Development and Evaluation of Indoor Hydroponic Fodder Production System

Abstract

Indoor hydroponic fodder production is a sustainable and innovative approach to addressing the fodder scarcity faced by livestock farmers. This study focuses on the development and evaluation of an indoor hydroponic system designed to produce maize fodder under controlled conditions without sunlight. A two-tier hydroponic structure was fabricated using locally available materials, equipped with LED spectrum lights and irrigation systems utilizing foggers and emitters. The system's performance was evaluated based on growth metrics, water use efficiency, and crude protein and fiber content. Results showed that fodder grown under LED lights yielded 3.5 kg per tray with a water use efficiency of 825.9 kg/m^3, significantly outperforming the fodder grown without LED lights. Additionally, the crude protein and crude fiber content under LED lights were 12.44% and 9.49%, respectively. These findings demonstrate that hydroponic systems can significantly enhance fodder quality and yield, offering a viable solution for resource-scarce regions.

Keywords: *Hydroponics, fodder production, water use efficiency, LED lights, crude protein, sustainable agriculture.*

1. Introduction

The increasing demand for sustainable agricultural practices has highlighted the need for innovative solutions to tackle challenges such as water scarcity, limited arable land, and the growing need for high-quality livestock feed. Hydroponic fodder production, a soil-less cultivation method, offers an effective alternative, enabling efficient resource utilization and consistent production of nutrient-rich green fodder. Research has shown that hydroponic systems significantly reduce water consumption, making them ideal for semi-arid regions (Ahmed et al., 2021; Sundaram et al., 2020). Hydroponic maize fodder, in particular, has demonstrated its potential to enhance digestibility and milk production in livestock, providing a sustainable solution to meet the increasing demand for quality fodder (Naik et al., 2017). Additionally, advancements in automated systems and LED spectrum lighting have improved the efficiency of hydroponic cultivation by optimizing photosynthetic activity and minimizing labor requirements (Matos et al., 2015; Promratrak et al., 2017).

In India, where the livestock sector plays a crucial role in agricultural productivity, hydroponic systems have garnered attention for addressing fodder shortages. These systems offer significant advantages, including higher water use efficiency and improved nutrient retention, making them suitable for regions with resource deficits (Malhi et al., 2020; Singh et al., 2015). However, challenges such as high initial costs and limited adoption among small-scale farmers hinder widespread implementation. To address these limitations, researchers have focused on developing cost-effective and scalable hydroponic systems tailored to the needs of smallholder farmers (Lende et al., 2021; Gebremedhin et al., 2015). This study builds upon these efforts by designing and evaluating an affordable indoor hydroponic fodder production system, emphasizing its potential to enhance water use efficiency, yield, and nutrient quality while offering a sustainable and practical solution for small-scale farmer.

2. Review of Literature

Hydroponic fodder production has emerged as an innovative technique to mitigate the challenges associated with traditional farming systems, including water scarcity, land limitations, and inconsistent climatic conditions. Fatima et al. (2021) demonstrated the use of treated wastewater in hydroponic wheat production, highlighting its potential as an alternative to freshwater in semi-arid regions. Similarly, Lende et al. (2021) emphasized the nutritional benefits of hydroponic fodder, showcasing its capacity to improve livestock health and immunity through the production of organic, disease-free green fodder.

Hydroponic systems have also been recognized for their efficiency in water usage. Sundaram et al. (2020) observed that maize fodder grown hydroponically achieved a water use efficiency of 656.55 kg/m^3, compared to traditional methods requiring substantially more water. Furthermore, Turakne et al. (2021) designed an automated hydroponic chamber, proving that controlled environments can sustain consistent fodder production throughout the year with minimal labor requirements.

In India, where livestock contributes significantly to agricultural productivity, studies by Malhi et al. (2020) and Ningoji et al. (2021) have highlighted the potential of hydroponic systems to address fodder scarcity. These systems are particularly beneficial for small and marginal farmers, providing high-nutrient fodder in a cost-effective manner. The integration of LED lighting, as demonstrated by Promratrak et al. (2017), further enhances the growth and quality of hydroponic fodder, making it a sustainable solution for resource-scarce regions.

This study builds upon the existing body of research by focusing on the development of an affordable indoor hydroponic fodder production system and evaluating its performance in terms of yield, water use efficiency, and nutrient content.

Objectives

1. **To develop** an indoor hydroponic fodder production system tailored for small-scale farmers.
2. **To evaluate** the performance of the system under varying environmental conditions with and without LED lighting.
3. **To analyze** the cost-effectiveness of the system, including fixed and variable costs.
4. **To assess** the nutritional quality of the fodder in terms of crude protein, crude fiber, and water use efficiency.

3. Materials and Methods

3.1 Study Location

The indoor hydroponic fodder production experiment was conducted at A.M. Reddy Memorial College of Engineering and Technology, Narasaraopet, Andhra Pradesh, India. The study area is located at 16°17'20.17"N latitude and 80°27'21.58"E longitude, with an elevation of 78 meters above mean sea level. The experimental room measured 6 m × 8 m, providing a controlled environment for the study.

3.2 Environmental Conditions

The average annual rainfall of the region is approximately 200 mm, with temperatures ranging from 22°C to 35°C and relative humidity between 40% and 80%. These conditions are conducive to the growth of hydroponic maize fodder.

3.3 Design of Hydroponic Fodder Production System

A two-tier hydroponic system was fabricated using locally sourced materials to ensure cost efficiency. The key components included:

1. **Slotted Angle Bars**: Constructed as a rectangular frame (180 cm × 110 cm × 100 cm), divided into two stages with a height of 60 cm each.

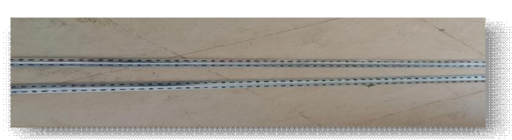

Figure 1: Slotted angular bars

2. **Hydroponic Trays**: Plastic trays (55 cm × 24 cm × 6.5 cm) with perforated bases for drainage.

Figure 2: Hydroponic trays

3. **Water Tank and Irrigation System**: A 25-liter water tank connected to laterals (6 mm diameter) through a 12V DC motor. Foggers and emitters were used for water application.

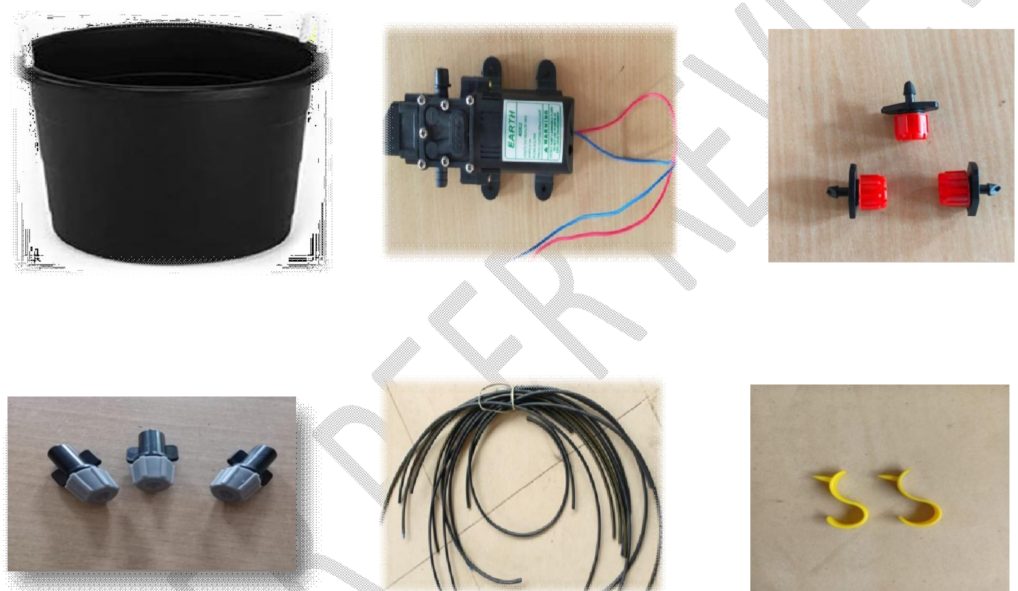

Figure 3: Components of water tank and Irrigation system

4. **Lighting System**: LED spectrum lights (400–700 nm wavelength) were installed to provide artificial photosynthesis for 4 hours daily.

Figure 4: LED spectrum lights

5. **Sensors**: A pH meter, TDS meter, and hygrometer were used to monitor water quality and environmental conditions, while a timer automated the lighting system.

A. pH meter

B. TDS Meter

c. Hygrometer

d. Timer

Figure 5: Different types of sensors

3.4 Experimental Procedure

1. **Seed Selection and Preparation**: Ganga variety maize seeds with over 80% germination rate were selected. Seeds were cleaned, soaked for 20–24 hours, and pre-germinated in wet gunny bags for 24 hours.

Figure 6: Ganga maize seeds

2. **System Setup**: Germinated seeds (1 kg per tray) were placed in hydroponic trays. Water was supplied through foggers and emitters at fixed intervals, with drained water collected for efficiency analysis.

3. **Growth Conditions**: Fodder was grown under two conditions:

   - **With LED Lights**: LED spectrum lights provided artificial photosynthesis.

- **Without LED Lights**: Trays were placed in ambient conditions without artificial lighting.

3.5 Data Collection and Analysis

1. **Water Use Efficiency (WUE)**: Calculated using the formula:

$$\textbf{WUE} = \frac{\text{Total water used (m}^3\text{/tray)}}{Total\ green\ fodder\ produced\ (kg/tray}$$

2. **Nutritional Analysis**: Crude protein and crude fiber were analyzed using standard procedures (Kjeldahl method for protein and acid/base boiling for fiber).

3. **Cost Analysis**: Fixed costs (depreciation, interest) and variable costs (seeds, electricity, labor) were calculated to evaluate economic feasibility.

3.6 Observations

1. **Growth Metrics**: The height of the fodder was recorded daily for 7 days under both conditions.
2. **Water Usage**: Total water applied and drained was measured daily to compute water use.
3. **Yield**: Fodder yield was recorded at the end of 7 days, along with root and shoot lengths.
4. **Cost Efficiency**: The cost per kilogram of fodder was analyzed to determine feasibility for small-scale farmers.

4. Results and Discussion

4.1 Construction

The two-stage indoor hydroponic fodder production system was designed and tested under controlled conditions to address the growing demand for high-quality fodder, particularly for farmers with limited land. The system utilized locally sourced materials, including four slotted angle bars (1.5 inches) assembled into a rectangular stand (180 cm × 110 cm × 100 cm) with two stages, each separated by a galvanized iron sheet (3 mm thickness) sloped for efficient water drainage. Each stage housed three hydroponic trays (54 cm × 40 cm × 6.5 cm), and four spectrum LED lights (4 feet) were installed to facilitate artificial photosynthesis. A 25-liter water tank supplied water to the system via a 12V DC motor, with laterals (6 mm diameter, 4 m length) connected using S-punched holes. Foggers, placed 15 cm apart along the laterals, ensured uniform water distribution. A timer controlled the LED lights, which operated for 4 hours daily, and the entire system was powered through a 3-pin plug. This efficient design optimized space and resources for sustainable fodder.

Figure 7: Main frame

4.2 System Performance Evaluation

The indoor hydroponic fodder production system demonstrated consistent performance in both lighting conditions. The system was capable of producing high-quality maize fodder within a 7-day growth cycle, with notable differences in growth rates and yields between the LED and non-LED setups.

Growth Metrics

Day-2

Day-3

Day-4

Day -5

Day-6

Day-7

Figure 8: Day wise growth metrics

Fodder grown under LED lights showed a faster growth rate, reaching an average height of 18 cm by Day 7, compared to 12 cm without LED lights. This highlights the importance of controlled lighting in accelerating photosynthesis and biomass production. The growth of maize crop is as shown in the below plate 1.

Table 1: The daily growth of maize fodder under LED and non-LED conditions

No. of Days	Growth with LED Lights (cm)	Growth without LED Lights (cm)
Day 1	0.5	0
Day 2	2	0.5
Day 3	5	2
Day 4	7	5
Day 5	10	8
Day 6	16	11
Day 7	18	12

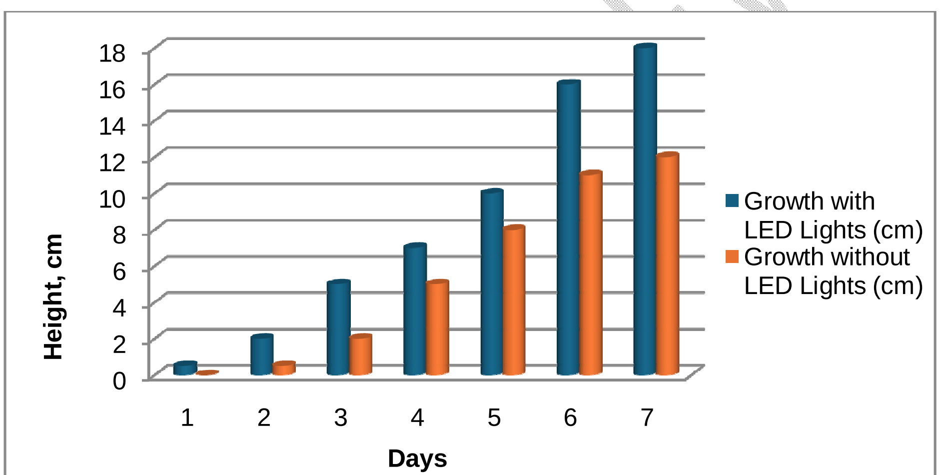

Plate 1: Daily growth of maize fodder crop

4.2 Water Use Efficiency (WUE)

Water use efficiency was calculated for both fogger and emitter irrigation systems under LED and non-LED conditions as shown in Table 2.

Table 2: Water Use Efficiency (WUE) (kg/m³)

Irrigation Method	WUE with LED Lights	WUE without LED Lights
Foggers	825.9	513.01
Emitters	762.5	507.7

The results indicate that foggers had a higher water use efficiency than emitters in both lighting conditions. This demonstrates the effectiveness of fogger systems in reducing water consumption while maintaining high yield.

4.3 Fodder Yield

The total yield of fodder per tray under different conditions is presented in Table 3.

Table 3: Fodder Yield (kg/tray)

S.No	No. of Days	Condition	Yield (kg/tray)
1	7	With LED Lights	3.5
2	7	Without LED Lights	2.2

The yield with LED lights was significantly higher, indicating the crucial role of artificial lighting in improving biomass production.

4.4 Nutritional Analysis

The crude protein and crude fiber content of the fodder were analyzed to assess its nutritional quality.

Table 4: Nutritional Content of Fodder

S.No	Condition	Crude Protein (%)	Crude Fiber (%)
1	With LED Lights	12.44	9.49
2	Without LED Lights	10.55	5.51

Fodder grown under LED lights showed superior nutritional quality, with higher crude protein and fiber content. This is attributed to enhanced photosynthesis and nutrient assimilation under controlled lighting.

4.5 Cost Analysis

The cost analysis revealed the system's economic feasibility for small-scale farmers.

- **Fixed Costs**: ₹ 25,000 (including depreciation and interest).
- **Variable Costs**: ₹ 1.5 per kg of fodder (including seeds, electricity, and labor).
- **Total Cost**: ₹ 3 per kg of fodder.

The low production cost makes this system accessible and profitable for farmers with limited resources.

Table 5: Cost estimation of hydro phonic system

S.No	Components	Quantity	Costin rupees
1.	Slotted bars	12	6000
2.	Hydroponic Trays	6	2000
3.	Self-locking zip ties	8	100
4.	Metal sheets	2	3000
5.	Drainpipes	2	150
6.	Water tank	1	100
7.	DC motor	1	200
8.	Timer	1	1000
9.	Spectrum lights	8	8000
10.	pH meter & TDS meter	1	600
11.	Maize seeds	6 kg	150
12.	Hygrometer	1	800
13.	Laterals	4 m	30
14.	Foggers	6	50
15.	Emitters	6	50
16.	Connectors	5	10
17.	Endcaps	2	10
18.	Eliminator	1	1000
19.	Wire	7m	960
20.	Shadedcloth	5m	850
		Total	26,860

4.5 Discussion

The study demonstrates the feasibility and efficiency of an indoor hydroponic fodder production system tailored for small-scale farmers. Key findings include:

- **Higher Yield with LEDs**: The use of LED spectrum lights significantly increased growth rates and biomass production.
- **Improved Water Use Efficiency**: Fogger irrigation systems outperformed emitters, reducing water usage without compromising yield.

- **Enhanced Nutritional Quality**: Fodder produced under LED lights had higher crude protein and fiber content, supporting better livestock health and productivity.

These results align with prior studies (e.g., Sundaram et al., 2020; Malhi et al., 2020) and validate the potential of hydroponic systems for sustainable agriculture in resource-scarce regions.

4.6 Conclusion

This study successfully developed and evaluated an indoor hydroponic fodder production system designed to address the challenges of limited land, water scarcity, and the need for high-quality livestock feed. The system utilized a cost-effective two-tier structure with LED spectrum lights and efficient irrigation systems (foggers and emitters). Key findings from the study include:

1. **Enhanced Growth and Yield**: Fodder grown under LED lighting conditions achieved a significantly higher yield (3.5 kg per tray) compared to non-LED conditions (2.2 kg per tray), with a faster growth rate and better overall biomass production.

2. **Improved Water Use Efficiency**: Fogger irrigation systems demonstrated superior water use efficiency (825.9 kg/m^3 under LED lighting) compared to emitters, highlighting their suitability for resource-scarce environments.

3. **Superior Nutritional Quality**: The crude protein and fiber content of fodder grown under LED lights were 12.44% and 9.49%, respectively, making it nutritionally superior to fodder grown without artificial lighting.

4. **Economic Feasibility**: The system's low production cost (₹ 3 per kg of fodder) and minimal maintenance requirements make it accessible to small-scale farmers.

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Here are the references formatted in a Scopus-compliant style (APA format). These are derived and adapted from the literature mentioned in your document.

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