Urban Gardening System for Home Organic Vegetables: LED Artificial Light and Irrigation Control

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Highlights:
- The proposed urban gardening system with LED artificial light could produce organic lettuce at about 1.27 kg per crop, which is higher than the baseline yield.
- 26.4 liters of water was used for the production of one crop.
- A red blue LED light ratio of 0.7 is appropriate for a high production yield of lettuce.

Abstract. Due to the limited amount of space in urban homes, the trend of indoor gardening is growing as it is the most suitable gardening method in the specified environment; moreover, it provides the possibility of growing organic vegetables at home. This paper presents the design and construction of an urban indoor gardening system for growing organic vegetables, with automated functions. LEDs in the spectra of R (637 nm) B (455 nm) and white (3500 K) were applied as horticultural light and were designed using the horticulture lighting calculation tool. The automated irrigation system was controlled by Arduino-based soil moisture sensors. The urban indoor gardener prototype had a cultivation bed of 0.385 m^2. The results showed that the LED panel could emit a photosynthetic photon flux density of around 200 ± 7 $\mu mol\ m^{-2}s^{-1}$ with an R to B ratio of 0.7 ± 0.04, and a photoperiod of 16 h per day. The soil moisture control system is automatic and can regulate the soil moisture to the appropriate percentage for agricultural use, which is 50% to 69%. Consequently, it is able to save water and provide an alternative method for efficient water use. The urban indoor gardening system is compact and can be placed in a small indoor corner. The presented system was able to produce organic green-oak lettuce with a weight of 1272.54 g/crop in a restricted area, providing an ease-of-use experience and requiring very little maintenance.

Keywords: *home cultivator; indoor gardening; irrigation control; LED artificial light; soil moisture contents.*

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1 Introduction

Urban gardening, also known as urban horticulture or urban agriculture, is the process of growing plants in an urban environment. Several concepts can be applied for urban gardening, such as container gardening, community gardening, green roots and indoor gardening. Urban gardening provides many environmental and health benefits, for example, it provides organic food and a green environment in the community, helps filter air pollution, and reduces the heat affect in the city. This study focused on indoor gardening, where plants are grown in a small container acting as an indoor greenhouse equipped with horticultural light and a controlled environment.

In 2018, the population of Thailand was about 68 million, where 50% of the population live in urban areas, which is equivalent to roughly 34 million people [1]. Urban living conditions change from living in houses with a yard area suitable for home gardening for household consumption to living in apartments, which have a smaller area of about 25-35 m^2 with many restrictions, including the absence of natural light, thus inhibiting home gardening. This raises the question of what could be done so that people living in such areas will be able to grow organic vegetables for household consumption by their families. Growing organic vegetables has many benefits, for instance, it provides safe, clean produce, encourages household interactions, increases green areas within the residence, and is aesthetically pleasing [2].

Photosynthesis is an important process to store energy from sunlight and transform it into the nutrients needed by plants. The range of sunlight used for photosynthesis is between 400 nm to 700 nm of the sunlight spectrum, which is called photosynthetic action radiation (PAR) [3,4]. Previous researchers successfully validated that red (660 nm) and blue light (420-460 nm) are the major light spectra for plant photosynthesis [5,6]. Researchers studied the influence of red (R) and blue (B) photons in incident light and realized that photons play a major role in regulating the morphology and physiology of plants [7,8]. This study found that the ratio of red and blue LED light has an effect on the growth and development of plants. The author found that LED light with a red to blue (R:B) ratio of 0.7 enabled the increase of antioxidant capacity of sweet basil when compared to control, while offering no significant difference in antioxidant capacity when compared to sweet basil grown under an LED R:B ratio of 1.1, 1.5, and 5.5. Moreover, an R:B ratio of 0.7 was also more efficient in decreasing NO_3 than an R:B ratio of 1.5, LED 5.5 and fluorescent light. In addition, it was found that an LED R:B ratio of 0.7 contributed to an increase of the fresh weight of sweet basil (gram $plant^{-1}$) and energy use efficiency (gram kW^{-1}) when compared to R:B ratios 1.1, 1.5, and 5.5 [9]. Due to these advantages, the author chose to use an LED R:B ratio of 0.7 to apply to the proposed urban indoor gardening system.

The author had the idea of developing a compact system that could be easily located in the corner of a room. The system should be able to control all the parameters necessary for agriculture appropriately, especially for salads and other commonly consumed vegetables. The system should have a lighting control system for the LEDs with an R:B ratio of 0.7 [9] and provide a photosynthetic photon flux density (PPFD) of around 200 µmol $m^{-2}s^{-1}$ [10,11] with a photoperiod of 16 h per day [11]. The indoor gardening system should have the ability to automatically control and regulate water replenishment so that the soil has the appropriate soil moisture content for the growth and development of plants, from sprouting to fruiting, for maximum yield [12]. This can be done by integrating a soil moisture sensor to measure the moisture content in the soil and regulate water pumps with a microcontroller to efficiently water the crop [13,14].

The objective of this study was to design and construct an urban indoor gardening system, which included the design of an LED panel that could emit a PPFD of about 200 ± 10 µmol $m^{-2}s^{-1}$, where the R:B ratio was 0.7 ± 0.05 with good uniformity. The moisture control system in the soil was also tested so that the system could function effectively to maintain the soil moisture at about 50% to 65%. Lastly, the operation of the urban indoor gardening was tested by applying the system to the growth of organic lettuce. Subsequently, the yield of the organic lettuce was measured.

2 Horticultural LED Design

2.1 LED Spectrum Simulation

The horticultural LED was designed by using the Horticulture Lighting Calculation tool (OSRAM) [15] and integrating Piovene's methodology [9] of LED 0.7. The author completed the simulation by choosing the LEDs in the library software. Three types of LEDs were used: the hyper red LED (635-666 nm), blue LED (450-480 nm) and white LED of 3500 K (to help the human eye to see the color of the plants better). The PPF in total was 200 µmol s^{-1} and the light ratio was 40% red, 56% blue to maintain an R:B ratio of 0.7 (40%/56% = 0.71). The system also had 4% of white light added in order to get 100% in total. The light production area was 420 mm × 240 mm, while the gardening area was 0.55 m × 0.35 m. The distance between the light production area and the gardening area was 0.4 m (this was the real distance of the urban gardening system). The simulation results can be found in Figure 1, where the photon flux of the red light was about 81 µmol s^{-1}, that of the blue light was 114 µmol s^{-1} and that of the white light was 8 µmol s^{-1}. The total photon flux (400-

700 nm) was 202 µmol s^{-1}. The number of diodes used to emit red light was 24. A total of 36 diodes were used for blue, and 4 were used for white. Figure 5(a) represents the simulated spectrum obtained from the design. The calculated R:B ratio was 0.71, which accorded with the aim of the author.

System setup and performance of one luminaire						
Color	**Product**	**Photon Flux Ratio**	**LED Quantity**	**Photon Flux**	**Photosynthetic Photon Flux**	**Radiant Flux**
Hyper Red (635-666nm)	GH CS8PM1.24	40 %	24 pcs	81 µmol/s	81 µmol/s	15 W
Blue (450-480nm)	GB CS8PM1.13	56 %	36 pcs	114 µmol/s	114 µmol/s	29 W
White	GW CS8PM1.CM 3500K	4 %	4 pcs	8 µmol/s	8 µmol/s	2 W
	Summary	100 %	64 pcs	203 µmol/s	202 µmol/s	46 W

System output of one luminaire		System output for the plant Area	
Luminaire Photon Flux (360-780nm)	203 µmol/s	Average Photon Flux Density (PFD) on plant Area	203 µmol/s/m²
Luminaire Photon Flux Efficacy (360-780nm)	2.14 µmol/j	Uniformity on plant area (PFDmin/PFDmax)	0.37
Luminaire Photosynthetic Photon Flux (400-700nm)	202 µmol/s	Minimum Photon Flux Density (PFD) on plant Area	244.95 µmol/s/m²
Luminaire Photosynthetic Photon Flux Efficacy (400-700nm)	2.12 µmol/j	Minimum Photon Flux Density (PFD) on plant Area	679.97 µmol/s/m²
Luminaire Power Consumption	95 W		

Figure 1 Simulation results of LED horticulture under R:B ratio = 0.71 by using the horticulture lighting calculation tool (OSRAM).

2.2 LED Panels

Two sets of LED panels were used in the indoor gardening system; each set used 64 3-watt LEDs. The LED breed type diameter was 8 mm, blue (460-465 nm), V_F = 3.0V, I_F = 600 mA, red (635-640 nm), V_F = 2.2V, I_F = 600 mA and white LED (3500 K) V_F = 3V, I_F = 350 mA. The LEDs were soldered on a PCB with a diameter size of 45 mm into 17 groups, each group consisting of 4 LEDs with a mix of colors so that the distribution of the light spectrum would be more or less the same at all points of the gardening area. The exception to this were groups A-2, C-2, A-5, and C-5, where each group only had 3 LEDs. All PCBs were installed on an aluminum heat sink 35 × 55 × 3.5 cm in size. The LEDs were arranged in three rows, with a distance between each row of about 6 cm. There were a total of 6 sets in row A, namely A-1 to A-6, 5 rows in row B, namely B-1 to B-5, and 6 rows in row C, namely C-1 to C-6. The positions of the LEDs were as depicted in Figure 2, where (1) indicates the blue LEDs, numbering 36 in total, (2) indicates the red LEDs, numbering 24 in total, and (3) indicates the white LEDs, numbering 4 in total. Red and blue LEDs in each group were active in supplying 12 V 600 mA DC, while the white LED group was active in supplying 12 V 350 mA DC. Overall, the LED panel had a light production area of 35 × 55cm. The LED panel could be controlled using a toggle switch (A controlled the bottom sets of the LED panel and B controlled the top sets of the LED panel). In this way, it was able to obtain 200 ± 10 µmol $m^{-2}s^{-1}$ of light energy for photosynthesis. The researcher maintained the LED duration for 16/8 h (light/dark) via a digital timer switch. This switch was then used for the automatic control of the two sets of LED panels in the indoor gardening system, contributing to controlling a suitable amount of light for horticultural purposes.

2.3 Urban Gardening System and Control

The urban gardening system's dimensions are 65 × 50 × 130 cm, with an aluminum profile structure of 30 × 30 cm. This is suitable for indoor gardening in a kitchen or in the corner of an apartment. The urban indoor gardening system has two platforms available for horticulture. Each platform has dimensions of 35 × 55 cm, which makes it suitable for gardening in plastic trays of about 35 × 55 cm in size. A total of 11-15 plastic pots of 10-15 cm in diameter can be placed in one platform, meaning that approximately 22-30 organic crops can be grown with this indoor gardening system.

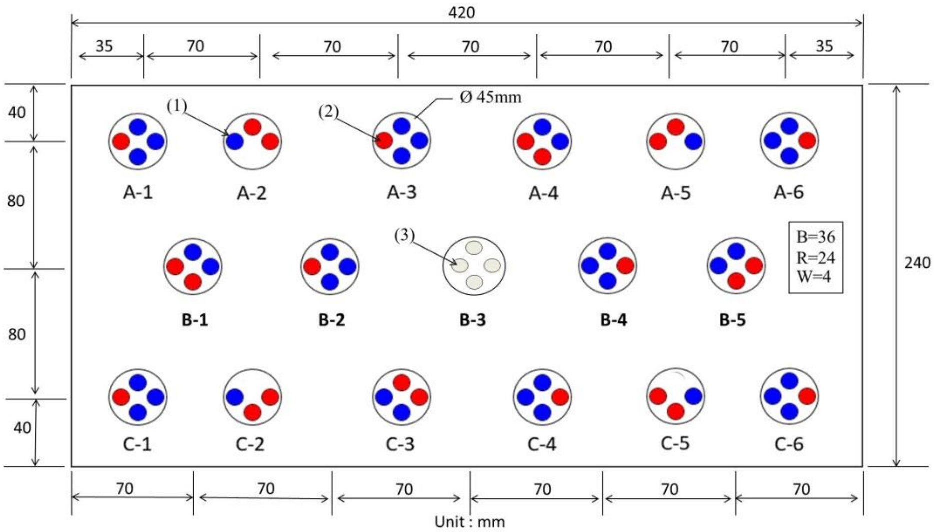

Figure 2 LED installation diagram of an LED lighting panel.

The automated watering system is made possible by measuring the moisture content in the soil with a capacitive soil moisture sensor [16]. This type of sensor has a longer operational life than two-leg electrode resistance moisture sensors; moreover, it has a compact size of merely 98 × 23 mm. The measured moisture value is translated into an analog DC value of 0~3.0 V through a PH2.54-3P interface. The first and second sensor are connected to the analog inputs 0 and 1 of an Arduino UNO [12], as shown in Figure 3(a). These sensors are measured and controlled by the Arduino microcontroller to activate and deactivate the motor and solenoids 1 and 2 for irrigation control of the crops on the platforms.

The designer programmed a moisture content that is suitable for common gardening crops; therefore, when the soil moisture is below 50%, the control system receives the real-time moisture content from the two sensors and relays this information to the microcontroller.

The microcontroller then interprets the data accordingly and activates the motor pumps as well as opening one solenoid valve to allow the transport of water from the water resolver through pipes of 5 mm in diameter. As the water exits the solenoid valve, it goes through a pipeline of the same diameter and flows accordingly into each pot.

At the end of each pipe, there is a valve to control the amount of water going into each pot; this is done by limiting each irrigation to 30 seconds, resulting in about 40 ml of water per pot used each time. Subsequently, the new moisture content is measured and the process is repeated. When the measured moisture content reaches 65% or higher, the control system stops administering water to the pots and thus the crops have a sufficient amount of water and the gardener does not use excessive water, making this system one that is sustainable to limit the overuse of natural resources. Figure 3(b) displays the urban indoor gardening's working mechanisms and control systems of the LED panels and the irrigation system.

2.4 Measurement Calibration and Data Collection

The spectrum measurement device used in this experiment was a spectroradiometer (Asensetek, Taiwan). The measurements were done at the center of the gardening area, 0.4 m away from the LED panel. Two capacitive soil moisture sensors were used to measure and record the soil moisture content, with one sensor for each gardening platform; the sensors were placed about 5-6 cm beneath the soil surface. Data recording was done via a database created by the researcher by using an Arduino R3 microcontroller to record soil moisture in 10 gardening pots, 12.5 cm in diameter, each day with a sampling time of 5 minutes. Mean standard deviation, error percentage and the t-test were the statistical methods used for further analysis of the obtained data.

The capacitive soil moisture sensors were calibrated by using the calibration range as given by the supplier, which can categorize soil moisture into 3 levels, namely, dry soil (520-430), moist soil (430-350), and soaked soil (350-260). Calibrating the obtained measurements from the sensors into percentages can be done by using simple regression; the relationship between the actual soil moisture (y) and the sensor response (x) of the indoor plantation at 26 °C could be given with the equation $y = 52206x^{-2.107}$ from [14].

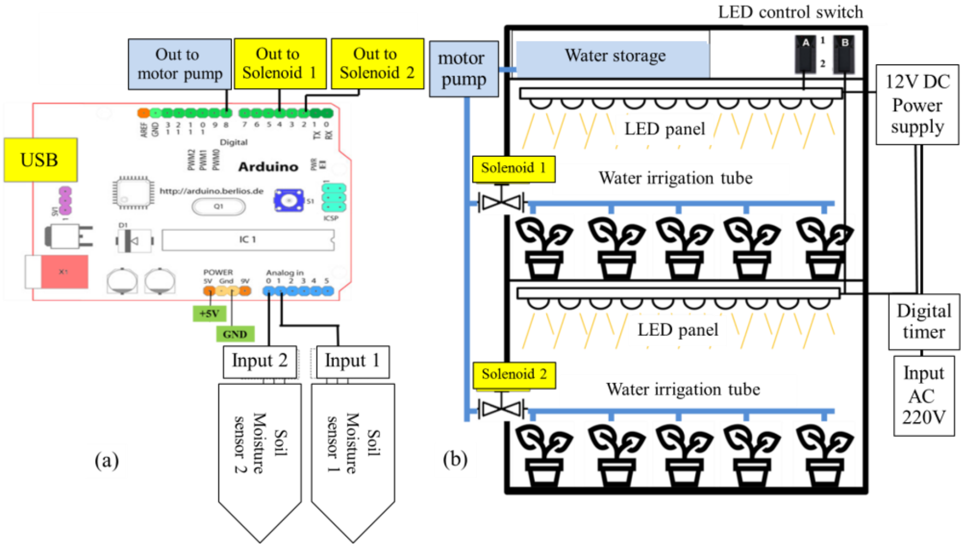

Figure 3 Urban indoor gardening system: (a) Arduino-based control soil moisture contents; (b) LED lighting control diagram and irrigation system.

Figure 4 Urban gardening system prototype with dimensions of 65 × 50 × 130 cm.

2.5 Baseline of Lettuce Yield

The author used the average yield of head lettuce in Arizona as baseline, since there are no data available for Thailand. It was quantified by using the average of the past ten years of agricultural census data (2003-2012), which were available from the National Agricultural Statistics Service (NASS) of the United States Department of Agriculture (USDA). The result was then converted into units of kilograms per square meter per year (kg $m^{-2}y^{-1}$). The average yield of conventional lettuce production was projected at 3.9 ± 0.21 kg $m^{-2}y^{-1}$ [17].

3 Results and Discussion

3.1 Artificial Light Spectrum and the Red and Blue Photon Flux Ratio

The PPFD measurement results and the scattering of the light spectrum from the LED panel revealed that the light spectrum measured was in accordance with the simulation results (Figure 5). To elaborate, the LED panel produced the colors blue, red, and white in a ratio that was similar to that of the simulation design; the experimental PPFD measurement (400-700nm) was 201.7/203 µmol $m^{-2}s^{-1}$, which deviated only 0.01% from the simulated results. The light intensity of 200 µmol $m^{-2}s^{-1}$ could promote the length of the longest root, fresh and dry weights, and number of leaves were greater than 100 or 300µmol $m^{-2}s^{-1}$ [10].

The measured red to blue light ratio (R: B) from the experiment was 0.74, which had a 0.05% deviation from the simulated data. When comparing only the red, blue, and green light at specific wavelengths, it was found that there was less than 0.29% deviation (Table 1), which means that the design and construction of the LED horticultural light proposed by the researcher would employ an R:B ratio of 0.74, which is in accordance with Piovene's study. This means that the light obtained was suitable for agricultural usage, as light with R:B ≈ 0.74 will contribute to achieve a low nitrate content and increase antioxidant compounds of some plants, which will positively affect health in the consumer in the long-term [9].

From the experimental and simulation results of the LED horticulture, it was found that the amplitude of the red-light spectrum was lower in the experimental result than that in the simulation. This was because the highest wavelength of the red LED used in the experiments was 637 nm, which differed from the value in the simulation, which was 655 nm. Despite this, it was found that the average red-light measurement was within 600-700 nm from the experiment and the simulation showed no difference; this can be seen in Table 1, line 2. However, the spectrum of the green light, measured to be within 500-600 nm (455 nm) in the experiment, was found to be slightly higher than in the simulation, which could be caused by the location of the white light installation. The white light was placed in the middle of the LED panel. Therefore, when measuring the light spectrum at this spot, the photosynthetic photon flux density of the color in question was higher than the simulated results. Nevertheless, the experimental results showed that the LED horticulture presented a spectrum of light and a photosynthetic photon flux density that was in line with the objectives of the research.

Table 1 Comparative results of the measured and simulated PPFD over 400 to 700 nm.

Parameters	PPFD output in PAR range			Unit
	Simulation	Measurement	%error	
PPFD (400-700 nm)	203	201.70	0.01	$\mu mol\ m^{-2}\ s^{-1}$
PPFD R (600-700 nm)	81	81.70	0.01	
PPFD G (500-599 nm)	8	10.35	0.29	
PPFD B (400-499 nm)	114	109.66	0.04	
R/B	0.71	0.74	0.05	none

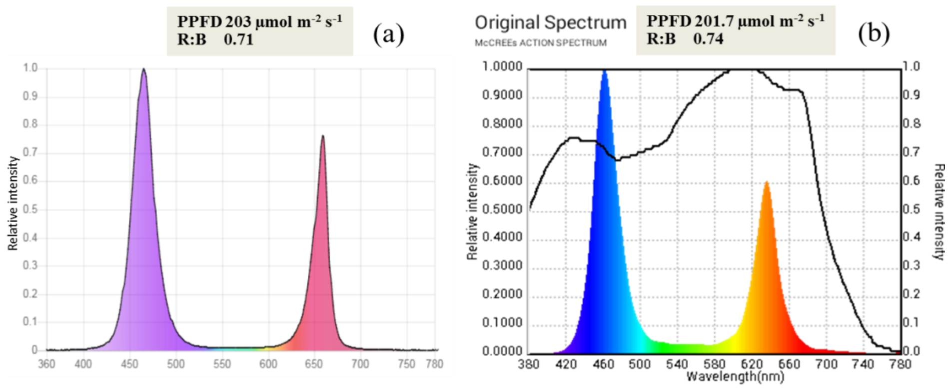

Figure 5 (a) Simulated spectrum and (b) measured spectrum distribution proposed by the author (the black line indicates the McCree action spectrum; this curve describes the actual photosynthetic rates and is the curve on which to base the spectral selections).

3.2 PPFD Uniformity on the Cultivation Area

Measurement of the PPFD light distribution was done for the light scattered on the two gardening platforms with dimensions of 35 × 55 cm. The researcher divided the gardening area into 12 equal parts and used a spectroradiometer to measure the center of each divided part, resulting in a total 12 measurement positions. The PPFD measurement result of the upper platform yielded 254 μmol

$m^{-2}s^{-1}$ as the highest value and 171 µmol $m^{-2}s^{-1}$ as the lowest value. For the lower platform, the highest PPFD measurement result was 234 µmol $m^{-2}s^{-1}$ and the lowest was 180 µmol $m^{-2}s^{-1}$ (Table 2).

Table 2 Measurement results of PPFD and calculated results of uniformity of light on the plant area.

PPFD on upper platform					PPFD on lower platform				
Position	**1**	**2**	**3**	**4**	**Position**	**1**	**2**	**3**	**4**
A	197	219	227	215	**A**	180	198	205	193
B	190	230	254	213	**B**	197	222	234	205
C	171	190	193	187	**C**	188	193	201	195
Average				207^{ns}	**Average**				201^{ns}

Not significant differences are indicated by 'ns'; $p > 0.05$

The average PPFD values were 207 µmol $m^{-2}s^{-1}$ on the upper gardening platform and 201 µmol $m^{-2}s^{-1}$ on the lower platform. The average PPFD on the upper platform did not show a significant difference ($p > 0.05$) compared to the lower platform. This was in line with the goal established by the researcher, which was 200 ± 10 µmol $m^{-2}s^{-1}$. Light uniformity is very important with indoor horticultural lighting. This was calculated by using the following formula: uniformity = minimum PPFD/average PPFD. The light variation is often extreme; differences in intensity of 50 percent or more are not uncommon. As the vertical farming industry develops, hopefully more attention will be paid to light uniformity and its importance for growing crops uniformly [18]. In the present study, when testing the consistency of the light energy used for the upper and lower gardening platforms, the results were 0.82 and 0.89, respectively. These values indicated that the scattering of light was consistent and uniform in the whole gardening area and was appropriate for indoor vertical farming.

3.3 Measurement of Soil Moisture Content

The irrigation system used an Arduino UNO microcontroller as the main control equipment along with the water supply equipment, including the sensors, solenoid valve, and motor pumps. The listed water supply equipment operations were tested under operating conditions (not shown in this article). The researcher recorded the average soil moisture, which was measured from two capacitive soil moisture sensors during 2 days, with each measurement lasting 5 minutes. Data obtained were then compared and analyzed; the experimental results yielded that the soil moisture in the gardening containers used had an average value of 61.5% (Figure 6) when the volume of water supplied each time to the containers was adjusted to 20 ml. From the experiment, it could be observed that the moisture in the soil had a maximum value of 69% and a minimum value of 50% (Figure 6). This method gave a soil moisture percentage that was 11.5% higher than the minimum set value. The irrigation system proposed could efficiently distribute water to each gardening container and maintain the appropriate soil moisture for agricultural use, which is between 50% to 65%. Therefore, this is a simple and suitable method to set and maintain soil moisture for common gardening crops and lettuces. It is in line with the reports of Kothawade [13] and Karmokar [12], who used two-leg soil moisture sensors with an Arduino to control the distribution of water for greenhouse gardening with efficient results. The benefits of automatic irrigation control by using the proposed system includes efficient water management, water conservation, better plant yields, and cost efficiency [12,14].

Accordingly, the watering time in the proposed system was set to last 30 seconds (water volume 40 ml). This caused the motor pump to operate only 1 time a day, which is beneficial to conserving water and electricity for urban gardening systems. In summary, the water used by this system was around 26.4 L per crop (1day × 40 ml × 22 pots × 30 days = 26.4 L).

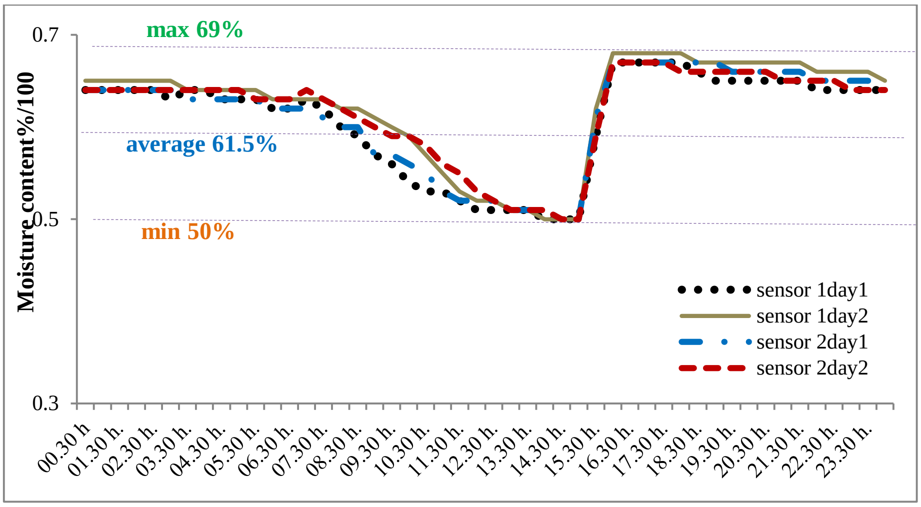

Figure 6 Comparison of the measurement of soil moisture content while gardening with a soil moisture sensor.

The water supply by using Arduino-based capacitive soil moisture sensors only required one implementation per plantation. The proposed system worked efficiently according to the researcher's engineered functions. Nevertheless, the urban gardening system is designed for indoor gardening, where users are able to observe and enjoy the gardening process. Users are able to see the operation of the system and should take note of the water level in the 15-liter storage tank and refill the water to the maximal point weekly to prevent damage to the pumps and crops grown if the water level is too low.

3.4 Yield of the Urban Indoor Gardening System

The author applied the urban indoor gardening system for growing green-oak lettuce under the same gardening methodology and time as Kim [5]. This involved placing the indoor gardening system inside a room with a regulated temperature of 25°/30 °C (night/day) and air moisture at around 55% to 70%. Thirty six days after sowing, the green-oak lettuce grown was removed from the ground (with roots intact) and weighed with a digital weighing scale. The upper and lower gardening platforms of the indoor gardening system each had 11 gardening pots at 12.5 cm in diameter, resulting in 11 green-oak lettuces from each gardening platform. Table 3, shows the comparative of crop yield details of the green-oak lettuces (sample as in Figure 7).

From the upper platform, the cultivation of the green-oak lettuce yielded 647.66 g in total, which means that each stalk in average had a mass of 58.88 g. From the lower platform, the total mass of the green-oak lettuce grown was 624.88 g, giving an average of 56.81 g/head. The total mass of lettuce grown was 1272.54 g. The average yield was 57.84 g/head. The production yield of lettuce from the upper and lower platform after 36 days indicated that the total fresh weight from them was not significantly different ($p > 0.05$).

Table 3 Plant yield measurements from the urban indoor gardening system 36 days after sowing.

Plant no	**Plant yield (g)**	
	Upper platform	**Lower platform**
1	59.17	55.03
2	61.29	59.92
3	56.83	56.70
4	64.00	60.54
5	56.28	65.00
6	55.71	60.25
7	55.49	54.85
8	64.32	48.62
9	59.81	56.67
10	56.12	56.70
11	58.64	50.60
Average	58.88^{ns}	56.81^{ns}
S.D.	3.21	4.64
Total	647.66	624.88
Average fresh weight (g/head)		**57.84**
Total yield per crop (g)		**1272.54**

No significant differences are indicated by ‘ns’; p > 0.05

Figure 7 Sample of green-oak lettuce.

In this study, the total lettuce yield per crop was 1.27 kg per 0.385 m^2. The urban gardening system could produce 9 lettuce crops per year. This is equivalent to 29.68 kg m^{-2} y^{-1} (kg m^{-2} y^{-1} = 29.68 = {(1.27 kg ÷ 0.385 m^2) × 9 crops/y}. Compared with the baseline lettuce production (3.9 ± 2.1 kg m^{-2} y^{-1}) [17] this study produced a higher yield of about 7.6 ± 2.1 times that of the baseline. From literature, the study of Kim [5], who grew lettuce under LED light with an R:W:B ratio of 4:2:1 at 63.68 µmol $m^{-2}s^{-1}$ in a mini-plant factory with a hydroponics grown system obtained an average mass of 47.86 g/head. In this study the lettuce yield was larger (57.93 g/head) because the system had a higher PPFD (200µmol $m^{-2}s^{-1}$. Compared to the lettuce grown in the closed-typed plant production system at Gyeongsang National University, the lettuce leaf and root fresh weight was about 46.3 g/head by light intensity at the same PPFD (200 µmol $m^{-2}s^{-1}$ at 18 h/day) after 22 days of treatment [10].

This was lower than our results, which is sensible because harvesting was done sooner. In fact, the fresh weight had a linear relation to the PPFD, which is in accordance with the results of the study regarding the relationship between plant yield and PPFD. With growing lettuce under a plant factory with artificial light (PFAL), the fresh weight of the leaves and roots were significantly affected by the PPFD during the seedling stage. The fresh weight of the leaves and roots were greatest under a PPFD of 200 µmol $m^{-2}s^{-1}$, i.e. 26.8% higher compared with that grown in treatments using LED light at 150 µmol $m^{-2}s^{-1}$ [11]. Meanwhile, in the case of the PFAL at Chiba University, Japan, operated by PlantX Corp, a typical productivity was about 80 g of fresh weight per head of leaf lettuce [19]. This result was better than the current study because the lettuce was grown in a PFAL and cultivated in a hydroponics bed with controlled environment (closed) system. The present study corresponded with the study of Piovene, who reported that using LED light with an R:B ratio of 0.7 produced a fresh weight of basil that was higher than cultivating the same crop under LED light with an R:B ratio of

1, 1.5, and 5.5 [9]. However, the plant yield does not relate only to the PPFD and the R:B. There are many other factors that have to be controlled, such as photoperiod, light spectrum, light uniformity, CO_2, temperature and humidity and cultivation technology (soil planting, hydroponics, aquaponics), and so on.

4 Conclusion

The proposed urban indoor gardening was applied for the cultivation of green-oak lettuce. After 36 days of cultivation, the total crop yield was around 1.27 kg, i.e. about 7.6 ± 2.1 times higher than that of the baseline lettuce yield. The system is suitable for planting various species of leafy vegetables, including common herbs and others short leaf plants. The indoor gardening system only requires an installation area of 65 × 50 cm, which makes it ideal to place inside a kitchen or a small apartment. The system is equipped with an automated LED system to control the amount of light received, as well as an automated irrigation system via an Arduino-based soil moisture control. With this, the user can cultivate crops easily and efficiently, and as a result the user will obtain crops with good nutritional quality. Nevertheless, improvements should still be made to the proposed urban indoor gardening system, for instance, by integrating an IoT system to provide a more user-friendly platform to improve the remote access and monitoring aspects of the system as well as to further reduce the frequency of human effort.

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