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Optimized LED-Integrated Agricultural Facilities for Adjusting the Growth of Water Bamboo (*Zizania latifolia*)

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Abstract: We investigated a light emitting diode (LED) lighting system applied to a water bamboo field during winter season at night, and the results indicated that this lighting system can prevent the stunting of water bamboo leaves and further assist its growth. Compared with previous LED systems, in which the LED bulbs were placed directly above water bamboo leaves, our LED lighting system presents the benefit of easy handling during harvest. To prevent the inhomogeneous coverage of LED light patterns, a new design of LED lenses was also incorporated.

Keywords: water bamboo; stunting; light emitting diode (LED)

1. Introduction

Water bamboo (*Zizania latifolia*) is considered a delicacy in Taiwan. Almost 90% yield of water bamboo is obtained from Puli township, Nantou. In 1999, basal stalk rot attacked water bamboo, leading to leaf stunting. Dr. Jin-Hsing Huang [1–3] investigated the causes of this disease. Finally, he cured stunting without using chemicals. According to him, water bamboo that grew near a ridge did not stunt. By observing the environmental conditions, he reported that street lights built near the ridge provided light during the night, which further helped leaves grow and prevented stunting. He taught farmers to use the lighting equipment for increasing the yield of water bamboo from one to three times per year. Supplying light to water bamboo at night during the winter season (between September and December), when the sunlight is not sufficient for the growth of young water bamboo leaves, provides high yields. The farmers used a high-pressure sodium (HPS) lamp as the lighting equipment. Compared with other lighting system, the HPS lamp is cheap and bright [4,5] and has been used for plant growth [6]; however, it consumes more electricity and has a short lasting time. Due to the rapid development of inexpensive light-emitting diodes (LEDs) with energy-saving properties [7], Dr. Huang et al. replaced HPS lamps with an LED lighting system in 2010 at the Industrial Technology

Research Institute (ITRI) and proved that the use of blue and red LED bulbs prevented the stunting of water bamboo leaves. However, the complexity and high cost of LED lighting systems hindered their application as a technology for stunting prevention. During the past decade, LEDs have been widely used in agriculture [8–19]. In 2017, we attempted to resolve the construction complexity issue of LED systems by using various LED lighting systems. ITRI teams employed red and blue LED bulbs, and each light bulb was placed directly above the water bamboo leaves (Figure 1a). The net-like design was required to have a strong grip on both sides of the field to provide adequate strength to support the LED light bulbs. Another major drawback of this design was that it made farming difficult when the LED lighting system was not being used during the harvest period. Our design used an LED array module, and the LED lighting system was constructed near the ridge (Figure 1b), similar to the street light. Indoor and field experiments were conducted for two years to prove that our LED lighting system could not only save energy, but also prevent the stunting disease. Moreover, we optimized our LED array design to solve the inhomogeneous coverage of the LED lights. The construction cost of our design was 50% of that of ITRI teams. Furthermore, compared with HPS lamps, our LED lighting system saved 90% of electricity expenses (Table 1). The new design can also provide easy farming when the LED lighting system is not being used during the harvest period of water bamboo.

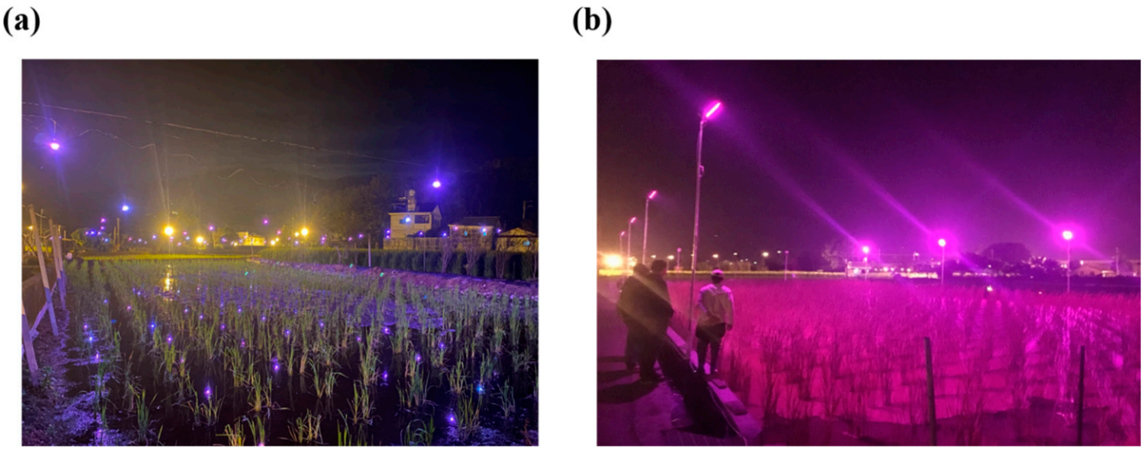

Figure 1. (**a**) A light emitting diode (LED) lamp-integrated agriculture facility constructed by the Industrial Technology Research Institute (ITRI) team in Taiwan. Each LED lamp is hanging above the water bamboo leaves. (**b**) An LED array module lighting lamp, with blue and red LED bulbs constructed near the ridge in an array format.

Table 1. Comparison between high-pressure sodium (HPS) and light emitting diode lamp.

	Lasting Time	**Power**	**Electricity Fee**	**Price (US dollar)**
HPS lamp	2–3 years	400 W	1	60
LED lamp	10 years	60 W	1/10	80

2. Experimental

LED modules were purchased from the original equipment manufacturer (OEM) company, which fabricated an LED lamp with different lenses and power setup for our designs and requirements. Figure 2a illustrates the LED array used in this study, which comprises three rows. Each row uses a different type of lens to improve the homogeneity of LED light exposure area. We used the same type of lens with a 90° lens design (Figure 2a). Each LED module of 60 W (each row of 20 W) with blue and red LEDs at the ratio of 1:6 was mounted on a zinc-coated stainless steel tube with a design of three sections where the tube height was adjusted to obtain the homogeneity of the LED light exposure area. The typical tube height was approximately 4 m. A field of 53.8 × 28.5 m^2 was used for growing water bamboo. We placed eight LED modules on the field and divided the field into 36 observation areas to assess the growth of water bamboo leaves corresponding to LED light exposure at night. Figure 2b presents the schematic of the position of the LEDs, area of the water bamboo field, and 36 separated observation areas.

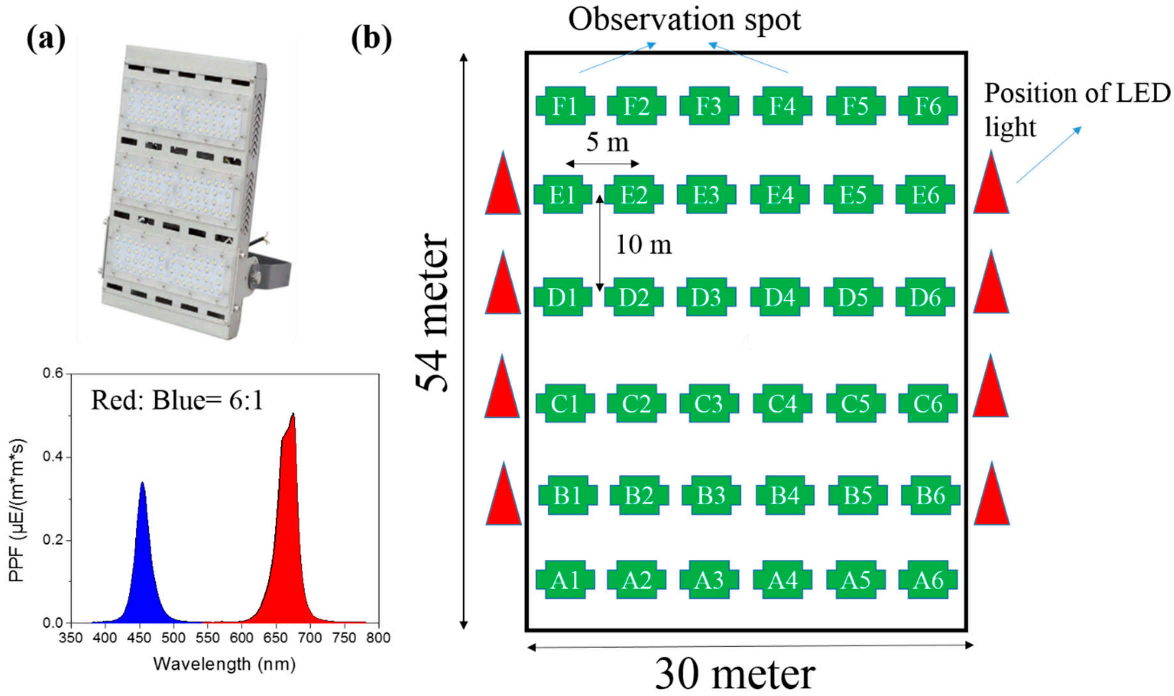

Figure 2. (**a**) LED lamp module and blue (λ_{peak} = 460 nm) and red (λ_{peak} = 670 nm) LED light spectrum. (**b**) Schematic of the area and observation section of the water bamboo field.

To resolve the problem of the inhomogeneous coverage of LED lighting systems, we used different LED array lamp modules by changing the curvature of the LED lens design. Figure 3 presents the design of the new LED module and portable spectrometer (Rainbow-Light, HSM-02) measurements of blue and red light intensity obtained from the LED module.

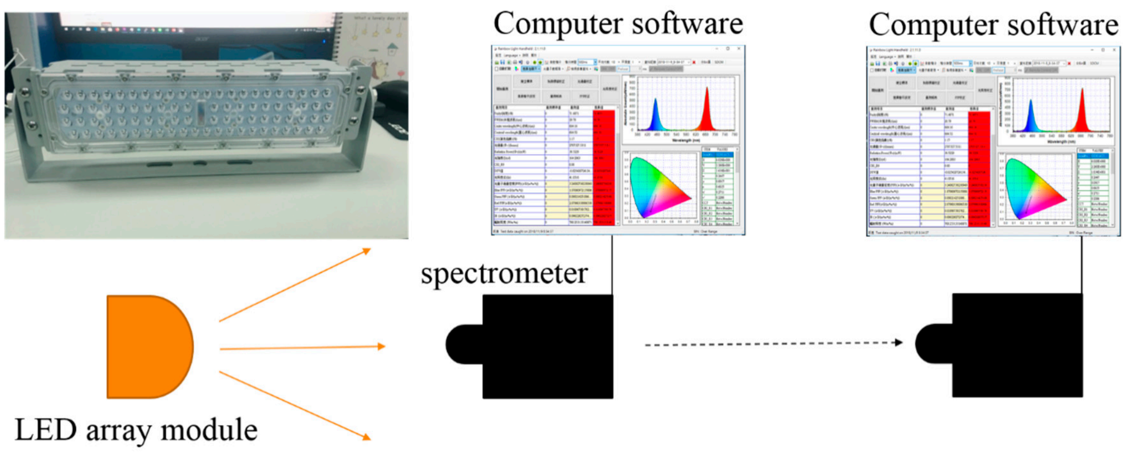

Figure 3. New design of the LED module with different arrangements of red and blue LED bulbs, and the schematic of measurement of the red and blue light intensity corresponding to the distance. The ratio of red to blue LED bulbs inside the LED modules was 6:1.

3. Results and Discussion

Figure 4 illustrates the used LED lighting system, which is similar to the design of the street light, and presents an aerial photograph of the water bamboo field with the LED light switched on. Obvious color difference between the LED (pink area) and HPS (yellow) light exposure area can be observed. The farmers previously used two HPS lamps to prevent stunting disease, and we used eight LED lamps in the same field. Moreover, according to the farmers, the use of HPS lamp can indirectly damage the frog habitat and possibly other species present near the field because of its strong and shining light. The possible adverse effect of LEDs on the environment is under investigation.

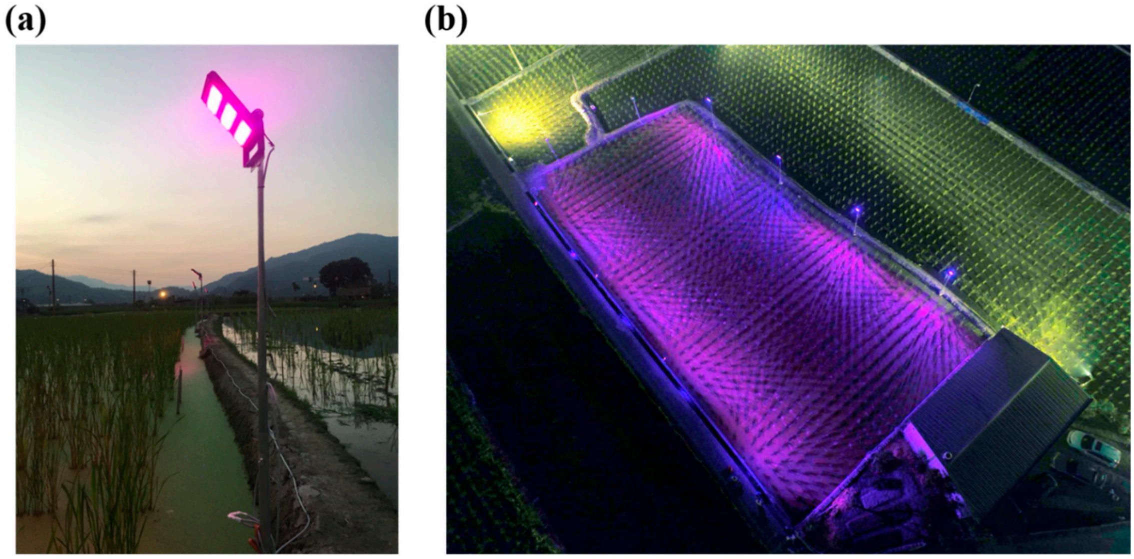

Figure 4. (**a**) Zoom-in image of LED lamp constructed near the ridge. (**b**) Water bamboo field with eight LED lamps switched on. The HPS lamps were used in the other field. Inhomogeneity of light coverage was observed in both fields. The ratio of red to blue LED bulbs inside the LED modules was 6: 1.

To evaluate the relationship between light intensity and growth of bamboo leaves, we measured the height of water bamboo leaves every week. Figure 5a presents the growth of water bamboo leaves measured after exposure to our LED lighting system for two weeks during the night. The exposure time during the night was approximately 10 hours. Several observation spots, namely A1, A5, A6, C1, D1, E1, F1, C6, D6, E6, and F6, near the ridge exhibited a slow growth rate. The coverage measurement of LEDs was completed using a spectrometer, and the results are shown in Figure 5b. Here, we used the unit of lux to represent the measuring of luminous flux (lum) per unit area (1 lux = 1 lum/m^2). Different colors indicate different light intensity, and the corner area indicates weak light intensity. In the field, 80% of water bamboo received sufficient LED light exposure (the area corresponding to the value >5). However, the area with the value <5 might possibly experience stunting. To resolve the problem of the inhomogeneous coverage of the LED light, we used two LED lens designs, one was a 136 × 78 LED lens design and the other was a 60 × 60 LED lens design. The numbers represent the distribution patterns of the LED light.

Figure 6a illustrates the distribution pattern of the 136 × 78 lens design. Figure 6b presents the real measurement of light distribution in the direction vertical to the LED light module. The light intensity decreased with an increase in the distance. Studies have reported that the blue and red light exhibit the major wavelengths for the growth of plants. The use of the correct equipment to measure the LED light intensity is essential for determining the sufficient amount of the artificial light, especially LED light, for plant growth. Figure 6c presents the vertical distance dependent on the blue and red LED intensity in the unit of photosynthetic photon flux density (PPFD). Furthermore, the PPFD value measured using the blue and red LED light decreased with an increase in the distance and reached a value of 0.2 PPFD for the blue LED light at a vertical distance of 8 m. Figure 6d presents the distance-dependent light intensity in the PPFD unit measured in the horizontal direction. The light intensity decreased with increasing distance; however, in the horizontal direction, the coverage of LED light increased with an increase in the distance. The horizontal coverage changed from 5 to 7 m when the vertical distance changed from 3 to 6 m, that is, the major reason for low light coverage near the ridge is provided in Figure 3.

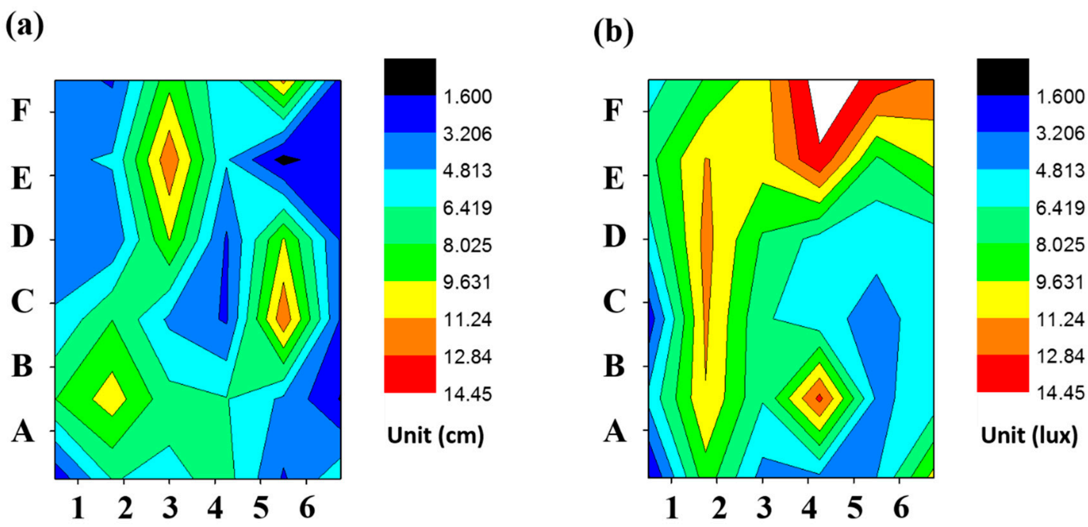

Figure 5. 2D distribution of (**a**) growth of water bamboo leaves and (**b**) light intensity measured in the field of water bamboo leaves.

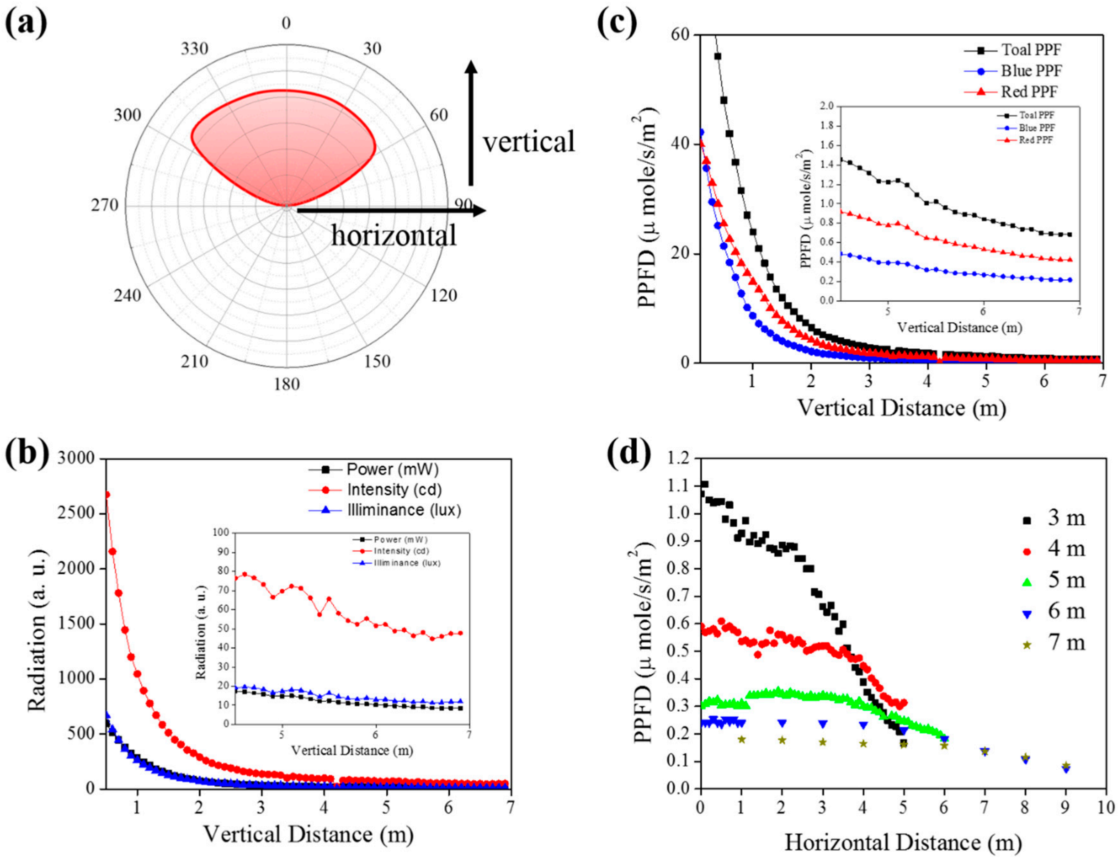

Figure 6. (**a**) Distribution pattern of the 136 × 78 lens design of the LED module. (**b**) Total LED intensity containing blue and red light dependent on the measured distance. (**c**) LED light intensity (in photosynthetic photon flux density, PPFD, unit) dependent on the vertical distance. (**d**) Blue LED light intensity (in PPFD unit) dependent on the horizontal distance.

Studies [1–3] have indicated the minimum total PPFD value for preventing water bamboo from stunting as 0.2. Our LED light system with an LED array module of the 136 × 78 lens design provided inhomogeneous coverage exactly below the system. Therefore, different LED patterns must be used to prevent inhomogeneous light distribution. Figure 7 presents the distribution pattern of the 60 × 60 LED lens design and corresponding measurements of the PPFD values of blue and red LEDs, which were dependent on the vertical and horizontal distance. For the vertical distance, the intensity suddenly decreased with an increase in the distance; however, for the horizontal distance measured at the vertical distance of >5 m, the intensity decreased slowly with an increase in the distance. This finding suggests that the 60 × 60 LED lens design can serve as a lighting system positioned between two 136 × 78 LED modules. Figure 8 illustrates the final proposed design.

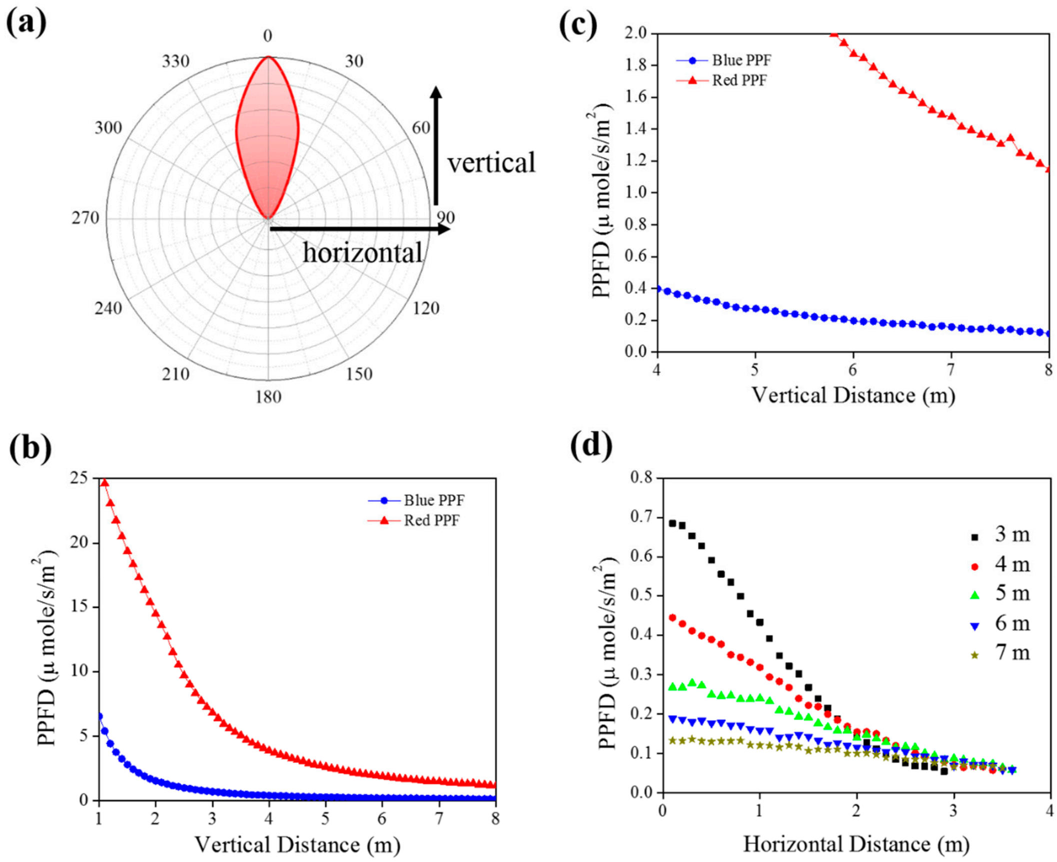

Figure 7. (**a**) Distribution pattern of the 60 × 60 lens design of the LED module. (**b**) Blue and red LED light intensity (in PPFD unit) dependent on the vertical distance. (**c**) Magnified scale from (**b**) in the vertical distance in 4 to 8 m. (**d**) Blue LED light intensity (in PPFD unit) dependent on the horizontal distance at different vertical distance between the position of LED lamp and measured positions.

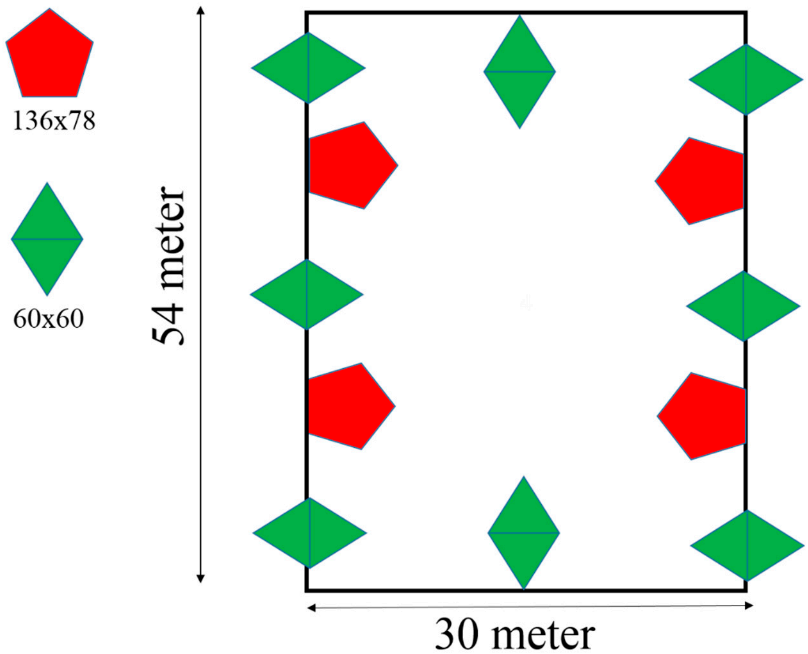

Figure 8. Proposed setup of the LED construction with two light distribution patterns.

4. Conclusions

We conducted a 2-year study to establish a new design of a LED lighting construction setup in the water bamboo field to prevent stunting. The initial LED construction of an eight LED array module with a 136 × 78 LED light distribution pattern could provide sufficient light to prevent stunting. To solve the problem of the inhomogeneous coverage of LED light, we performed the indoor measurement of light intensity dependent on the distance and obtained a suitable arrangement of LED light modules by incorporating a 60 × 60 LED light distribution pattern. Our findings can not only be used as a reference for a water bamboo field, where a light supply is required at night during winter, but can also be applied to other farming fields such as growing graph, dragon fruit, and shaky.

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Conflicts of Interest: The authors declare no conflict of interest.

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