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Metabolic Variations in Grass *C. dactylon* and Selection of Optimal LEDs for the Horticulture Luminaire Using LM Algorithm

R. SOWMYA[1], S. NARASIMHAN[2], CIJI PEARL KURIAN[1], (Senior Member, IEEE), AND R. SRIVIDYA[1]

[1]Department of Electrical and Electronics Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, India
[2]Department of Biotechnology Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal 576104, India

Corresponding author: Ciji Pearl Kurian (ciji.pearl@manipal.edu)

ABSTRACT Healing of various ailments using herbal medicines is gaining much interest. Plants classified as grasses, specifically *Cynodon dactylon*, are an appreciated group of monocots used in many herbal remedies. In this work, *C. dactylon*, is grown naturally and also under market available LED Luminaires with different lighting conditions. Until 2010, most of the plants are grown under conventional lamps that are not spectrally tunable. *Cynodon dactylon*, the grass is grown under two different light spectrum, two light levels and three photoperiods (9hours, 12 hours, 15 hours) to extend our experiential knowledge. The biomass accumulation was the highest when grown under a lower RB ratio-12-hour-163μmol/s, and phenolic content was the highest at 92.8 mg/g wt Gallic Acid Equivalents under combined light source at 15-hour photoperiod. A spectrally tunable LED light source with an optimal quantity of LEDs saves cost, space and energy. Considering the light parameters from the light sources used for growing *C. dactylon*, Levenberg–Marquardt (LM) algorithm is implemented to select an optimal LED quantity that composes the light source. The algorithm simulates the given target spectrum with minimum fitness error. The method applied to model LEDs, its validation against the practical LED spectrum, spectrum matching and computation of Luminous flux, Photosynthetic Photon Flux and efficacy are also presented. Many spectrums are simulated to validate the performance of the algorithm. A solution of optimal LEDs for three Photosynthetic Photon Flux (PPF) levels with LEDs is derived, and it is observed that the number of LEDs increased with PPF.

INDEX TERMS LED lamps, photosynthetic active radiation, photosynthetic photon efficiency, spectral power density, applied optimization, LM algorithm.

I. INTRODUCTION

The process of converting light energy into chemical energy used as fuel by plants is called photosynthesis. It needs three components mainly – water, light and carbon dioxide. Light is one of the vital parameters that aid the growth and development of a plant. It is also responsible for organogenesis, the formation and accumulation of secondary metabolites. Sunlight is the only light source available naturally, abundantly, freely on earth used by plants for photosynthesis. Changes in the atmospheric conditions, seasons, time of day, and geographic location also affect the earth's light. Hence, there is a need for an artificial light source. Light spectrums, light intensities and photoperiods affect the morphogenesis, biomass, physiological metabolism, nutrition, growth and development. The artificial light source also promotes year-round crop production [1]. In the early 1970s, the McCree curve developed by McCree measured photosynthetic efficiency as a function of wavelength for many plants, which indicated that the plant uses the green spectrum for photosynthesis but at lower efficiency than the red spectrum [2]. But in practical applications, evaluating the total plant growth is more relevant than focusing only on photosynthesis. For few crops, fresh weight is higher without green, and for others, green does not affect fresh weight [3], [4].

The presence/absence of green spectrum was found on the plant fresh weight in various lettuce crops and medicinal cannabis. The efficacy of red LEDs is higher than blue and green. However, a small amount of green, approximately 6%,

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is preferred for good colour recognition and higher energy efficiency than the sun-like spectrum [5]. The most likely large number of the photoreceptors are present in the Red and Blue region of the visible spectrum. These LEDs have peak wavelengths in the range 620 nm, 670 nm and 440 nm with a bandwidth of ±15 nm that are the most commonly used wavelengths in the market available grow lights [2]–[4]. The light requirement varies from plant species to species. A few plants may require a few more wavelengths other than red and blue [6], [7].

The medicinal value of plants lies in their chemical composition, which often influences biological activities. *C. dactylon* (Family: Poaceae, Bermuda grass) is an odourless monocot light green grass. The plant reproduces vegetatively from the stolons. It is one of the promising herbs used in Ayurveda medicine preparation. It is spicy, bitter, fragrant and appetizer [8]. Its consumption addresses Vitamin A problems and age-related muscular issues. In the present scenario, World Health Organization and American Diabetes Association have also accepted that people with diabetes have more complications than the general population when infected with COVID-19 [10], [11]. Reduction in hyperglycaemia and hyperlipidaemia was observed after administration of the grass extract into diabetic rats [12]–[14]. Plant phenolic content is considered the best natural antioxidant to prevent several illnesses such as cancer, diabetes, inflammatory problems [8]. Phenolic compounds are synthesized by plants to survive stress conditions and play a vital role in accumulating phenolic compounds [15], [16].

The conventional sources were used in horticulture until a decade ago. These sources were replaced by LED fixtures which are much more promising due to less heat, long life and low energy consumption. Also, their spectrum is not tunable because of which they partially aid the growth and development of plants [17]. Hence, it has been estimated that 50% of greenhouses are expected to replace or install LED light sources by 2025. This technology change also adds high crop value because they can be grown during the off-season. Due to these reasons, it has been estimated that horticulture's compound annual growth rate may increase 26-30% by 2025 [18].

Radiometric and photometric quantities of light sources are only used for human vision applications. Since the horticulture standards are still not published, a few photometric quantities are still being used in horticulture. Color Rendering Index (CRI) of grow light is not relevant as the plant growth may or may not require all wavelengths [7]. Instead of Correlated Color Temperature (CCT), the Red to Blue (RB) ratio is the deciding parameter for biomass production, plant growth rate, and fruit production in horticulture light sources. The range for RB ratio varies from 0.5 to 19. However, the choice of RB ratio depends on the plant and plant parameters of concern. The RB ratio of 2 to 5 is considered apt for most vegetative and medicinal plant growth [19], [20]. Most photoreceptors mainly use the Red and Blue (RB) spectrum. RB LEDs have the highest efficacy in terms of the photosynthetic photon emitted per unit watt electricity. Hence, most of the available horticulture Light Emitting Diode (LED) luminaires are manufactured with RB LEDs. There are reports of many vegetative and ornamental species of plants grown successfully under these lamps.

The proposed work was done for more than a year to analyze the effect of lighting parameters on the growth and phenolic content of *C. dactylon* and then develop a simulation model to achieve the grow light spectrum with optimal LEDs. The plant selected for the study has significant medicinal properties, established pharmacological activities [8] and are potential species for indoor cultivation under artificial lighting systems. The results indicated that the light quantity and light quality need to be varied based on the parameter of interest. Hence, a simulation model to obtain the user-defined light spectrum with the optimal number of LEDs has been developed. In this simulation model, any user-defined light spectrum is also referred to as target spectrum, and PPF with RB ratio in the range 2 to 5 can be given as input to compute the optimal number of LEDs required to fit the target spectrum minimum fitness error. Hence, the LM algorithm is used in this application. In science and engineering, many mono or multi-objective problems have been addressed using optimization algorithms. The deterministic algorithms are used to find the local minima or maxima. Levenberg–Marquardt (LM) algorithm adapts to the parameter iteratively, reducing the fitness error between function and data points at every wavelength. The LM algorithm, the standard technique to solve the non-linear least square problem has been used in this work [21], [22]. Figure 1 shows all the processes involved in the work.

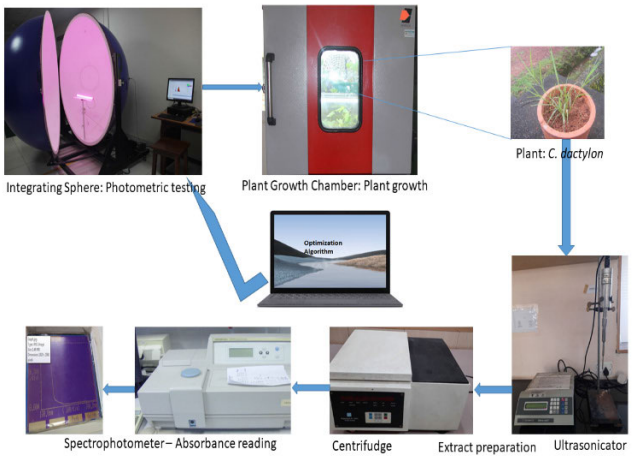

FIGURE 1. Pictorial representation of process involved.

The work starts with the purchase and photometric testing of market-available LED fixtures. If a good RB ratio and PPF are obtained, it is further placed inside the plant growth chamber (PGC) and the grass for growth. The grass is grown under the light source for 30 days under various light quality and quantity, photoperiod. The plant is watered daily. On the 31st day, the plant is washed thoroughly using tap water.

The fresh weight and chlorophyll content are measured and noted. The plant is shade dried for a day, and the dry weight is noted. The extract is prepared using the Ultrasonicator, centrifuged to separate particles from the extract and quantified using the spectrophotometer's absorbance value against the prepared standard.

II. DESIGN PARAMETERS FOR SIMULATION

A. PHOTOSYNTHETIC PHOTON FLUX (PPF)

In the process of plant photosynthesis, they absorb light in the form of a photon. PPF is a measure of the number of photons emitted by the light source. PPF is computed using "(1),"

$$\Phi_p\left(\frac{\mu mol}{s}\right) = 8.35 * 10^{-3} \sum_{\lambda=400}^{700} \lambda * \Phi(\lambda) * \Delta\lambda \quad (1)$$

where $\boldsymbol{\lambda}$ is wavelength from 400nm to 700nm, $\boldsymbol{\Delta\lambda}$ is the wavelength interval 1nm, and $\Phi(\boldsymbol{\lambda})$ is the light source spectrum in the visible range [23].

B. LUMINOUS FLUX

Presently, the horticulture LEDs in the entire photosynthetic active radiation (PAR) are unavailable. Hence, the general lighting LEDs are taken to fill the gap. To match each LED source's spectral power density (SPD) and luminous flux, we need to determine the total luminous flux of individual LED [24]. The luminous flux is calculated using "(2),"

$$\Phi_v(lm) = k \int \Phi(\lambda) * V(\lambda) * d\lambda \quad (2)$$

k is constant 683 lm/W at 555 nm used to convert radiant flux in Watts to luminous flux in lumens. V($\boldsymbol{\lambda}$) is the Jud-Vos modified photopic luminosity function.

C. PHOTOSYNTHETIC PHOTON EFFICACY (PPE)

PPE defines the efficiency of a horticulture lighting system to convert electrical energy to PAR photons. Higher the PPE value, efficient the lighting system [7]. PPE is calculated using "(3),"

$$Efficacy\left(\frac{\mu mol}{J}\right) = \frac{PPF(\frac{\mu mol}{s})}{Inputpower(W)} \quad (3)$$

D. ROOT MEAN SQUARE ERROR (RMSE)

The relative fitness error e($\boldsymbol{\lambda}$) of the test spectrum at each wavelength $\boldsymbol{\lambda}$ is calculated in steps of 1nm in the PAR spectrum using "(4),"

$$e(\boldsymbol{\lambda}) = \mathbf{1} - \frac{\boldsymbol{SS}(\boldsymbol{\lambda})}{\boldsymbol{TS}(\boldsymbol{\lambda})}; \quad \mathbf{400}\boldsymbol{nm} < \boldsymbol{\lambda} \leq \mathbf{700}\boldsymbol{nm} \quad (4)$$

SS($\boldsymbol{\lambda}$) is the SPD of the simulated spectrum, and TS($\boldsymbol{\lambda}$) is the SPD of the target spectrum. The total error is calculated as the average of Root Mean Square (RMS) of all individual errors using "(5) " and expressed in percentage [29].

$$E = \sqrt{\frac{\sum_\lambda e(\lambda)^2}{\lambda_{end} - \lambda_{start} + 1}} \quad (5)$$

where $\boldsymbol{\lambda}_{start}$ and $\boldsymbol{\lambda}_{end}$ are the start and end of wavelength in PAR.

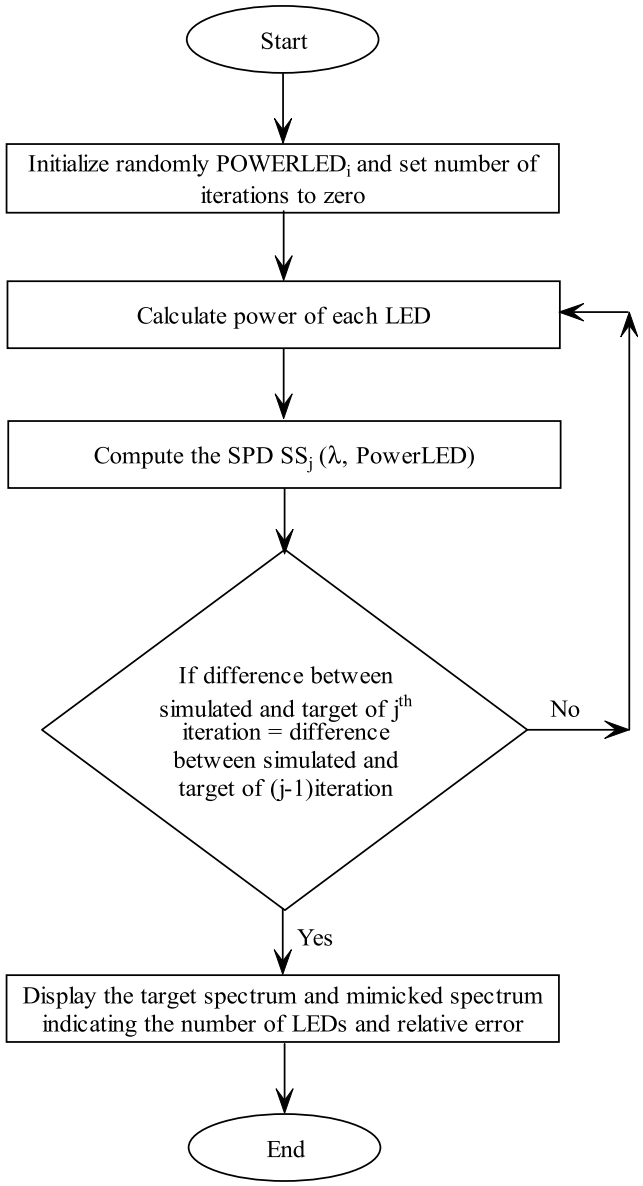

FIGURE 2. LM algorithm for horticulture.

III. LM ALGORITHM FOR HORTICULTURE

Levenberg first introduced the LM algorithm in 1944 and was perfected by Marquardt in 1963. This method is a combination of Steepest descent and the Gauss-Newton method. When the current solution is far from the correct solution steepest descent method is applied, and when they are close Gauss-Newton method is applied [21], [22]. This method determines the power per LED PowerLED$_i$, where i = 1, 2, . . . , the number of LEDs that needs to be applied to achieve the target spectrum. Let SPDLED$_i$($\boldsymbol{\lambda}$) define the SPD of the modelled LEDs [24], [26], [27]. The implementation of the LM algorithm given in Figure 2 is described below [21], [22].

Step 1: Select the initial value for each PowerLED$_i$

Step 2: Calculate the jth value of the PowerLED where j represents the number of iterations starting with j = 0

a. Calculate the difference between the simulated (I_{SS}) and the target spectrum (I_{TS}) for each wavelength using "(6),"

$$R(\lambda) = I_{SS}\left(\lambda, PowerLED^{j-1}\right) - I_{TS}(\lambda) \quad (6)$$

b. Calculate Jacobian matrix using "(7),"

$$J^{j-1}_{I_{SS}(\lambda)}\left(PowerLED^{j-1}\right) = \left[\frac{\partial I_{SS}(\lambda, PowerLED^{j-1})}{\partial PowerLED^{j-1}}\right] \quad (7)$$

c. j^{th} value of PowerLED is represented as

$$PowerLED^{j} = PowerLED^{j-1} - \left[\left(J^T J + diag\left(J^T J\right)\alpha\right)^{-1} J^T R\right] \quad (8)$$

Step 3: If

$$\sum_{\lambda=400}^{700}\left|I_{ss}\left(\lambda, PowerLED^{j}\right) - I_{TS}(\lambda)\right| = \sum_{\lambda=400}^{700}\left|I_{ss}\left(\lambda, PowerLED^{j-1}\right) - I_{TS}(\lambda)\right| \quad (9)$$

Then $PowerLED^{j}$ comprises the final value of the power coefficients i.e

$$I_{SS}(\lambda, PowerLED) = \sum_{400}^{700} PowerLED_i SPDLED_i(\lambda) \quad (10)$$

The coefficient α, which is the damping factor of the LM is empirically determined as 0.01. The LM algorithm adapts the parameters iteratively, reducing the squared sum of the fitness error at every wavelength with each iteration.

IV. METHODOLOGY

A. PLANT MATERIAL AND METHOD

1) PLANT MATERIAL AND GROWTH CONDITIONS

C. dactylon grass was grown in the controllable PGC. The growth conditions are under light quantities – two levels, photoperiods- 9-hour, 12-hour and 15-hour, growth period - 30 days, temperature −25±1°C, relative humidity – 70%, water regularly. The PGC measures 600 mm * 600 mm * 900 mm (L * W * H) and has two racks. The plant and PGC are as shown in Figure 3.

2) CHEMICALS AND REAGENTS

Only methanol and water used were of gradient grade. Whatman brand 0.45 μm nylon filter was used for filtration.

3) INSTRUMENTATION

All weighing was done on an electronic balance (Shimadzu AUW 120D). PGC used for plant growth was procured from Isotech Technology Pvt Ltd. The Labsphere integrating sphere (Labsphere, North Sutton, NH, US) was used to measure the light source parameters.

FIGURE 3. Plant growth chamber (PGC).

4) QUANTITATIVE ANALYSIS

a: ESTIMATION OF CHLOROPHYLL

Quantitative analysis of chlorophyll a and b were done by using the 1 g fresh, finely cut leaves ground in 80% acetone repeatedly until the residue is colourless using mortar and pestle. The sample was then centrifuged at 5000 rpm for 10 min, and the residue was filtered. The volume was made to 100 ml using 80% acetone [28].

b: ESTIMATION OF TOTAL PHENOL CONTENT

For the analysis of biomass, *C. dactylon* plant samples were cut into small pieces, shade dried for one day, and the dry weight biomass was noted. The dried plant biomass was finely powdered using mortar. The extract was prepared using the dried plant biomass, methanol and Ultrasonicator equipment operated at room temperature for 20 minutes with 30 seconds on time and off time 5 seconds. The extract was further centrifuged at 5000 rpm for 20 minutes and filtered.

Folin–Ciocalteu method was used to quantify total phenolic in the methanol grass extract using Gallic acid as the standard [23]. Calibration curve plotted using this method gave the regression equation y = 0.0694x-0.0765; R^2 = 0.9874 [29]. Plants grown under greenhouse conditions served as controls; the plants selected for the study were of the same age. Gallic acid equivalent (GAE) in mg per gram dry weight was used to express total phenolic content.

5) STATISTICAL ANALYSIS

Experiments were carried out in seven replications each. Statistical analysis (mean ± standard error) was performed using Duncan's multiple range tests using the Statistical Packages for Social Sciences (SPSS) software for $P < 0.05$.

B. LED LIGHT SOURCES

The 401-500 nm was considered blue region, 501-600 nm as green, and 601-700 nm as a red [5], [7]. The normalized SPD of the light sources used for experimentation is shown in Figure 4. The measurement of PPF was repeated three

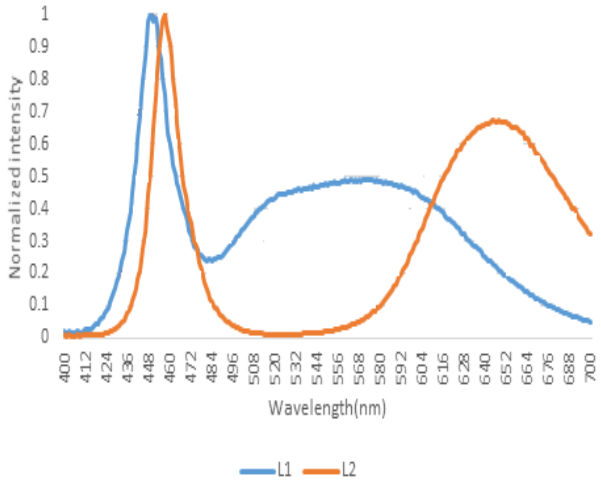

FIGURE 4. SPDs of LED light sources.

TABLE 1. Light source characteristics.

Characteristics	General LED light Source (L1)	Horticulture LED light Source (L2)
Power Consumption/lamp (W)	9	10
Number of fixtures	8	8
Total Power Consumption (W)	72	80
Total Photosynthetic Active Radiation (PAR) output (µmol/s)-Level I3	103.25 µmol/s ± 0.003	78.55 µmol/s ± 0.09
Total Photosynthetic Active Radiation (PAR) output (µmol/s)-Level I4	163.12 µmol/s ± 0.086	117.77 µmol/s ± 0.086
RB ratio	2.66:1	4.5:1
Colour Rendering Index (CRI)	80	-17
Correlated Color Temperature (CCT) (K)	6000K	1674K

times and expressed as mean ± standard error. The PPF indicates the total PPF of eight light sources.

Light source 3 (L3): To know the effect of RB ratio and the final growth conditions, which play a critical role in growth, development and accumulating plant attributes, the third light source used was a combination of the two light sources. For the first fifteen days, the plants were grown under L2 LED light source, and for the next fifteen days, the plants were grown under L1 LED light source.

C. LED MODELLING

The daylight spectra, which are the plants' apt spectra to grow, contain all wavelengths in the PAR region. However, the availability of horticulture LEDs in the market is mainly in the red and blue spectrum. Hence, this crucial requirement for plant growth cannot be met by considering red and blue horticulture LEDs. Therefore, when choosing the spectra for the plant, many horticulture and general lighting LEDs in the PAR range were chosen. Full width half maximum $\boldsymbol{\Delta\lambda}_{0.5}$ in nm, peak wavelength $\boldsymbol{\lambda}_o$ in nm, PPF Φ_p in μmol/s for horticulture LEDs or Φ_e(watt) – total radiant power or Φ_v (lumen) – luminous flux for chosen available LEDs were noted from the datasheet. The LEDs were modelled using the Gaussian model to get the normalized spectrum [24], [25] using "(11)," [29], [30].

$$\Phi\left(\lambda, \Delta\lambda_{0.5}, \lambda_0\right) = \frac{g\left(\lambda, \Delta\lambda_{0.5}, \lambda_0\right) + 2 * g^5((\lambda, \Delta\lambda_{0.5}, \lambda_0)}{3} \tag{11}$$

where g is the Gaussian distribution given by "(12),"

$$g = e^{-\left[\frac{\lambda-\lambda_0}{\Delta\lambda_{0.5}}\right]^2} \tag{12}$$

This normalized SPD is multiplied with the conversion factor F to obtain the simulated SPD [24] using "(13),"

$$\Phi_{e,v} = \Phi(\boldsymbol{\lambda}, \boldsymbol{\Delta\lambda}_{0.5}, \boldsymbol{\lambda}_o)^*\mathrm{F} \tag{13}$$

where F represents the ratio of total radiant power or luminous flux or PPF and integral of the normalized spectrum [23]. If the PPF is known, F can be calculated using "(14),"

$$F = \frac{\Phi_p}{8.359 * 10^{-3} * \sum_{k=400}^{700} \lambda * \Phi(\lambda, \Delta\lambda_{0.5}, \lambda_0) * \Delta\lambda} \tag{14}$$

If only the total radiant power is known, F can be calculated using "(15),"

$$F = \frac{\Phi_e}{\int \Phi\left(\lambda, \Delta\lambda_{0.5}, \lambda_0\right) * d\lambda} \tag{15}$$

If only the luminous flux is known, F can be calculated [24] using "(16),"

$$F = \frac{\Phi_v}{k \int \Phi\left(\lambda, \Delta\lambda_{0.5}, \lambda_0\right) * V\left(\lambda\right) * d\lambda} \tag{16}$$

Initially, the SPD of the LED light source was considered as the target spectrum. For mimicking the target spectrum, the selection of optimal LEDs is required. General lighting LED and horticulture LED database was created in the spectral range 400 nm to 700 nm. It is difficult to fill the "green gap" between 520 nm –600 nm and 675 nm-690 nm. The reason for this gap has been described in [7], [26], [27], [30]. The green gap can be covered with phosphor-coated LEDs. However, it's hard to fill the 675nm -690 nm because only high power LED indicators are manufactured. The LEDs were procured and characterized to obtain the actual models. The validation of the simulated model with the practical model produced satisfactory results. LEDs were mounted on the integrating sphere, and real SPD with 1 nm resolution was obtained. Figure 5 and Figure 6 show the SPD of modelled LED compared with SPD of real LED at 657 nm and 450 nm. Figure 7 shows the SPD of 71 LEDs with different peak wavelengths in the database. The range 400 nm-540 nm is sufficiently covered with general and horticulture LEDs. The range 540 nm-620 nm was covered with white and phosphor-coated LEDs. Due to the unavailability of LEDs in the market with peak wavelengths at 640 nm and 675 nm-700 nm, a wide gap was found in Figure 7. Phosphor coated LEDs extend

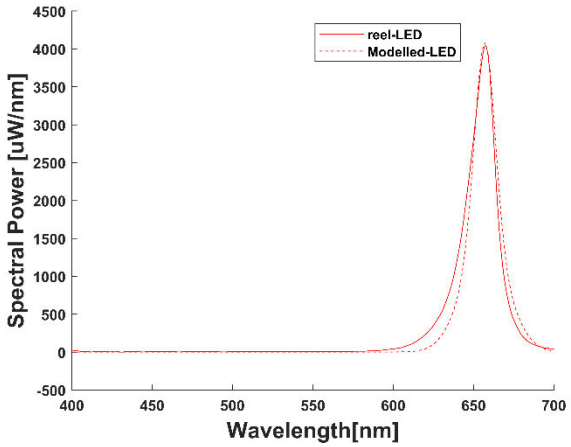

FIGURE 5. Comparison of SPD of real LED and LED model with a peak at 657nm.

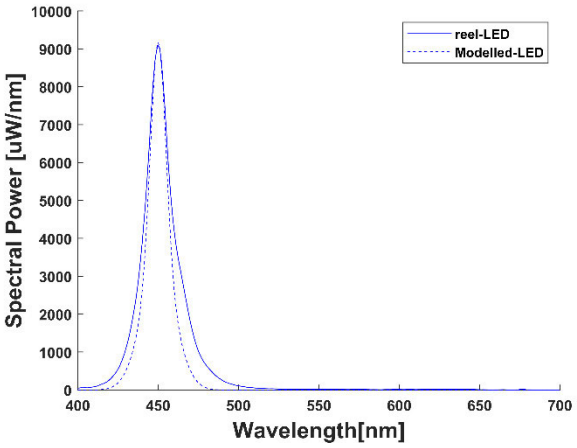

FIGURE 6. Comparison of SPD of actual LED and LED model with the peak at 450nm.

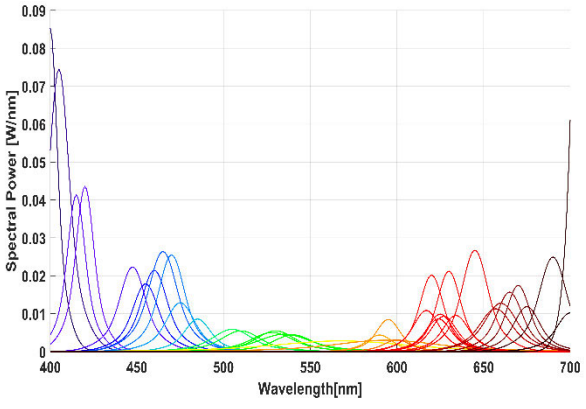

FIGURE 7. Individual SPD of 71 LEDs with different peaks.

their peak maximum up to 660 nm; hence these gaps cannot be covered.

Initially, the spectrum from LED grow lights, as shown in Figure 4, was practically obtained by mounting them on an integrating sphere considered the target spectrum. A tunable LED light source that mimics the input spectrums with optimal LEDs is to be designed. The selected LEDs must produce a PPF in the range of 30 μmol/s-170 μmol/s and PPE greater than 2 μmol/W. This range of PPF was chosen considering the grow light intensity requirement for most of the plants.

V. RESULTS

The results in Figure 8 indicate the plant's growth in terms of biomass under various lighting conditions. Biomass was maximum for the plant *C. dactylon* when grown under a high RB ratio, 12-hours photoperiod, 117μmol/s.

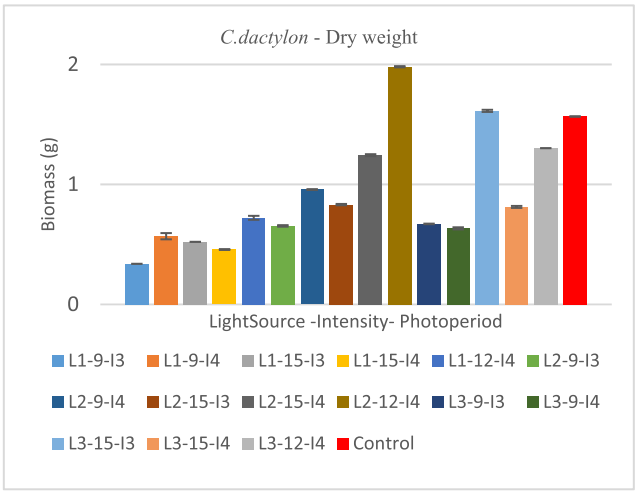

FIGURE 8. Growth of *C. dactylon* under various light conditions.

The procedure for chlorophyll estimation is mentioned in [28]. The experimental results indicate the variation in response to illumination in chlorophyll content (Table 2). *C. dactylon* showed enhanced pigment content in 15-hour photoperiod, at intensity (I3) under the combined light source.

TABLE 2. Total chlorophyll in *C. dactylon*.

Photoperiod - Intensity	Light Source	Total pigments (mg of C/g FW)
		Control - Total pigments $0.170^{g} \pm 0.001$
9-hour -I4	L1	$0.179^{i} \pm 0.005$
	L2	$0.126^{d} \pm 0.001$
	L3	$0.172^{gh} \pm 0.002$
9- hour -I3	L1	$0.135^{e} \pm 0.20$
	L2	$0.176^{hi} \pm 0.001$
	L3	$0.169^{g} \pm 0.001$
12- hour - I4	L1	$0.116^{b} \pm 0.02$
	L2	$0.100^{a} \pm 0.002$
	L3	$0.155^{f} \pm 0.001$
15- hour -I4	L1	$0.118^{bc} \pm 0.001$
	L2	$0.155^{f} \pm 0.001$
	L3	$0.237^{k} \pm 0.003$
15- hour -I3	L1	$0.121^{c} \pm 0.0003$
	L2	$0.194^{j} \pm 0.003$
	L3	$0.254^{l} \pm 0.003$

Values represent mean ± Standard error of 7 replications. Means followed by the same letters for each plant species are statistically not significant at $\alpha = 0.05$by Duncan's multiple range test.

The total phenolic content (Table 3) indicates a variation among LED illuminated *C. dactylon*. The yield of phenolic compounds indicates that the phenolic production depends on the initial RB ratio in *C. dactylon*. Phenols increased with the highest intensity for horticulture grow light (L2) and combinational grow light (L3), whereas the general LED light source decreased. 15-hour photoperiod is the most suited compared to the other two photoperiods. This indicates a trade-off between RB ratio, PPF and photoperiod for the yield of phenols and plant growth and development.

TABLE 3. Total phenolic compound of *C. dactylon* under different light parameters.

Photoperiod - Intensity	Light Source	Total phenolics (mg/g dry wt.) GAE*
		C. dactylon (control: $15.577^{cd} \pm 0.201$)
9-hour -I4	L1	$6.824^{a} \pm 0.034$
	L2	$63.437^{j} \pm 0.027$
	L3	$90.317^{l} \pm 0.069$
9- hour -I3	L1	$8.081^{b} \pm 0.038$
	L2	$14.604^{c} \pm 0.018$
	L3	$20.959^{e} \pm 0.020$
12- hour - I4	L1	$6.594^{a} \pm 0.015$
	L2	$15.903^{d} \pm 0.034$
	L3	$15.398^{cd} \pm 0.139$
15- hour -I4	L1	$22.447^{f} \pm 0.048$
	L2	$50.477^{i} \pm 0.041$
	L3	$92.874^{m} \pm 0.018$
15- hour -I3	L1	$26.706^{g} \pm 0.051$
	L2	$38.650^{h} \pm 0.027$
	L3	$78.032^{k} \pm 0.044$

Values represent mean ± Standard error of 7 replications. Means followed by the same letters for each plant species are statistically not significant at $\alpha = 0.05$by Duncan's multiple range test. * GAE = Gallic Acid Equivalents.

Growing environmental conditions decides the medicinal value of the grass. Light quantity, light quality and the photoperiod primarily influence their growth. The grass considered in this study *C. dactylon* grasses, is grown to recover the air quality and scenery in SO_2 polluted areas [31]. Better growth of this grass is possible by adjusting the light parameters, as depicted in the result. The phenol content synthesized by the grass indicates the level of stress and plays a vital role in regulating it. The results indicated that when the plant is under stress, it produces higher phenolic content. The results also infer that growing the plants under a tunable LED light source may result in the desirable plant parameter. Further, to achieve this, a simulation model was developed to know the minimal LEDs required to achieve any given spectrum.

The target SPD and the PPF were given as user input. Figure 9, Figure 10 and Figure 11 show the experimental and simulated spectrum at various PPF values. This was repeated with SPDs of other light sources. The number of LEDs increased with an increase in light quantity. The worst fitness is observed in the highest PPF, and the reason for the worst fitness error is already discussed in Sec IV.C, but the results are satisfactory for this application. The PPE of the system also slightly increased with an increase in PPF. Fitness error is computed as RMSE, error influences in proportion to its square; larger errors have a more significant influence on the total square error.

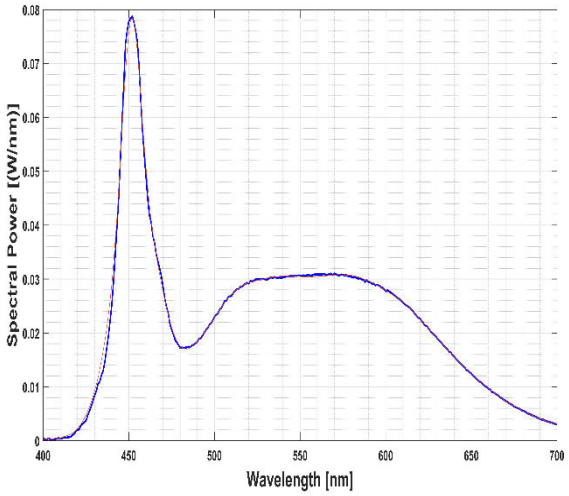

FIGURE 9. SPD of target and simulated spectrum at PPF 30 μmol/s.

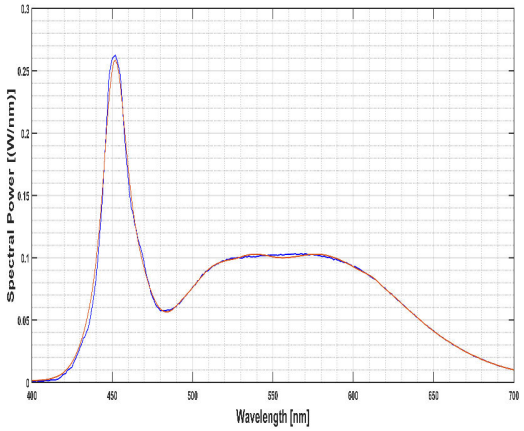

FIGURE 10. SPD of target and simulated spectrum at PPF 100 μmol/s.

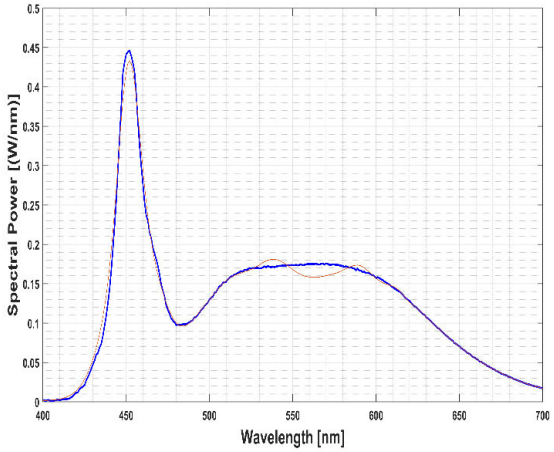

FIGURE 11. SPD of target and simulated spectrum at PPF 170 μmol/s.

VI. CONCLUSION

Experiments were carried out to quantify the phenol and growth of *C. dactylon* under various light conditions. The results indicated that phenol accumulation was more when the plant was stressed, and biomass growth varied with lighting conditions. The results indicated that the lighting conditions were to be changed for increasing the yield of the desired product. Hence, to meet this demand, a tailor-made LED light source needs to be developed. A generalized simulation model was developed to find the optimal number of LEDs producing the defined SPD and PPF using the LM algorithm in horticulture applications. The results also indicated that a given SPD increase in PPF increases the number of LEDs, RMSE and affects PPE value. The RMSE can be further reduced by filling the green gap. Due to the varying light requirements between plant species and within the species, this work can be further extended to other medicinal herbs, shrubs and climbers. This helps us to understand better the effect of LED lighting conditions on plant metabolites production and accumulation. The LEDs selected for the work is in the PAR range, but the range of LEDs can be extended to the UV spectrum. Further, a LED tunable source can be developed for different species, which aids plant growth and development.

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R. SOWMYA was born in India, in 1984. She received the B.E. degree in electronics and communication engineering form Visvesvaraya Technological University, in 2005, and the M.Tech. degree in power electronics systems and control, in 2013. She is currently pursuing the Ph.D. degree in electrical engineering with Manipal Academy of Higher Education, Manipal.

From 2006 to 2009, she was worked as a Software Engineer with the industry. Since 2011, she has been teaching with the Electrical and Electronics Engineering Department, Manipal Academy of Higher Education. Her research interests include solid-state lighting and control and plant biotechnology.

S. NARASIMHAN received the Ph.D. degree from the University of Kerala, in 2005, under CSIR (NET) Fellowship. Since then, he has been associated with teaching and research. He is currently teaching biology for engineers and bioinspired designs in engineering. His research interests include plant biotechnology and bio inspiration.

CIJI PEARL KURIAN (Senior Member, IEEE) was born in India, in 1964. She received the B.Tech. degree in electrical and electronics engineering from Calicut University, in 1986, the M.Tech. degree in lighting science and engineering from Mangalore University, in 1994, and the Ph.D. degree in electrical engineering from Manipal University, Manipal, India, in 2007.

Since 1987, she has been teaching with the Electrical and Electronics Engineering Department, Manipal Institute of Technology, Manipal, a constituent institution of Manipal Academy of Higher Education, India. Her research interests include lighting controls—technology and applications.

Dr. Kurian is a fellow of the Institution of Engineers India and a Life Member of professional bodies, Indian Society of Lighting Engineers, Indian Society for Technical Education, and Systems Society of India.

R. SRIVIDYA received the B.E. degree in electronics and communication engineering from Anna University, Chennai, in 2006, the M.Tech. degree in VLSI design from SRM University, Chennai, Tamil Nadu, India, in 2009, and the Ph.D. degree in electrical engineering from Manipal Academy of Higher education, Manipal, India, in 2020.

She is currently a Faculty Member with Manipal Institute of Technology, Mahe, Manipal. She has ten years of teaching experience. Her research interests include solid state lighting-control and applications, machine learning, and embedded systems applications. She is a Life Member of professional bodies, such as Indian Society of Lighting Engineers, Indian Society for Technical Education.