifically set at 24, 12, and 6 hours. This automation was set up using a digital timer connected to the pump. In total, 9 distinct treatments were carried out in this research, which included A24, A12, A6, B24, B12, B6, C24, C12, and C6. Each treatment was replicated using eight Tatsoi plant. Consequently, a total of 72 plants were observed in this experiment.

## **Data collection and analysis**

The parameters examined in this research included various aspects of plant morphology and physiology, as well as key data related to hydroponic system and greenhouse microclimate. Furthermore, plant morphology data included leaves area, number of leaves, plant height, root length, and plant weight. The collected physiological data included leaf temperature, as well as photosynthetic, and transpiration rates. Additionally, microclimate data comprised essential environmental factors, such as air temperature, relative humidity, and sunlight intensity within greenhouse. All of the data were collected using non-destructive approaches, except for plant weight and leaf chlorophyll content.

Leaves area was measured using the Easy Leaves Area (ELA) application installed in Android OS mobile phones, while plant height and root length were determined using a ruler manually every two days. Leaves temperature was determined using an infrared thermometer (SK 8700II Sato Keiryoki MFG) three times a day, namely morning (07.30), noon (12.30), and evening (17.30). Furthermore, plant wet weight was measured using a digital scale (i2000 Taffware Digipounds) at harvest.

The rate of photosynthesis and leaves transpiration was assessed using a portable Photosynthesis system (IRGA, LI-6400, LI-COR, Inc., Lincoln, NE, USA) during the peak vegetative period of plant. Data on water levels in nutrient container were collected both manually, using a ruler, and automatically, using the HC-SR04 Ultrasonic sensor mounted at the top of nutrient container. Microclimate data, including air temperature and humidity, were recorded using the DHT22 sensor. In addition, the intensity of sunlight was measured using the GY49 sensor connected to the Arduino UNO R3 microcontroller equipped with a 20x4 LCD and a data logger that records the data once every 1 minute.

# **Results**

## **Microclimate data**

The microclimate conditions within greenhouse exhibited a strong correlation with the ambient climate outside greenhouse. Given that microclimate data inside greenhouse often significantly influences plant growth, monitoring these changes throughout the experiment was necessary. Table 1 shows the average microclimate data during experiment inside the greenhouse.

Sunlight intensity was mitigated by applying paranet to cover the roof and walls of hydroponic module. Specifically, the maximum reduction of sunlight intensity was found in the morning; where A treatment showed 13,060.26 lux, decreased to 1280.88 lux (90.19%) in the B treatment and 144.34 lux (98.89%) in the C treatment. The intensity reduction occurred due to the application of paranet on the hydroponic module preventing the sunlight to intercept.

Furthermore, the intensity reduction slightly affects the temperature and relative humidity change at each treatment. On average, the morning temperatures in the A treatment were higher than those in the B and C treatments. In contrast, during the afternoon and evening, the A treatment exhibited lower temperatures compared to the B and C treatments. The relative humidity levels exhibited an inverse relationship with temperature, such as the temperature increased, the humidity decreased. The highest humidity level (75.08%) was recorded in the evening within the A treatment, coinciding with the lowest temperature (28.51°C). Conversely, the lowest humidity level (60.55%) was observed during the afternoon in the C treatment, accompanied by the highest temperature (32.52°C).

## **Light intensity importance in Tatsoi plant stress**

In order to determine which environmental factors, play the most critical role in Tatsoi plant stress, an ANN method was conducted. This model was further analyzed using the Garson method to determine the important value of each parameter, as shown in Figure 2.

The parameters incorporated as the input layer in this model include the average daily air temperature (I1), relative humidity (I2), and sunlight intensity (I3) during Tatsoi growth period of each treatment in the first round. The model features five hidden layers (H1, H2, H3, H4, H5), with Tatsoi plant leaves canopy area defined as the output (O1) layer. As shown in Figure 2 (a), the input parameter exhibiting the strongest positive correlation with the output is sunlight intensity, denoted by the thickest black line originating from the intensity circle. Further analysis using the Garson method as in Figure 2 (b), showed that the intensity parameter increased the highest importance value for each watering duration, averaging at 0.47. The lowest importance value is achieved by relative humidity at an average of 0.25.

## **Leaves canopy area & leaves number**

Tatsoi is typically consumed for its leaves, hence, monitoring changes in its leaves is essential as stress indicator. The observed changes in Tatsoi leaves over a 27-day after planting (DAP) are shown in Figures 3.

The results show a consistent growth in leaves number and canopy area with time in both experimental rounds. On average, the treatment without shading (A) exhibited the highest rates of change, with 0.66 leaves.day-1 and 15.61 cm2.day-1, respectively. Conversely, the lowest rates were observed in the treatment with two sheets of 75% paranet shading (C), where there were only 0.14 leaves.day-1and 0.21 cm2.day-1 of change. The combination of no shading and a 24-hour watering duration (A24) resulted in the highest leaves count (24 leaves) and canopy area (514.568 cm²) after 27 DAP.

At the 24-hour watering duration, the reduction in sunlight intensity by 87.43% (B24) was found to significantly decrease both leaves count and canopy area to 54.17% (11 leaves) and 95.01% (25.66 cm2), respectively. An even more substantial reduction in sunlight intensity by 98.78% (C24) resulted in a further decrease in leaves count and canopy area to 79.17% (5 leaves) and 99.17% (4.25 cm²), respectively. The pattern of declining leaves count and canopy area was also found in different watering durations (12 and 6 hours). These changes in leaves count and canopy area clearly indicate that Tatsoi plant experienced stress due to insufficient light and water.

The average leaves count and canopy area data for each treatment at harvest time are shown in Figure 4. The results of the two-way ANOVA revealed that sunlight intensity significantly affected plant leaves count and canopy area (P < 0.05). The changes in Tatsoi leaves count and canopy area under conditions of reduced light intensity is shown in Figure 5.

## **Plant height & root length**

Figures 6 show valuable insights into the changes in Tatsoi plant height and root length up to 27 DAP. In addition, these parameters serve as significant indicators of plant stress.

According to Figures 6, growth of plant height and root length show similar trends with leaves count and canopy area. On average, the treatment without shading (A) showed the highest rates of change in plant height and root length of 0.38 cm.day-1 and 0.53 cm.day-11. In contrast, the treatment with two sheets of paranet shading (C) had the lowest rates of change, with plant height and root length increasing by 0.17 cm.day-1 and 0.01 cm/day.

The treatment without shading and a 24-hour watering duration (A24) resulted in the tallest plant and longest roots after 27 DAP, measuring 12.36 cm and 16.15 cm, respectively. The reduction in sunlight intensity had distinct effects on both plant height and root length. When this variable was decreased by 87.43% (B24), it led to a significant reduction in plant height and root length of 32.25% (8.34 cm) and 94.97% (0.813 cm) respectively. A more drastic reduction of 98.78% in sunlight intensity (C24) resulted in a pronounced decrease in plant height and root length to 72.3% (3.43 cm) and 97.52% (0.4 cm).

The observed changes in plant height and root length clearly shows that Tatsoi plant experiences stress due to reduced light. In addition, similar patterns were observed, regardless of the watering durations (12 and 6 hours). Interestingly, under the lowest light intensity (C), the plant of the less watering duration (6 hours) showed the highest plant height.

The average plant height and root length data at harvest time for each treatment were further analyzed using a two-way ANOVA, as shown in Figure 7. The result shows that sunlight intensity significantly influenced plant height and root length (P < 0.05).

## **Biomass yield**

The changes in leaves count, canopy area, plant height, and root length tend to directly affect plant biomass yield at the harvesting time. Therefore, it is essential to closely observe the changes in plant weight. The harvested fresh weight of Tatsoi plant of the experiment are shown in Figure 8.

Tatsoi plant weight is highly affected by sunlight reduction at different watering durations, as shown in Figure 8. In general, weight reduction reaches approximately 97.55% and 99.28% with sunlight intensity reductions of 87.43% (B) and 98.78% (C), respectively. These weight fluctuations clearly indicate that Tatsoi plant experienced stress due to reduced light. This pattern is consistent across all watering durations of the experiment. Furthermore, the results of the two-way ANOVA showed that sunlight intensity significantly affected plant weight (P < 0.05).

## **Photosynthesis & transpiration rate**

Plant growth generally relies on photosynthesis, which depends on the following factors light, transpiration, and water availability. Therefore, observing changes in photosynthesis and transpiration rate can serve as crucial indicators of plant stress. The data on the photosynthesis and transpiration rates of Tatsoi plant are shown in Figure 9.

According to Figure 9, the photosynthesis and transpiration rates decreased to 13.93% and 76.10% due to a reduction of 87.43% (B) in sunlight intensity. This reduction was more pronounced when sunlight intensity was further reduced by 98.78% (C), with a decrease of 17.33% and 87.53% in photosynthesis and transpiration.

The results of the two-way ANOVA test (Figure 9) shows that light intensity have a significant impact on plant photosynthesis and transpiration (P < 0.05). In addition, the reduction in sunlight intensity has a more pronounced effect on transpiration compared to photosynthesis.

## **Plant water consumption & leaves temperature**

In this experiment, water consumption (dV) was assessed by monitoring evapotranspiration, which is determined based on water level reduction (dH) in nutrient solution reservoir. The highest daily water consumption and water level reduction occurred in the treatment without shading, combine with a 24-hour watering duration (A24), *i.e.* 648 ml/day and 0.54 cm/day, respectively as shown in Figure 10. When sunlight intensity was reduced by 87.43% (B) and 98.78% (C), water consumption decreased by approximately 29.05% and 18.57%, respectively, as evidenced by reduced water level reduction of 32.62% and 23.93%.

Leaves temperature change is highly correlated with air inside greenhouse. In plant cultivation, alterations in air temperature have a significant effect on the processes of evaporation and transpiration, collectively referred to as evapotranspiration. However, these fluctuations directly impact plant water consumption. As a result, monitoring changes in both leaves temperature and water consumption can serve as reliable indicators of plant stress. Data on Tatsoi leaves temperature alongside air temperature inside greenhouse, covering a span of 27 DAP are shown in Figure 10.

According to the experimental result, the most significant gap between Tatsoi leaves and air temperature occurred in the morning (Figure 11 (a)) within treatment without shading under 24 hours watering duration (A24), measuring approximately 5.03°C. Conversely, the lowest gap of 2.44°C was recorded in the evening (Figure 11 (c)), within the treatment comprising an 87.43% reduction in sunlight intensity and 24 hours watering duration (B24). The result from ANOVA, as in Figure 11 (d), statistically showed no significant difference in the temperature gap between Tatsoi leaves and air for each treatment.

## **Correlation analysis in Tatsoi plant stress**

A correlogram analysis was conducted to determine the correlation between stress source and the observed parameter in this research as shown in Figures 12. The results revealed a positive correlation between sunlight intensity with several plant morphological and physiological characteristics.

The intensity correlation value (r) achieved approximately 0.95 for leaves canopy, leaves number, plant height, weight, and root length, as shown in Figure 12. Conversely, relative humidity and air temperature exhibited lesser correlation values of 0.29 and -0.372, respectively. These results are consistent with the correlation values between sunlight intensity, photosynthesis and transpiration rates, which were also significantly high, at 0.88 on average. For relative humidity and temperature, the average correlation values were 0.28 and -0.345, respectively. Leaves temperature was found to have the smallest correlation value (< 0.5) of all parameters, similar to that of air. The correlation value for the difference between leaves and air temperature (dT) showed a negative moderate-type relationship for most parameters, approximately 0.46. There were exceptions to this trend, including relative humidity (-0.71), air temperature (0.74), leaves number (-0.68), and plant height (-0.78).

# **Discussion**

This experiment investigated stress characteristics of Tatsoi plant resulting from variations in sunlight intensity. The results clearly proved that this plant is more severely impacted by reductions in sunlight intensity compared to water deficits. This observation was based on the fundamental role of sunlight in plant metabolism, specifically in the process of photosynthesis. In addition, this process converts water (H2O) and carbon dioxide (CO2) into glucose (C6H12O6) with sunlight serving as a photon energy source. Sunlight plays an essential role in supporting two primary rounds of photosynthesis, namely light-dependent reaction (LDR) and light-independent reaction (LIR), occurring in the thylakoids, and stroma (Yustiningsih, 2019).

Based on Table 1, the sunlight intensity inside greenhouse fluctuates and is non-steady. This phenomenon is due to the changing angle of the sun direction towards the earth. The aforementioned phenomenon is known as the Daily Apparent Motion of the Sun, which causes its position to change from east to west every day (Myori *et al.*, 2019). As the angle of the sun gradually increases, a corresponding increase in sunlight intensity was observed, which peaks in the afternoon. Subsequently, as the day progresses towards evening, the sunlight intensity gradually decreases.

In a previous research by (Kume *et al.*, 2018), it was reported that direct and diffuse solar radiation, referred to as PARdir and PARdiff, respectively, exhibited peak spectral photon flux densities (SPFD) at approximately 680 nm and 460 nm during the afternoon. However, in this experiment, it was observed that the average sunlight intensity in the treatment without shading during the afternoon was lower than in the morning. This discrepancy could be attributed to the presence of clouds in the sky. Urban *et al.* (2014), stated that cloud cover enhances the ratio of diffuse to direct solar radiation and reduce temperature and Vapor Pressure Deficit (VPD). In the experiment, when shading was applied in both the B and C treatments, an effect similar to that of cloud cover was observed. This resulted in reduced sunlight intensity and lower temperature.

The relative humidity inside greenhouse showed a slight increase, which can be attributed to the decrease in temperature. This observation is consistent with the results by Zou *et al.* (2017), who also reported similar trends in temperature and air humidity changes within greenhouse. Shamshiri *et al.* (2018) stated that greenhouse humidity is influenced by several factors, including the condensation on the covering, vapor losses through ventilation, and the delicate balance between plant transpiration and soil evapotranspiration. At the same time, temperature is the critical factor best used to determine reference evapotranspiration (Valipour, 2015).

According to the importance analysis result obtained using the Garson method alongside the AAN method (Figure 2), it was proven that the temperature and relative humidity inside greenhouse have a relatively minor impact on Tatsoi plant, compared to the insufficient sunlight intensity. This observation is in line with the results of Putra *et al.* (2022), that the importance value of light intensity was the highest (0.463), followed by humidity (0.26) in affecting the porous area of chili plant leaves.

Insufficient sunlight intensity is a major source of stress for Tatsoi plant, and it significantly affects plant morphology. This stress is indicated by the considerable reduction of leaves number and canopy area (Figures 3, 4, 5), plant height and root length (Figures 6, 7), and even the fresh weight at the harvest period (Figure 8). These results are consistent with prior research that observed decreased sage leaves area under 57% shade (Kumar *et al.*, 2013), reduced sage leaves number under 50% and 75% shade (Rezai *et al.*, 2018), as well as diminished height and weight of red firespike under 45% and 65% shade (Rezazadeh *et al.*, 2018).

Stress characteristics observed in the experiment arose from disruptions in plant physiology, as evident from the decreased rates of photosynthesis and transpiration. This result is in line with previous research findings that have shown a consistent trend. Reduced light intensity has been linked to a decrease in the maximum photosynthetic rate (Dong *et al.*, 2014; Baird *et al.*, 2017). Additionally, transpiration is more sensitive to the effects of light stress compared to photosynthesis. Putra *et al.* (2023), reported that under low-light conditions (80% shade), stomatal and pore areas were significantly smaller, indicating stomatal closure and reduced transpiration. This observation is in line with the results shown in Figure 10, where plant water consumption and water level reduction tended to be lower in the low-light (B & C) treatment compared to that of the full sunlight (A). Additionally, in water stress condition (12 and 6 hours watering duration), the plant water consumption were lower than in the full watering duration (24 hours). This indicate that the plant’s undergo an adaptation mechanism to keep the water inside the plant cell and avoid dehydration.

Another interesting result in this research was that the difference between leaves and air temperatures (Figure 11) was prone to be directly proportional to plant water consumption (evapotranspiration) (Figure 10). This result is in line with the findings of Kibler *et al.* (2023), which emphasized the role of evapotranspiration in regulating leaf temperature, and controlling energy flux at the surface. Furthermore, it is consistent with the results of Zhang *et al.* (2019), who previously reported that changes in leaves temperature can indirectly indicate alterations in its water content and transpiration rates. Leaves temperature difference observed in this research is in line with the results of Fukai & Mitchell (2022), who reported that the temperature of the canopy tends to decrease within the range of 3 to 5 °C due to the evaporative cooling effect.

The largest disparity between leaves and air temperatures was observed under the shortest watering duration (6 hours) across all light treatment, and it inversely correlates with plant water consumption. This counterintuitive trend indicates that Tatsoi plant experiencing water stress tend to exhibit reduced evapotranspiration. According to Putra *et al.* (2022b), lower stomatal index implies that plant under water stress typically reduce transpiration. Perera *et al.* (2020), stated that plants under water stress tend to decrease stomatal conductance, a response closely related to the size, density, and distribution of stomata on the leaf surfaces (Fanourakis *et al.*, 2015). Consequently, leaves with lower conductance exhibit reduced rates of transpiration and photosynthesis.

The correlogram analysis in Figure 12 shows that sunlight intensity has a positive and significant correlation with Tatsoi plant morphology (leaves canopy, and number, plant height, and weight, including root length) and physiology (transpiration). As previously discussed, sunlight is the primary energy source driving photosynthesis in plant. The result showed that under extreme sunlight deficiency, statistically, the photosynthesis rate in Tatsoi plant is not significantly affected (P > 0.05). Therefore, this research suggested that the substantial reduction in Tatsoi plant morphology under sunlight stress is primarily due to a significant decrease in transpiration rates, likely caused by reduced stomatal diffusive resistances. This result is in line with the research by Miskin *et al.* (1972), who reported statistically different stomatal diffusive resistances and transpiration rates among barley plant while result no significant difference in photosynthesis.

# **Conclusion**

In conclusion, insufficient sunlight had a significant impact on tatsoi plant growth. This research revealed that extreme sunlight deficit significantly impacted the morphology and physiology of tatsoi plant cultivated inside tropical greenhouse under water stress. It was reported that sunlight stress had significant effect on plant growth, primarily due to reduction in the transpiration rate. An inverse correlation reportedly existed between leaves-air temperature difference and Tatsoi plant water consumption. Future research should explore the possibility of early detection of Tatsoi plant stress indicators using changes in leaves-air temperature difference.

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# **Author contributions**

DAS, LS, N, and M planned the experiments; DAS conducted the field work; DAS statistically analyzed the data and made illustrations; DAS drafted the original manuscript; LS, N, and M interpret the analyzed data and reviewed the manuscript.

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**Table 1:** Average microclimate data inside greenhouse during the experiment

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Parameter | Treatment | Morning  (07.00 – 10.00) | Afternoon  (11.00 – 14.00) | Evening  (15.00 – 18.00) |
| Sunlight intensity (lux) | A | 13,060.26 | 11,693.68 | 2,169.03 |
| B | 1280.88 | 1323.63 | 301.47 |
| C | 144.34 | 143.51 | 29.41 |
| Temperature (°C) | A | 30.58 | 32.40 | 28.51 |
| B | 29.12 | 32.35 | 28.80 |
| C | 29.65 | 32.52 | 29.19 |
| Relative humidity (%) | A | 68.48 | 63.42 | 75.08 |
| B | 69.40 | 60.78 | 70.84 |
| C | 69.22 | 60.55 | 70.61 |

*Note*. A = 0% shade (without shading); B = 90% shade, (shading with one sheet of paranet); C = 99% shade (shading with two sheets of paranet).

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| --- | --- |
|  | |
| (a) | |
|  |  |
| (b) | (c) |
| **Fig. 1:** Top view of the experimental design (a), three dimensional view of one hydroponic module design (b), picture of the hydroponic module inside the greenhouse under various shading treatments (c)  *Note.* a = nutrient distribution pipe, b = drainage pipe, c = nutrient reservoir. A = 0% shade (without shading); B = 90% shade, (shading with one sheet of paranet); C = 99% shade (shading with two sheets of paranet). | |

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |

**Fig. 2:** ANN architecture (a) and Garson method plot of Tatsoi leaves canopy area (b) under various watering duration

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| --- | --- |
|  |  |
| (a) | (b) |
| **Fig. 3:** Leaves number (a) and canopy area (b) change of Tatsoi plant under various shading treatments   |  |  |  | | --- | --- | --- | |  | | | |  |  | |  |  | |  | |  |  |  | | --- | --- | |  |  | | (a) | (b) | | **Fig. 4:***.* Average leaves number (a) and canopy area (b) at various shading after harvested (27 DAP)    **Fig. 5:***.* Tatsoi plant’s leaves number and canopy change at various shading treatments  *Note.* The red square area is 2 cm x 2 cm, which is a calibrator for leaves Easy Area application | | | |

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| --- | --- | --- | --- | --- |
|  | | |  | |
| (a) | | | (b) | |
| **Fig. 6:** Plant height (a) and root length (b) change of Tatsoi plant at various shading treatments | | | | |
|  | | | | |
|  |  | |
| (a) | (b) | |
| **Fig. 7:** Average plant height (a) and root length (b) at various shading after harvested (27 DAP) | | |

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| **Fig. 8:** Average plant weight at various shading after 27 DAP |

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |
| **Fig. 9:** Average photosynthesis (a) and transpiration (b) rate at various shading treatments | |



**Fig. 10:**Plant water consumption (dV) and water level reduction (dH) at various shading treatments

|  |  |
| --- | --- |
|  |  |
| (a) | (b) |
|  |  |
| (c) | (d) |

**Fig. 11:** Average Tatsoi leaves temperature and air temperature inside greenhouse at (a) in the morning, (b) in the afternoon, (c) in the evening; (d) the average temperature gap (dT) between Tatsoi leaves and air temperature inside greenhouse at various shading treatments.

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| **Fig. 12:** Correlogram plot of the parameter at various shading  *Note*. \*, \*\*, \*\*\* Statistically significant at P < 0.05, 0.01, and 0.001; r = Correlation coefficient. The color intensity of the circle indicates the strength of the correlation between parameters. Non-star means not-statistically significant at P > 0.05. Blue and red indicate positive and negative correlations |