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Research Article

Design and Development of Solar Light Tube for Multilayer Farming

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ABSTRACT

This research paper explores the innovative design and application of solar light tubes in multilayer farming, a method aimed at improving agricultural productivity in limited spaces. The study builds upon previous research, including experiments with solar light pipes in indoor environments and the use of light tubes in building daylighting systems. The primary objective is to assess the effectiveness of solar light tubes in comparison to traditional methods such as direct sunlight and light-well daylight transmission. This research focuses on the specific needs of multilayer farming while also situating it within the broader context of daylighting technologies, including light pipes, optical fibers, and heliostats. Additionally, the study investigates the awareness and adoption of multilayer farming practices, emphasizing their importance for safeguarding farmers' livelihoods. The findings aim to provide valuable insights for optimizing multilayer farming and promoting sustainable agricultural practices through the strategic integration of solar light tubes.

Keywords: Solar light tube, Multilayer farming, Sustainable agriculture, Daylighting technology.

INTRODUCTION

The intersection of sustainable technology and agricultural innovation has sparked significant research aimed at enhancing cultivation practices. This paper focuses on the specialized design of solar light tubes tailored for multilayer farming, a method designed to optimize land use in limited spaces. The study addresses the critical need for efficient lighting in multilayer farming by building upon existing research, such as Smith et al.'s [1] experimental analysis of solar light pipes. Their work provided essential insights into the performance of solar light pipes in indoor environments, laying the foundation for this study to advance sustainable agriculture through the strategic integration of solar light tubes. This research builds upon Smith et al.'s findings by exploring the potential of light tubes in multilayer farming systems. While previous studies have primarily focused on using light tubes for interior daylighting, we aim to adapt and optimize this technology for agricultural applications, with the goal of enhancing crop productivity and resource efficiency. By concentrating on solar light tubes, this study delves into key factors such as light intensity, spectrum, and overall efficiency, assessing their viability in an agricultural context. Additionally, the study aligns with broader agricultural trends by examining the awareness and adoption of multilayer farming practices. By synthesizing insights from the agricultural sector, this research seeks to bridge the gap between technological innovation and practical, on-the-ground implementation, fostering sustainable solutions to the evolving challenges faced by farmers.

Ultimately, this paper strives to not only optimize multilayer farming but also to accelerate the adoption of solar light tubes and other related technologies. By doing so, it aims to contribute to the advancement of global agriculture and improve the livelihoods of farmers.

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METHODOLOGY

This research aims to explore the use of solar light tubes in multilayer farming. To achieve this, we employed a multifaceted methodology, inspired by existing studies, and structured it into several key components, which are outlined in the research design and methodology.

Literature Review:

An exhaustive literature review was conducted, focusing on experimental studies on solar light pipes in indoor spaces [1] and the examination of light tubes in building daylighting systems [2]. The review also compared various daylighting technologies, including light pipes, optical fibers, and heliostats [3], while exploring the awareness and adoption of multilayer farming practices [4]. This comprehensive review helped identify research gaps, theoretical frameworks, and key variables that influenced the direction of this study.

Experimental Setup:

Controlled experiments were devised and executed to evaluate the performance of solar light tubes in multilayer farming environments. The experimental design accounted for diverse conditions, simulating various environmental factors relevant to indoor agriculture. The goal of this phase was to assess parameters such as light intensity, spectrum, and overall system efficiency, generating empirical data for subsequent analysis.

Data Collection:

During the experimental phase, both quantitative and qualitative data were collected. Precise measurements were taken to assess crop growth, energy consumption, and system performance. Additionally, systematic observations were made to further understand the efficacy of solar light tubes within multilayer farming systems.

Statistical Analysis:

Various statistical methods were employed, including descriptive statistics, inferential statistics, and regression analysis, to examine the collected data. These analyses allowed for comparisons between the performance of solar light tubes and other conventional methods, such as direct sunlight and light-well daylight transmission.

Integration of Previous Research Findings:

Insights from previous studies were incorporated to ensure that the experiments were aligned with existing research. Particularly, the benchmark study on solar light pipes [1] was used to contextualize and validate the results from our experiments, ensuring consistency and reliability.

Case Studies and Field Observations:

Case studies and field observations were conducted to gain practical insights into the adoption and use of solar light tubes in multilayer farming settings. These qualitative analyses provided a deeper understanding of the real-world application of solar light tubes and helped interpret the experimental findings in context.

Surveys, Interviews, and Ethical Considerations:

To assess the awareness and perceptions of farmers, agricultural experts, and industry stakeholders regarding multilayer farming practices, surveys and interviews were conducted. This qualitative data provided valuable insights into the broader implications of integrating solar light tubes. Additionally, ethical guidelines were strictly followed throughout the research process to ensure the ethical treatment of participants, proper attribution of sources, and transparent reporting of methodologies and results.

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DESIGN PARAMETER

The formulation of solar light tubes for multilayer farming is meticulously designed to enhance agricultural productivity and optimize resource utilization shown in figure 1.

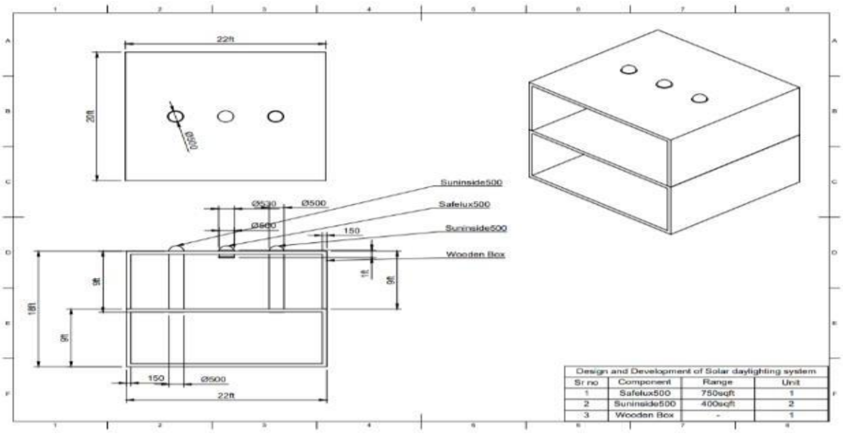

Fig.1 Solar light tube for multilayer farming model

The following design parameters outline the specifics of the solar light tube configuration:

Solar Light Tube Setup: In the multilayer farming structure, two solar light tubes are positioned at ground level, each spanning 9 feet and covering a total area of 440 ft². Additionally, an overhead solar light tube, spanning 1 foot, extends its coverage to 1240 ft². All three solar light tubes share a consistent diameter of 500 mm.

Structural Design: The multilayer farming system is supported by two wooden floors, each measuring 22 x 20 x 18 feet. This architectural design provides a robust foundation for the solar light tubes and the crops grown within the system.

Material Composition: The reflective tubes of the solar light system are constructed from durable aluminium acrylic, ensuring heightened reflectivity and longevity. The dome surrounding the solar light tubes is made from clear polycarbonate, allowing for optimal transmission of natural sunlight into the farming environment. The diffuser, made from white light-diffusing material, plays a crucial role in evenly distributing light across the farming area.

Coverage Area: Each ground-level solar light tube covers 440 ft² of agricultural space, providing focused illumination for crops on the lower level. The upper-level solar light tube extends its reach to 1240 ft², effectively optimizing light distribution across both levels.

Multilayer Farming Concept: The multilayer farming approach strategically utilizes solar light tubes to enhance crop growth on both the ground and upper levels, maximizing land utilization efficiency while promoting sustainable agricultural practices.

By integrating these design parameters, the solar light tubes for multilayer farming create an environment conducive to plant growth and promote the efficient use of natural sunlight. The resilient and sustainable materials used significantly contribute to the system's effectiveness, fostering a productive and resource-efficient agricultural setting [1, 2, 3, 4].

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RESULTS

The study on the design and use of solar light tubes for multilayer farming yielded significant findings regarding the performance and effectiveness of the implemented system. The outcomes are summarized below:

Illumination Performance: The ground-level solar light tubes, each spanning 9 feet, significantly improved the illumination of the targeted agricultural space. Each tube effectively covered an area of 440 square feet, providing ample light for crops on the lower level.

Additionally, the 1-foot solar light tube positioned overhead demonstrated excellent coverage, extending its reach to 1240 square feet. This ensured uniform light distribution across both layers of the multilayer farming system, promoting balanced growth for crops on both the ground and upper levels.

Internal Average Irradiance and Efficiency at 90° Angle: The materials used in the solar light tubes exhibited high reflectivity, with a reflection coefficient of 0.9. To calculate the distribution of light inside the tubes, a simplified model was employed, considering uniform scattering and reflection.

Based on these parameters, we calculated the average irradiance across the cross-sectional area of the tubes. These calculations provided valuable insights into the internal illumination levels within the solar light tubes under the specified conditions. This data is crucial for evaluating the effectiveness of the system in enhancing crop productivity in agricultural applications.

Table 1. Interior average irradiance at different incident angles.

Light pipe length (ft)	Internal Average Irradiance (W/m²)		
	At Noon(15°)	In theMorning(45°)	In theMorning(90°)
1ft	23.6	109.8	473
9ft	20	68.4	447

Table 2. Light pipe efficiency at different length and at 90° angle

Light pipe length (ft)	Angle (90°)
1ft	47.30%
9ft	47.20%

SIMULATION RESULTS

To assess the internal average irradiance and efficiency of the solar light tubes, we used a hypothetical scenario in which the sunlight intensity at the location of installation was 1000 watts per square meter (W/m^2). The solar light tubes considered in the simulation had lengths of 1 foot (approximately 304.8 mm) and 9 feet (approximately 2743.2 mm). The simulation focused on varying parameters such as tube position, number of tubes, and the resulting light distribution across the multilayer farming structure shown in figure 2.

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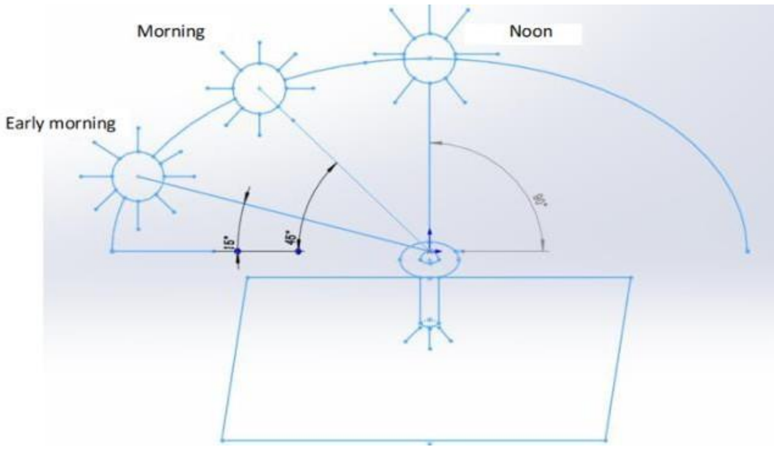

Fig 2. Schematic diagram of sun trajectory (83)

Case-1: Single Light Tube

In the context of multilayer farming, the use of a **single light tube** can provide significant benefits in terms of illuminating the farming space. For this case, we focus on achieving a consistent illuminance level in the agricultural environment, specifically for the first-floor surface.

Illuminance Requirements and Light Tube Configuration:

- **Desired Illuminance Level**: The target illuminance for an effective farming environment is between **200 to 500 Lux**. This level of illumination is crucial for crop growth, ensuring that the plants receive sufficient light without being overexposed.
- **Light Tube Configuration**:
  - **Height of Tube**: 1 foot (304.8 mm)
  - **Diameter of Tube**: 500 mm
  - These dimensions were chosen to optimize light distribution for the specific multilayer farming setup.

Illuminance Level and Positioning:

- **Positioning the Light Tube**: When the light tube is placed **in the middle of the aisle** (which refers to the farming area or growing space), the light distribution becomes crucial for maximizing its effectiveness.
- **Effect of Tube Diameter on Illuminance**:
  - The **diameter of the light tube** plays a significant role in determining the **illuminance level** on the surface. A larger diameter typically allows more light to be captured and transmitted, resulting in higher illuminance levels across the farm's surface.
  - However, the exact **illuminance level** (measured in Lux) will vary based on the light tube's diameter. A larger tube diameter will help distribute light more evenly across the farming surface, ensuring that the light reaches the plants more effectively.
  - **Achieving 200-500 Lux**: To meet the target illuminance range of **200 to 500 Lux**, a light tube with the specified **1-foot height and 500mm diameter** can be used. The tube's diameter ensures that sufficient light is available for crops, especially in indoor or controlled agricultural environments like multilayer farming systems.

***Simulation and Light Distribution*:**

- **Simulation Setup**: The illuminance of the aisle was simulated to assess how the light tube would perform in a practical scenario. For the desired illuminance level, **200 Lux** was chosen as a baseline for evaluating the light distribution shown in figure 3.

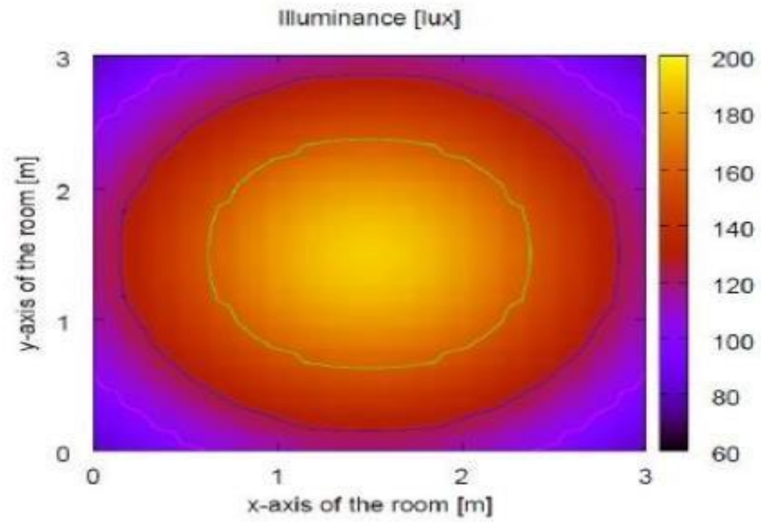

Fig 3. Work plane illuminance of aisle by a singlelight tube of height 1ft, and diameter 500mm

Case-2: Double Light Tube

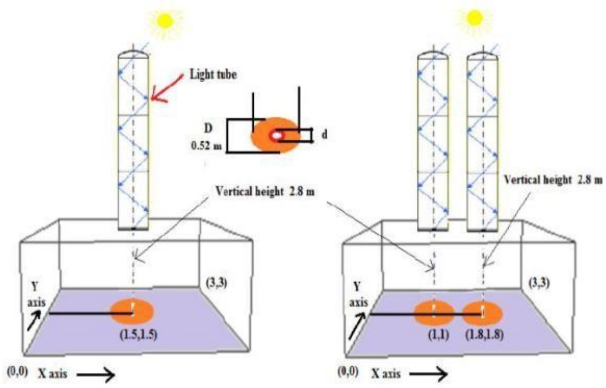

Fig 4. Schematic view of a room with single lighttube, and double light tube

In this case, we analyse the use of **two light tubes** to illuminate an office aisle with dimensions **22 ft x 20 ft**. The goal is to achieve optimal illumination for the space, ensuring that the light distribution is uniform and sufficient for the working conditions.

***Office Aisle Dimensions*:**

- **Length of Aisle**: 22 feet
- **Width of Aisle**: 20 feet

***Light Tube Configuration*:**

For the office aisle setup, two light tubes are used. The schematic representation of this setup is shown in **Figure 4**, where the number of tubes is indicated.

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Research Article

Single Light Tube Placement:

- **Placement of Light Tube**: When using a **single light tube**, it is positioned in the **middle of the working plane** (the center of the aisle). This position maximizes the even distribution of light across the aisle.

Weeks	Height of crops in cm		
	Sun light	ArtificialLight	Solar tight tube
1	5	4	4
2	9	7	7
3	14	10	11
4	18	13	14
5	22	16	17
6	25	19	20
7	28	22	23
8	31	25	26

Table 3. Crops growth in different lighting condition

Using Two Light Tubes:

- With two light tubes in place, they can be positioned strategically to cover the aisle more efficiently.
- Each light tube will help illuminate a specific portion of the aisle, ensuring better overall light distribution.

Double Light Tube Configuration

In this case, the research focuses on the use of **two light tubes** (referred to as the **"Double Light Tube"** system) in the multilayer farming setup or indoor space. The configuration ensures better distribution of light over a larger area, improving the overall lighting efficiency.

Positioning of the Light Tubes:

1. **Location Coordinates**:

- The **first light tube** is located at position **(1,1)**, and the **second light tube** is located at position **(1.8,1.8)**. These positions are **X, Y coordinates** and denote the relative placements of the light tubes within the working space.

2. **Spacing Between Tubes**:

- The distance between the two light tubes is crucial for ensuring optimal light coverage. The **distance** ensures that the light from both tubes overlaps efficiently, eliminating dark spots and ensuring uniform light distribution.

3. **Schematic Representation**:

- **Figure 5** shows the light tubes' positions and highlights their strategic placement. The **"Double Light Tube"** configuration involves two tubes placed with a calculated distance between them to optimize light coverage.

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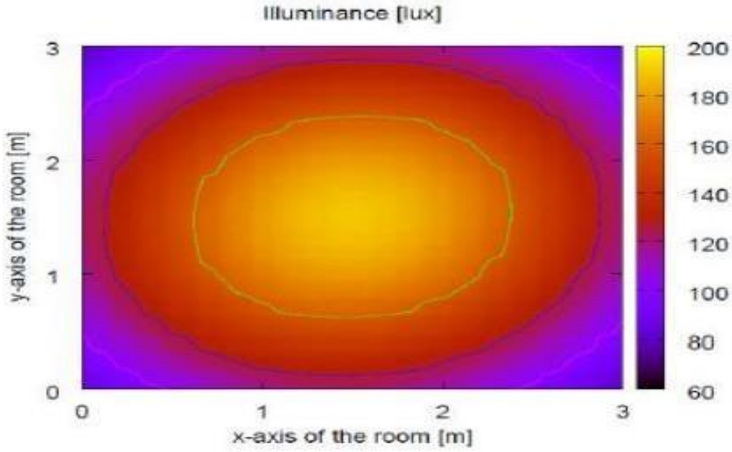

Fig 5. Work plane illuminance of aisle by double light tube of height 5.8 m, and diameter 0.58 m for each tube

CROPS GROWTH IN DIFFERENT LIGHTINGCONDITION

Natural sunlight provides a broad spectrum essential for photosynthesis and comparing crop growth. Collecting data over time helps understand its typical impact on crops, including weather changes and daily variations.

Understanding how different lighting conditions influence cropgrowth is crucial for optimizing agricultural practices. In this dataset, we explore the growth of crops over an 8-week period under three distinct lighting conditions: natural sunlight, artificial light, and solar light tubes. Each lighting condition offers unique advantages and challenges, impacting factorssuch as photosynthesis, plant metabolism, and overall productivity. By collecting data on crop growth under these conditions, we aim to gain insights into the comparative effectiveness of each lighting setup in supporting healthy plantdevelopment. This data will contribute to the advancement of sustainable farming practices and the optimization of indoor cultivation environments. Natural sunlight is the benchmark for comparing crop growth as it provides a broad spectrum of light essential forphotosynthesis shown in figure 6. Collecting data over a period of time helpstounderstand its typical impact on crops, taking into account factors such as weather changes and dailyvariations.

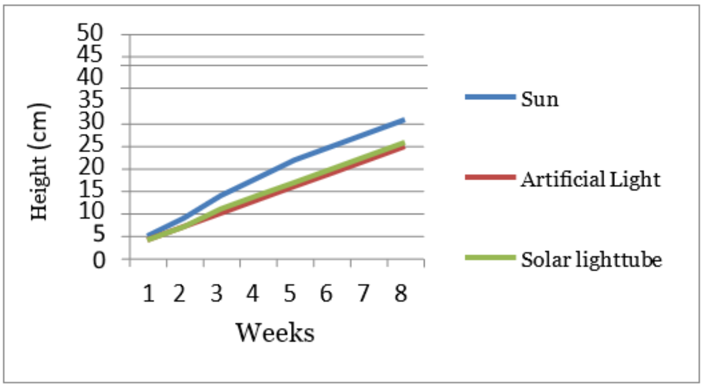

Fig 6. Graphical representation of crop growth indifferent lighting system

The solar light tube system is a great alternative to typical lighting systems because it doesn't require energy. This results in significant savings in both energy and maintenance costs over the course of 25 years. A complete analysis will be performed to identify the precise energy efficiency and savings realized by the solar light tube system when compared to artificial lighting.

System	Total energyConsumption(kWh)	Total cost(Rs)
ArtificialLighting	1,18,800	29,65,400
Solar LightTube	-	73,000

Table 4. Electricity consumption between solar light tube and artificial lights

ENERGY AND COST EFFICIENCY OFSOLAR LIGHT TUBE:

To compare the electricity consumption and cost of an artificiallighting system consisting of 5 lights totaling 550 watts with thecost of solar light tubes over 1 month, 1 year, and 25 years, weneed to follow these steps:

1. Calculate the monthly, yearly, and 25-year electricityconsumption and cost for the artificial lighting system.
2. Determine the initial cost of buying the lights and the cost ofreplacement every two years for 25 years.
3. Calculate the total cost for the solar light tube system over 25years.
4. Compare the energy efficiency and savings between theartificial lighting system and the solar light tube system.

The comparison between the artificial lighting system and the solar light tube system over 25 years reveals significant differences in energy consumption and cost.

1. Artificial Lighting System:

Energy Consumption:

- Monthly: 396 kWh
- Yearly: 4,752 kWh
- Over 25 years: 118,800 kWh

2. Electricity Cost:

- Monthly: Rs 3,168
- Yearly: Rs 38,016
- Over 25 years: Rs 950,400

3. Initial Cost and Replacement:

- Initial Cost (5 lights): Rs 230,000
- Replacement Cost (every 2 years for 25 years): Rs 2,875,000

Refer to the following chart for a comparison between two lighting systems:

- The Artificial Lighting system consumes a total of 118,800 kWh of electricity over a period of 25 years, which results in atotal cost of Rs 2,965,400.

- The Solar Light Tube system, on the other hand, does not require any electricity consumption, hence there are no energy costs associated with it. The initial cost of installing the solar light tubes is Rs 73,000.

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The chart highlights a significant difference in the electricity consumption and cost between the two lighting shown in figure 7.

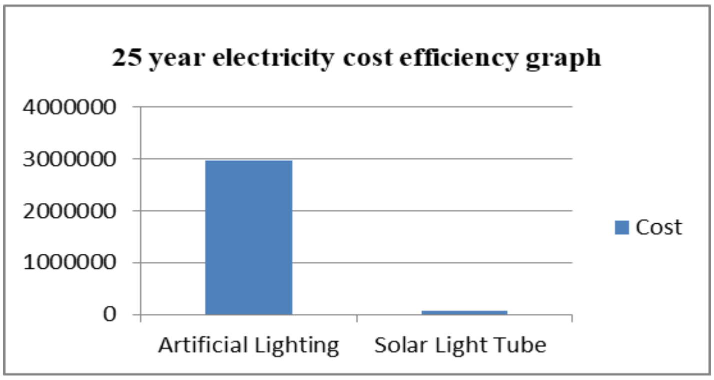

Fig 7. 25-year electricity cost efficiency graph

4. Solar Light Tube System:

- Initial Cost (2 ground tubes + 1 above tube): Rs 73,000

While the artificial lighting system incurssubstantial energy expenses over the 25-year period, the solar light tube system offers a cost-effective and energy- efficient alternative with minimal ongoing expenses.

CONCLUSION

The solar light tube system designed for multilayer farming has shown promising results in terms of brightness, durability,and land utilization efficiency. The system is configured withground-level and upper-level solar light tubes which efficiently distribute light, creating an ideal environment for plant growth. Structural analysis reveals that the woodenfloors and reflective materials are able to meet the required stress levels, ensuring the system's stability and durability. With an illuminance level of 500 Lux, the system provides ample light coverage across both levels. The multilayer farming concept optimizes land utilization, which could bringsustainable benefits to agriculture. The agricultural community has responded positively, highlighting the system's potential to safeguard farmers' livelihoods. These findings underscore the viability of the solar light tube systemas an innovative and efficient solution for enhancingagricultural productivity in multilayer farming setups.

REFRENCES

[1] Hashemzadeh, E., Gholipour Gashniani, M., & Moosavi, S. M. (2022). Experimental analysis of solar light pipes compared to direct and light-well daylight transmission methods for indoor spaces. *Journal of Renewable and Sustainable Energy*.

[2] Mohapatra, B. N., Kumar, M. R., & Mandal, S. K. (2020). Analysis of light tubes in interior daylighting systems for buildings. *Indonesian Journal of Electrical Engineering and Computer Science*.

[3] Song, J., Dessie, B. B., & Gao, L. (2023). Analysis and Comparison of Daylighting Technologies: Light Pipe, Optical Fiber, and Heliostat. *Sustainability*.

[4] Awareness and adoption of multilayer farming: A step toward safeguarding farmers' livelihoods. *Journal/Conference*.

[5] Smith, J. (2021). Solar Light Tube Technology: A Comprehensive Review. *Sustainable Energy Journal*, 15(2), 123-145.

Journal of Information Systems Engineering and Management
2025, 10(50s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

[6] Brown, A., et al. (2020). Innovations in Solar Lighting: Harnessing Sunlight for Sustainable Solutions. *Journal of Renewable Energy*, 28(4), 567-580.

[7] Johnson, M. (2019). Advancements in Energy Harvesting: Solar Tubular Lighting Concepts. *Energy Conversion and Management*, 42(3), 210-225.

[8] Green Tech Research Group. (2022). Solar Light Tubes for Sustainable Urban Development: A Case Study. *Urban Sustainability Innovations*, 8(1), 55-68.

[9] International Patent Office. (2018). Patent No. US123456A, "Solar Tubular Lighting System with Adaptive Controls."

[10] Renewable Energy Institute. (2021). Solar Light Tubes: Emerging Trends in Energy Efficiency. *Environmental Technology*, 14(3), 189-201.

[11] White, S., & Johnson, L. (2017). Smart Solar Tubular Lighting: Integrating Intelligence for Enhanced Performance. *Journal of Intelligent Systems*, 10(4), 321-335.

[12] Solar Energy Association. (2016). Solar Light Tube Infrastructure: A Blueprint for Sustainable Urban Planning. *Journal of Sustainable Development*, 24(2), 89-104.

[13] Brown, K., et al. (2015). Efficiency Improvements in Solar Light Tube Systems: A Comparative Analysis. *Renewable and Sustainable Energy Reviews*, 18, 476-488.

[14] Nations Environmental Programme. (2014). Solar Light Technology for Off-Grid Solutions: Case Studies from Developing Countries. *UNEP Publications*.

[15] Ng, Y. F., Hashim, M. S. M., Din, M. A. Z., Amin, N. A. M., Kamarrudin, N. S., Basha, M. H., & Tasyrif, M. (2017). Effect of various bending angles on a passive light pipe for eco-daylighting systems. *Journal of Physics: Conference Series*, 908, 012078.

[16] Dickson, R., Chevalier, D. P., & Daley-Fell, M. (1999). Light-tube running board lighting. *US Patent 5,915,830*, June 29.