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by Afik Hardanto

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Biomass growth of red spinach in plant-factory system under three kinds of LED light sources

Ardiansyah*, A Hardanto and E Sumarni

Department of Agricultural Engineering, Jendral Soedirman University, Purwokerto, Indonesia

Corresponding author: ard@unsoed.ac.id

Abstract. The research is trying to observe the effect of different light sources on red spinach (*Amaranthus Tricolor L*) plant. Plant-factories were installed and divided into three compartments. Each compartment was given three light sources: Red-Blue LED (R-B), Multi-Color LED (M-C), and White LED (W). The energy of each light sources R-B, M-C, and W were 192 Watt, 92 Watt, and 8 Watt, respectively. The research took place on March 2018 in the Agriculture Technology Laboratory, Jenderal Soedirman University, Indonesia. The growth parameters measured were plant height, biomass, and number of leaves. Results showed that there was significant difference of growth parameters of treatment R-B compared to treatment M-C, and W. Shierary Model were used to study the mechanism of growth parameter difference. The model used the input of radiation energy of light sources that were affected by leaves development, that called the intercepted radiation. The result of the model showed that the intercepted radiation influenced the growth parameters. Treatment R-B, which generates commonly used light wave for photosynthetic, caused better plant growth. The influence of the heat emerged from the light sources were seemed to create better micro-climate for photosynthesis.

1. Introduction

Several studies showed the relationships between climatic factors and plant growth. These factors, for example, influence plant physiology [1], canopy resistance [2] or water stress [3]. *Plant-factory* or controlled crop chamber are intensive cultivation methods carried out in chamber, in which all climate factors can be adjusted and managed. It can improve yields and be efficient in land use [4-6]. Research shows that there is an acceleration of growth and an increase in biomass if light, temperature, humidity, and CO_2concentrations are controlled at a certain level [7].

Plant's micro-climate arrangement is possible to manage; because it relates to parameters that can be controlled technically using mechanical or electrical devices. Information about good growth conditions can be obtained by experiments using various controlled parameters. Automatic control is the keyword to get the optimum parameters (in experiments), also to control the plant environment at optimum conditions (in production). Biomass production is affected by photosynthetic activity, which is influenced by various factors. Automatic control of these optimum factors allows maximum biomass growth. Thus, the micro-climate arrangement can be optimized to grow optimum biomass in production scale.

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The need to predict biomass growth based on micro-climate condition is the key for optimizing micro-climate parameter in *Plant-factory*. The biomass predictors, such as canopy resistance, water stress, carbon dioxide assimilation can be used to estimate biomass. However, to measure or calculate those predictors are difficult to do. It needs complex measurement and sophisticated instrument. Consequently, the requirement to use simple parameter to predict biomass growth is urgent. Light or radiation can be used as predictor. The measurement is simple, and the instrument is easy to buy or to assemble. This research will use different kind of LED light sources (treatments) and observe the biomass growth under the treatments.

The purposes of this research are firstly, observing radiation intercepted by the plant canopy under three types of artificial light, secondly, measuring changes in growth parameters and biomass under three types of artificial light, and thirdly, applying biomass modeling to predict biomass growth and development, by incorporating intercepted light as input variable.

2. Materials and methods

2.1. Experiment setting

The type of plant-factory used in this research is a complete-control type [6], where all the factor such as light, temperature, and humidity is electrically controlled. Measurement variables include measurement of a) external production factors (input: light, humidity, temperature) and b) plant growth response (plant height, number of leaves, and biomass development). Figure 1 shows the experiment setting.

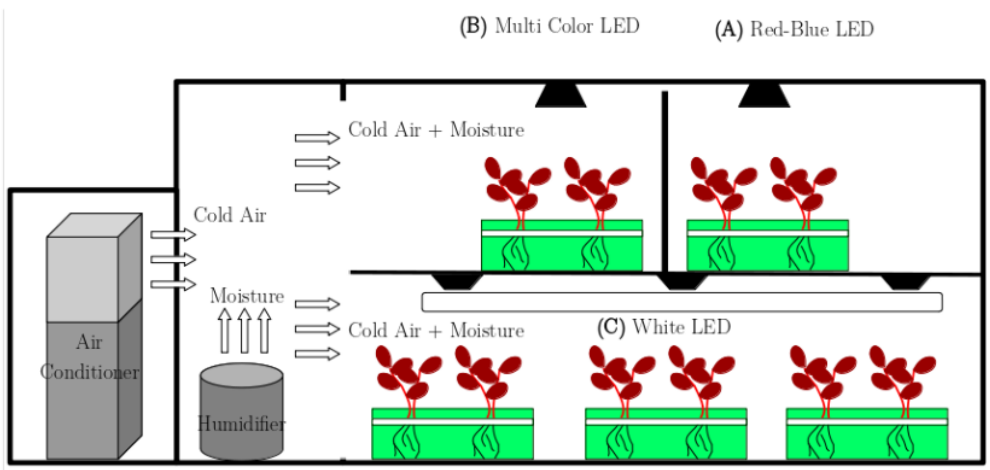

Figure 1. Experiment Setting

2.2. Biomass modelling

Concept applied for biomass modelling is microclimate condition that stated by Thermal Unit (TU). The main concept is that the growth phase is moving from existing phase to next phase after the TU is fulfilled [8–10]. After the concept of TU, the biomass growth described by the conversion of photosynthetic radiation into biomass. The model called Shierary Rice Model [11]. Conversion from radiation into biomass controlled by coefficient called radiation efficiency (ϵ). The equation is appeared in Equation (1).

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$$dW = \epsilon . Q_{intercept} \tag{1}$$

where dW is total biomass production (g), ϵ= 1.65 gMJ^{-1} is radiation efficiency of converting light into biomass.

Intercepted radiation ($Q_{intercept}$, $MJ.m^{-2}$) is calculated using equation (2) :

$$Q_{interception} = (1 - \tau). Q_s \tag{2}$$

where τ ($\tau = e^{-k.LAI}$ or $\tau = \frac{Q_{trans}}{Q_s}$) is fraction of light transmitted below the canopy. Q_s is daily incoming radiation ($MJ.m^{-2}$).

Partition of whole biomass growth (1) into their plant-organs (root, stem, leaves) is using equation (3(

$$dW_x = \eta_x dW - R_g - R_m \tag{3}$$

dW_x is biomass development in plant-organs (x) (gm^{-2}), η_x= allocation of biomass for certain organs (root, straw, leaves, or grains). Growth respiration (R_g, gm^{-2}) and maintenance respiration (R_m, gm^{-2}) [12] is the energy used by the plant. They're using result of photosynthesis. They were calculated using Equation (4) and Equation (5):

$$R_g = k_g . \eta_x . dW. \tag{4}$$

$$R_m = k_m . W_x . Q_{10} \tag{5}$$

where k_g is growth respiration coeficcient = 0.0108, dan k_m= maintenance respiration ceoficcient = 0.13. W_x= biomass of pant-organ (g), Q_{10}[13] were calculated as $Q_{10} = \left(\frac{K_2}{K_1}\right)^{\frac{10}{(T_2 - T_1)}}$ which accordingly can be stated as:

$$Q_{10} = 2^{\frac{10}{(T-20)}} \tag{6}$$

Graphically, the concept of modeling plant biomass growth is shown in the Figure 2. The variables calculated in equations (1) to (6) are listed in the nodes in the chart. The lines connecting one node to another node show the transformation of the calculation to the variable shown in the arrow.

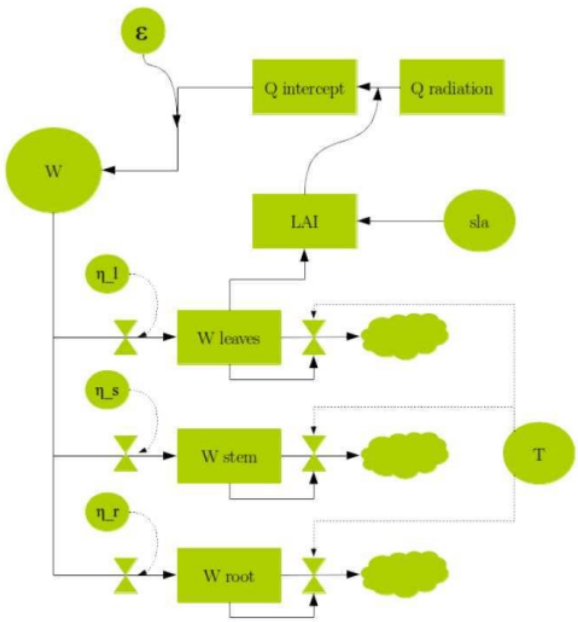

Figure 2. Model Calculation in Graphical Form

3. Results and discussion

3.1. Plant growth and development

Acceptance of radiation intercepted by leaves becomes material for photosynthesis. Energy will be converted into biomass and allocated to organs in the plant. The growth of organs can be used as an indicator of biomass growth. The concept of biomass growth can be seen in Figure 3.

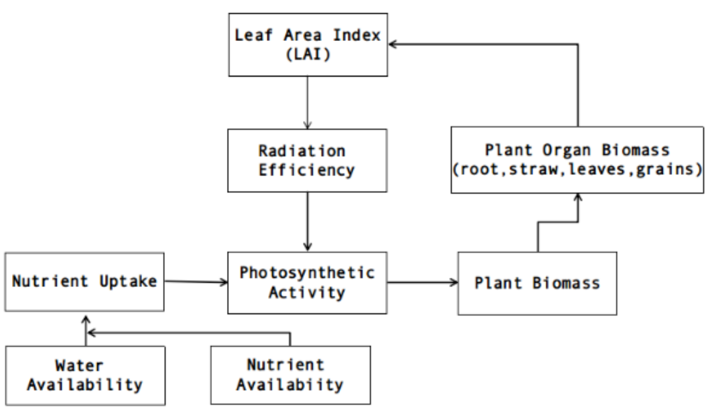

Figure 3. Biomass Growth Concept [19]

Time series data on plant height, number of leaves, root length, wet weight and dry weight are presented in graphical form. The data includes measurements on day 0 (after planting) until day 27. The use of photosynthetic lamps to replace sunlight needs to consider the spectrum of light used.

Figure 4 shows the growth of spinach plants with Red-Blue LED lighting (192 Watts) and Multi-Color LED (92 Watts). The best growth is seen in plants with Red-Blue LED. When compared with White LED (8 Watts) with color temperatures of 6500 K, then both types of Red-Blue and Multi-Color LED show much better results.

The development of leaf number and plant height during the planting period also indicates that Red-Blue LEDs provide better growth than Multi-Color LED. White LEDs provide significantly less yield than Red-Blue LED and Multi-Color LED (Figure 5 and Figure 6).

The highest growth of leaf numbers is shown in the order of Red-Blue light, followed by Multi-Color light, and White light. This growth pattern is exponential as any other growth pattern [14–16] . On the 15th day, plants with Blue-Red LED lighting showed a rapid increase compared to plants with Multi-Color LED lighting.

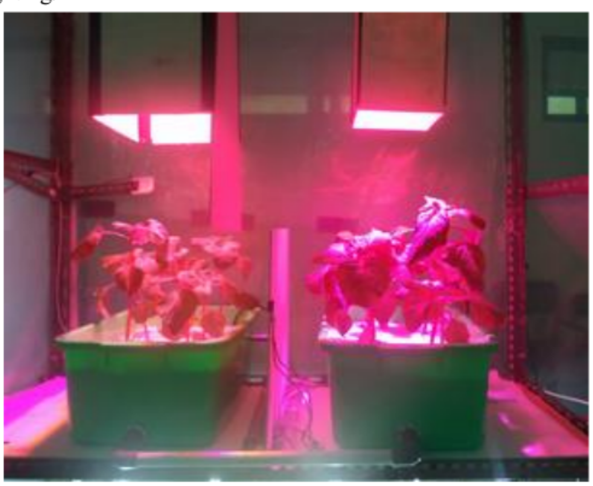

Figure 4. Growth of Spinach on Multi-Color LED Lights (92 Watts) and Red-Blue LEDs (192 Watts)

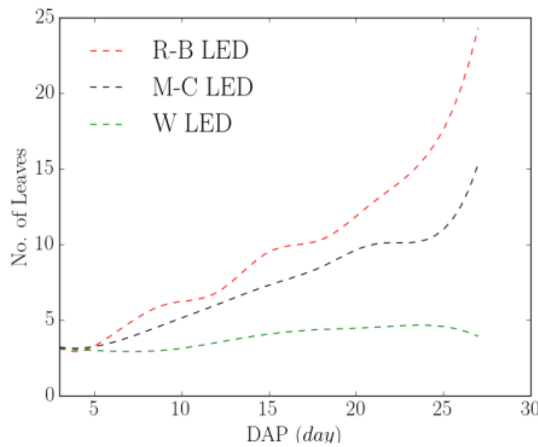

Figure 5. Development of Amounts of Spinach Leaves on 3 Types of Lighting

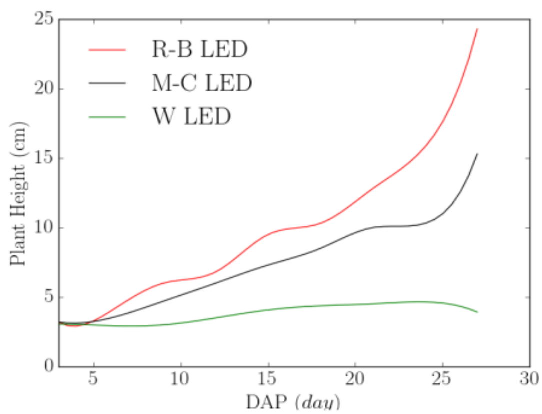

Figure 6. High Development of Spinach Plants in 3 Types of Lighting

3.2. Biomass development

Root length is the implication of biomass growth. The flow of photosynthesis results, one of which will be used to increase root mass. The Red-Blue LED treatment gave the best results, with a root length of 38.42 cm, followed by Multi-Color LEDs (30.83 cm) and White LEDs (3.10 cm) (Figure 7)

Wet and dry weight in the Red-Blue LED treatment was higher (29.08 grams and 1.09 grams) compared to Multi-Color LEDs (14.90 grams and 0.55 grams) and White LEDs (0.13 grams and nearly 0 gram). This parameter still shows that the Red-Blue LED gives the best results (Figure 8). Of the various growth parameters used, it is known that Red-Blue LEDs provide the best results compared to Multi-Color LEDs and White LEDs. The R-B LED said to increase the ratio of a/b chlorophyll [17]

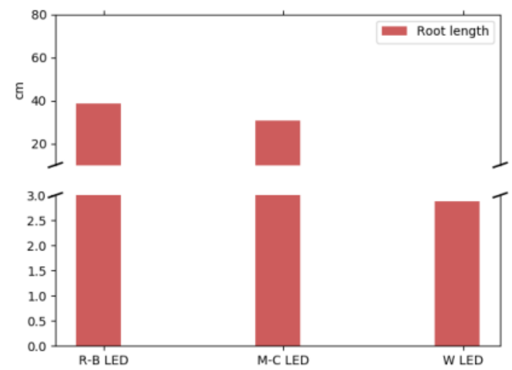

Figure 7. Development of Spinach Root Length in 3 Types of Lighting

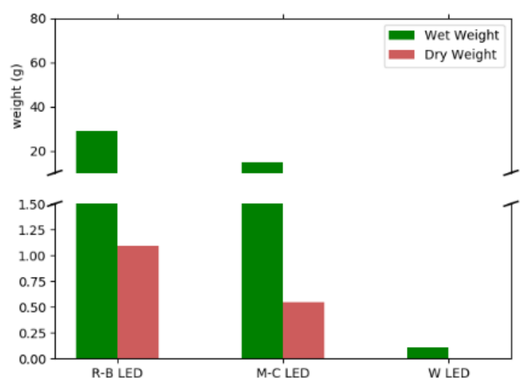

Figure 8. Wet weight and dry weight in 3 types of lighting

The experimental results show that the difference in growth is strongly influenced by the artificial light used. The growth and development of biomass depends not only on the type of light, but also on the interception of light by plant canopy [18]. This is illustrated in Figure 3, where there is an interdependence between LAI and radiation absorption efficiency. The greater the intercepted light in the plant canopy, the greater the photosynthetic activity which results in an increase in plant biomass.

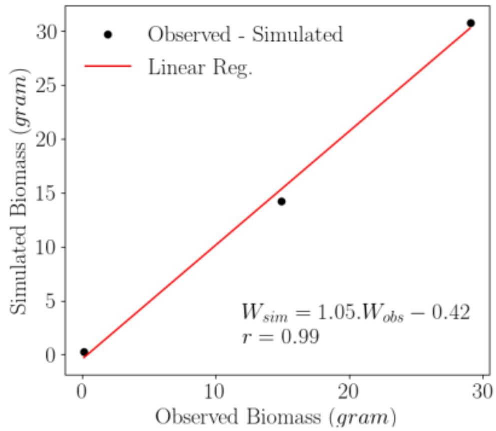

Figure 9. Observed and Simulated Biomass

The simulation using the biomass growth model shows the correspondence between the observed results and the simulation results with a correlation coefficient of 0.99 (Figure 9). These results indicate that the use of a biomass model with the main parameters of radiation or artificial lighting is sufficient to describe the actual growth process. The conversion factor from light to biomass is an important factor that must be calibrated for other crops. In micro-climatic conditions that meet the requirements for plant growth, photosynthesis will occur optimally depending on the amount of lighting provided. When the micro-climate does not support, for example, in terms of air temperature, then growth is stunted, providing light suitable for growth will not increase the biomass produced by growth. In the Thermal Unit (TU) concept, the plant will not move to the next growth phase when TU is not achieved.

Much higher light intensity causes more energy use for photosynthesis. The temperature in the Red-Blue LED is relatively higher than the other two treatments. Temperature will stimulate metabolism and stomatal opening. Another influential factor is humidity. At higher air temperatures, air humidity tends to be low in conditions without a source of evaporation. The plants use hydroponic nutrient planting media covered by Styrofoam, so there is no additional evaporation into the micro air. As a low RH will increase the Vapor Pressure Deficit (D) and drive an increase in transpiration. The nutrients carried to the leaves by the transpiration process will meet with sufficient light intensity from the Red-Blue LED.

4. Conclusion

The biomass model used could predict the biomass growth of the experiment because the simulated biomass matched the observed biomass. Both biomass model result and experiment result showed the 3 artificial lighting has difference in radiation absorption efficiency (ϵ). R-B LED provided highest treatment in all parameter (plant height, number of leaves, root length, and biomass). It means that the intercepted radiation was used for photosynthesis effectively.

The radiation of R-B LED was used the wavelength of red and blue light which is enable for leaves to absorb and use it for photosynthetic. The energy of the LED is also play role to provide enough micro-climate factor for photosynthesis to occur.

Overall, the approach used by the model which is using light interception as main parameter for biomass growth is appropriate. As long as the micro-climate is favorable, light interception greatly determines the increase in plant biomass. In a plant-factory system, proper radiation is required using R-B LED for optimal growth.

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