Scientific Publishing House
Trends in Ecological and Indoor Environmental Engineering

Alman Sikder & Sayed Huzaifa Mumit
TEIEE 2(4) 2024

RESEARCH ARTICLE
https://doi.org/10.62622/TEIEE.024.2.4.18-27
OPEN ACCESS
ISSN 2956-9761

INVESTIGATION OF THE EFFECTIVENESS OF USING *LUFFA CYLINDRICA* TO REDUCE WATER CONSUMPTION IN AGRICULTURE

Alman Sikder[1], Sayed Huzaifa Mumit[2*]
[1]Department of Science, Birshrestha Noor Mohammad Public College, Dhaka, Bangladesh
[2]Department of Biochemistry and Biotechnology University of Science and Technology Chittagong, Chittagong, Bangladesh
*Corresponding email: huzaifamumit2004@gmail.com

Received: 17.11.2024; ***Accepted:*** 21.12.2024; ***Available online:*** 30.12.2024 ***Published:*** 30.12.2024

Cite this article: Sikder, A., & Mumit, S. H. (2024). Investigation of the Effectiveness of Using Luffa Cylindrica to Reduce Water Consumption in Agriculture. *Trends in Ecological and Indoor Environment Engineering*, 2(4), 18–27.

Background: To achieve the Sustainable Development Goals: Zero Hunger, a stable and accessible water supply in agriculture is essential. The projected steady increase in population will contribute to a moderate increase in consumption, which in turn will require the development of technologies that increase soil productivity. With the increasing impact of global warming, droughts are becoming increasingly common in the northern region of Bangladesh. Notably, Bangladeshi farmers currently allocate about 37% of the total cost of rice production to irrigation. **Objectives:** The current study aims to overcome the problem of water shortage in agriculture, particularly in rice cultivation. It is expected that the use of biological sponge extracted from dried *Luffa cylindrica* will help retain water for its uptake by rice roots. That is, it is expected that by using *Luffa cylindrica* it will be possible to prevent or significantly reduce evapotranspiration and water seepage into the soil. **Methods:** This work is an experimental study on rice cultivation in soil with and without *Luffa cylindrica*. The study controlled the main factors contributing to water loss: evaporation and percolation, for the quantitative measurement of which different systems and methods were used. In addition, other extensive measurements related to irrigation were carried out and contribute to the understanding of the effectiveness/ineffectiveness of the studied approach to reducing water use. **Results:** A comparison of fields with and without *Luffa cylindrica* shows a marked contrast in water storage capacity. Initial observations indicate that integrating *Luffa cylindrica* into rice paddies improves water retention, thereby reducing losses due to evaporation and seepage. It was found that the irrigation frequency was above the optimum threshold to achieve the desired result. In addition, more water was required to fill the Luffa-containing field than the Luffa-containing field, as the dry *Luffa cylindrica* also had to be saturated. Despite these issues, the use of *Luffa cylindrica* resulted in water savings of 26.97%. **Conclusion:** Through rigorous experimentation and analysis, this study demonstrated the effectiveness of *Luffa cylindrica* in reducing water consumption and improving soil moisture retention in rice paddies. By utilizing the fibrous structure of dry *Luffa cylindrica*, water losses due to evapotranspiration and seepage were significantly reduced, resulting in substantial water savings and reduced costs for farmers. The eco-friendliness and cost-effectiveness of *Luffa cylindrica* highlights its potential as a sustainable water management solution for agricultural practices. Its availability and ease of cultivation make it a viable option for farmers, with minimal investment required to implement the technique on a large scale.

Keywords: paddy irrigation; sustainable farming; evapotranspiration, soil moisture retention; microbial habitats; eco-friendly; water-saving techniques; soil fertility; sustainable development.

INTRODUCTION

An important component in achieving global food security, which is defined as one of the Sustainable Development Goals (Goal 2: Zero Hunger), is accessible water supply in agriculture. According to the United Nations (2014), 40 countries, representing approximately 3.5 billion people, are at risk due to growing water scarcity. At the same time, practice shows that agriculture uses 70% to 80% of available water supplies worldwide (FAO, 2017). Over the past 30 years, food production has increased by more than 100% (FAO, 2017). Taking into account the progressive climate change, these data indicate that meeting global irrigation needs will only be possible with the introduction of accessible and affordable technologies (Attwater et al., 2016).

Traditionally, paddy has been a staple food in many countries around the world, especially in Asia. The projected steady increase in population will drive moderate growth in consumption, which in turn will require development of technologies to increase paddy yields. It is worth noting that to produce 1 kg of uncultivated paddy in a paddy field, approximately 4000 L of water (from rainfall and/or irrigation) is required. These 4000 L include all outflows of evapotranspiration, seepage and percolation. With the increasing impact of global warming, droughts are becoming increasingly common in the northern region of Bangladesh (Rahaman et al., 2016). In many areas, open water sources such as rivers, ponds and drains are either unavailable or unsuitable. Consequently, farmers are forced to rely on groundwater extracted through pumping methods, exacerbating the scarcity of groundwater resources. Notably, Bangladeshi farmers currently allocate about 37% of the total cost of paddy production to irrigation (Ibarrola-Rivas et al., 2016). These costs are primarily related to the operation of irrigation pumps, which are often operated by the pump owners.

When irrigating paddy fields one week before and one week after flowering, the recommended method is to keep the field flooded, maintaining a depth of 0.04 m as needed (IRRI, 2024). This practice exposes a large portion of the water to sunlight during the day, covering a large surface area. Consequently, a large percentage of the water evaporates, contributing to the overall water loss. This phenomenon can be quantified using the water evaporation formula given and taking into account the percentage of water that evaporates.

Luffa cylindrica, also known as Sponge Gourd, is a cucumber variant indigenous to Bangladesh, India, and other South Asian regions. For centuries, it has served as a natural exfoliant (Mim et al., 2021). When *Luffa cylindrica* decomposes in soil, typically within 10 to 15 weeks, it releases nutrients beneficial to paddy plants, thereby reducing reliance on synthetic fertilizers. It also provides a habitat for microorganisms vital for providing plants with essential nutrients. The fibres obtained from *Luffa cylindrica* fruits have a higher specific strength and are both renewable and biodegradable. The plant is a lignocellulosic material consisting of crisscrossed fibres with hydrophilic properties that form a three-dimensional network structure. *Luffa cylindrica* fibres are composed of approximately 60% cellulose, 30% hemicellulose and 10% lignin (Anastopoulos

journal homepage: https://www.teiee.net/

& Pashalidis 2020; Sahayaraj et al., 2023). In addition to high water absorption efficiency, *Luffa cylindrica* fibres also exhibit high stability and a large surface area (Anastopoulos & Pashalidis 2020). The plant is hardy and easily adapts to infertile soil. The fibre structure exhibits remarkable strength under significant loads (Gurjar et al., 2024; Psarra & Papanicolaou, 2021; Zhang et al., 2021). When *Luffa cylindrica* is buried or pressed into the silty soil of a paddy field, it functions like a miniature aquifer, retaining water within its confines and replenishing itself whenever water is applied. The root system of the paddy plant surrounds it, using it as a vital source of water. Situated in the mud, exposure to sunlight is limited, preventing rapid evaporation of water. As the water level gradually decreases over time, the soil absorbs water from the loofah, thereby prolonging its moisture content. Consequently, the frequency of watering the plants can be reduced, resulting in reduced water requirements and lower irrigation costs. It is a renewable biomass material, widely available, cost-effective, and easy to obtain (Han et al., 2024).

Based on the above information, the current study aims to overcome the problem of water shortage in agriculture, particularly in paddy cultivation. It is expected that the use of biological sponge extracted from dried *Luffa cylindrica* will help retain water for the uptake of paddy roots. That is, it is expected that by using *Luffa cylindrica*, evapotranspiration and water seepage into the soil will be prevented or significantly reduced.

MATERIALS AND METHODS

Materials

The study utilized:

– biological sponges extracted from dried *Luffa cylindrica*;

– a paddy field located in Ramdia Kashiani, Gopalgonj used for conducting field trials to assess the feasibility. The soils of the field are a mixture of clayey and alluvial.

Preparation of dry *Luffa cylindrica*

Initially, the dry *Luffa cylindrica* were halved from the middle. Considering that the average height of the used *Luffa cylindrica* is 0.35 m, with an average radius of 0.025 m, half-sized dry *Luffa cylindrica* have an average volume of $0.5 \cdot 35 \cdot \pi(2.5)^2$ cm^3, which equals $3.436 \cdot 10^4$ m^3. Then, the seeds from inside the dry luffa were removed.

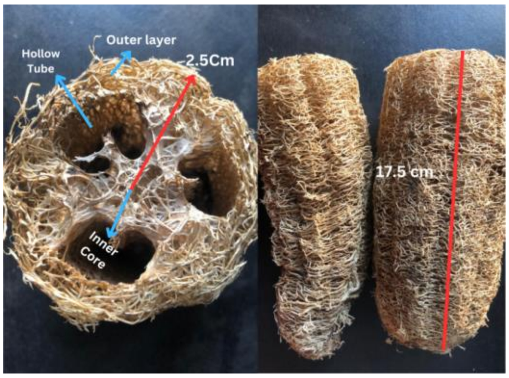

Figure 1. Dry *Luffa cylindrica* (Sponge Gourd)

Preparation of paddy fields

Initially, the paddy field used in the test underwent pre-treatment similar to a standard paddy field, including the application of fertilizers and pesticides. A week after treating the paddy field, prepared dry *Luffa cylindrica* were inserted into the muddy soil by hand, pressing them into holes 0.175 m deep when the soil was sufficiently wet and soft. Each *Luffa cylindrica* sponge was inserted in the middle of four rice plants, positioned 0.25 m apart in a square shape.

The experimental field was divided into two rectangular-shaped sections (Figure 2). The dry *Luffa cylindrica* plot covered an area of 4.77 m^2 and contained 8 rows and 12 columns of paddy plants (Figure 3, 4). The non-luffa plot covered an area of 1.06 m^2 and contained 8 rows and 4 columns of paddy plants.

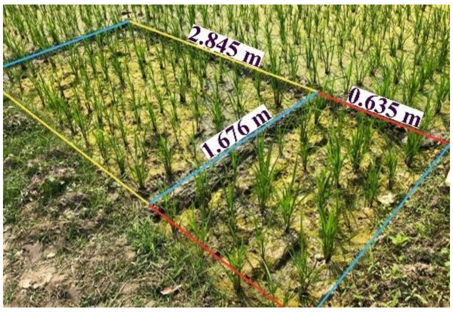

Figure 2. Paddy field's with and without Luffa cylindrica sections

Figure 3. Preparation of paddy field with Luffa cylindrica

Figure 4. Implementation of *Luffa cylindrica*

Research methods

The primary factors contributing to water loss are vaporization and seepage, and two systems were developed to precisely quantify these amounts. To gain a comprehensive understanding on the possibility of reducing water consumption in irrigating rice fields and identify factors associated with irrigation, extensive measurements were undertaken. Various systems and methods were employed to conduct these measurements.

1. System 01 (to measure vaporization rate). A cuboid-shaped glass container with dimensions of 0.3 m (length) × 0.18 m (breadth) × 0.2 m (height) was utilized to determine the rate of vaporization. A portion of 0.09 m in height was filled with soil from the paddy field to replicate real-world conditions. The container was open at the top to allow vapor to escape. It was positioned outdoors for a duration of 4 days to enhance accuracy in the experiment (Figure 5).

a

b

Figure 5. System 01: a – initial height; b – after 2 days

2. System 02 (to measure water seepage rate). A cuboid-shaped tin container with dimensions of 0.24 m (length) × 0.215 m (breadth) × 0.34 m (height) was employed to determine the rate of water seepage per hour. The container was partially open at both the top and bottom sides. It was filled with three layers of soil, with each layer measuring 0.09 m in height within the container. To prevent blockage from mud, sponges were placed at the bottom of the system. The experiment was conducted outdoors during night-time to eliminate the influence of sunlight (Figure 6).

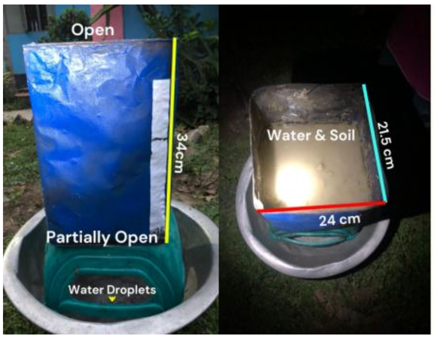

Figure 6. System 02

3. Water capacity of Luffa cylindrica. To determine the water-holding capacity of Luffa's fibre, a weight scale was utilized. Additionally, to ascertain the volume of a *Luffa cylindrica*, a mould of an average-sized *Luffa cylindrica* was created using mud.

4. Water level depth. To monitor the soil moisture level over time in the field, a method involving the use of a stick was employed at three distinct locations. The stick was inserted into the mud with consistent pressure to gauge its penetration depth. Subsequently, the depth of insertion was measured using a millimetre-level scale (Figure 7).

Figure 7. Depth of a stick by applying same force

5. Water Capacity of Luffa cylindrica. *Luffa cylindrica*, also known as dry sponge gourd, is a biological sponge with the capacity to absorb water into its fibres. To determine its water absorption capability, several dry luffas were cut into pieces to facilitate water absorption solely into their fibres. These pieces were then soaked in water for an hour, allowing for the measurement of weight differences between dry and wet luffa samples (Figure 8).

Figure 8. Dry and wet *Luffa cylindrica*

6. Limitations. Due to insufficient funding and the current level of development of the agricultural sector in the region under study, the current study has some limitations, as indicated below:

– limited funding and resources hindered extensive soil testing, preventing the identification of luffa's fertilization effect after degradation;

– irregular irrigation, caused by load shedding, resulted in intermittent watering, with plants submerged in lower-than-recommended water levels;

– water spillage beyond the designated field boundaries occurred during the experiment.

RESULTS

Vaporization rate

From System 01, it was observed that the water level decreased by 0.07 m and 0.08 m in the first two days, respectively, after placing the system outdoors. During this period, the average humidity was 54%, with an average temperature of 32 °C.

Subsequently, in the following two days, the water level decreased by 0.09 m and 0.08 m, respectively. The average humidity during this period was 52.5%, with an average temperature of 32.5 °C. These observations provide insights into the water loss dynamics of the system under varying environmental conditions, highlighting the influence of humidity and temperature on evaporation rates (Table 1, Figure 9).

Seepage rate

Using the second system constructed, the seepage rate of water over time was investigated in both Alluvial and Clay soil types. Upon pouring water into the soil, it took approximately 6 min for water to begin seeping from the bottom side of the system. In each soil layer, the initial seepage rate was higher due to elevated surface moisture tension and the presence of air pockets, which gradually filled with mud over time.

The test was conducted over an 8-hour period, during which the seepage rate of water exhibited a gradual decline until the 7th hour. After the 7th hour, the seepage rate stabilized, remaining constant at 0.67 L m^{-2} h^{-1}. This consistent seepage rate indicates a steady flow of water through the soil, providing valuable insights into its permeability characteristics and behaviour over time (Table 2, Figure 10).

Water quality over time

The water quality of the irrigation water was monitored over time, focusing on parameters such as Total Dissolved Solids (TDS), Electrical Conductivity (EC), pH, and temperature. It was observed that TDS, EC, and pH levels increased as the water levels dropped due to evaporation. As water evaporates, the concentration of minerals and salts in the remaining water increases, leading to higher TDS and EC readings (Table 3). Additionally, pH levels tend to rise as the water becomes more concentrated with minerals.

These minerals, while beneficial for plant growth as they provide essential nutrients, can accumulate in the soil over time. As a result, a dark brown layer may form, indicating the presence of these minerals. While this layer can contribute to soil fertility, it is essential to monitor water quality parameters to ensure optimal conditions for plant growth and prevent excessive mineral build-up in the soil.

Table 1. Experimental data of the study of the evaporation rate

Day	Δh, m	Area, m^2	Water loss, L	Vaporization rate, L m^{-2} h^{-1}	Humid	Temperature, °C
1	0.07	0.054	0.378	0.292	56%	31.8
2	0.08		0.432	0.33	52%	32.2
3	0.09		0.486	0.375	50%	32.8
4	0.08		0.432	0.33	53%	32.3

Table 2. Experimental data of the study of the seepage rate

Time, hour	Seeped water (single layer), ml	Seeped water (double layer), ml	Seeped water (triple layer), ml	Area, m^2	Seepage rate, Lm^{-2}h^{-1}
1	65	57	55	0.0516	0.82
2	48	42	37		0.801
3	46	39	37		0.788
4	41	38	35		0.736
5	38	36	34		0.698
6	37	35	33		0.678
7	36	35	33		0.67
8	36	35	33		0.67

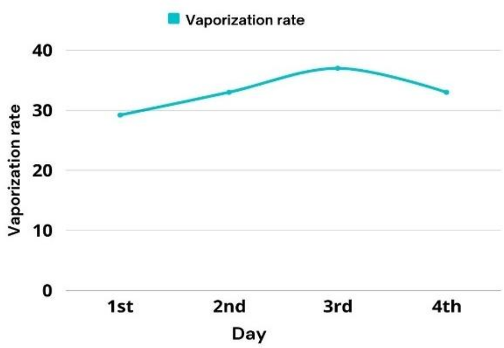

Figure 9. Vaporization rate
(values are multiplied by 100, L m^{-2} h^{-1}) (own results)

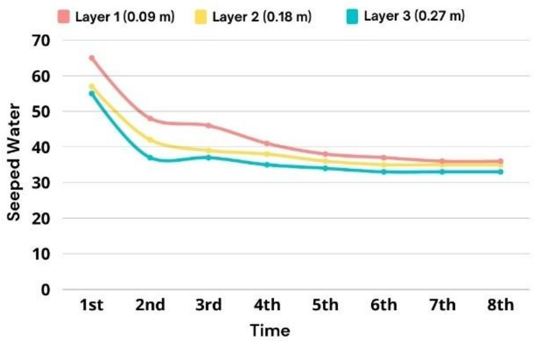

Figure 10. Seepage rate
(ml per 0.0515 m^2) (own results)

Table 3. Water quality over time

Time, hour	TDS, ppm	EC, µS	pH	Temperature, °C
0	473	966	7.21	32.2
3	496	990	7.32	34
6	524	1022	7.46	35.6
9	570	1112	7.57	35.2
12	611	1193	7.6	32

Weather records

The tests were conducted between February 14, 2024, and April 20, 2024 (Table 4). Throughout this period, the weather exhibited significant variability, which influenced the test results. Initially, the weather was relatively cool with higher humidity and partly cloudy conditions. However, as time progressed, the temperature gradually increased, accompanied by a decrease in humidity, as sunny days became more frequent. Although there were instances of rainfall during the testing period, the duration of precipitation events was brief (Figure 11, Figure 12).

Water capacity of *Luffa cylindrica*

The weight differential between dry and wet *Luffa cylindrica* was quantified at 1114 g. Remarkably, a dry *Luffa cylindrica* can absorb an astounding 492.9% more water relative to the weight of its fibre. Additionally, when integrated into mud, the structural composition of *Luffa cylindrica* enables it to retain water within its hollow tubes and empty spaces. The water storage capacity within these hollow tubes exceeds the volume of the fibres, resulting in a remarkable increase in water retention. Specifically, the volume of water that can be stored in the hollow tubes of *Luffa cylindrica*, relative to its dry weight, amounts to an impressive 45016%. When considering both stages of water absorption and storage, the total water retention capacity of *Luffa cylindrica* amounts to an astonishing 45509.6% more than its dry weight (Table 5, Figure 13).

Table 4. Weather record

Day	at 12 am		at 12 pm		Day type
	Temperature, °C	Humidity, %	Temperature, °C	Humidity, %	
0	20	74	28	39	PC
5	21	76	30	43	Haze
10	20	87	28	44	SC
15	21	74	30	38	PS
20	25	66	30	32	S
25	21	53	29	23	S
30	25	87	34	40	SC
35	24	72	27	67	LC
40	27	90	34	61	PS
45	27	88	38	36	S
50	28	67	36	34	SC
55	28	60	37	33	PS
60	30	86	38	36	PC
65	31	84	39	33	PC

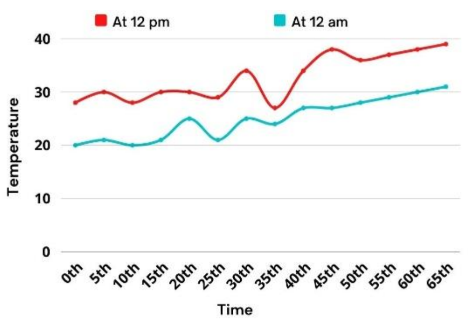

Figure 11. Weather records of temperature, °C (own results)

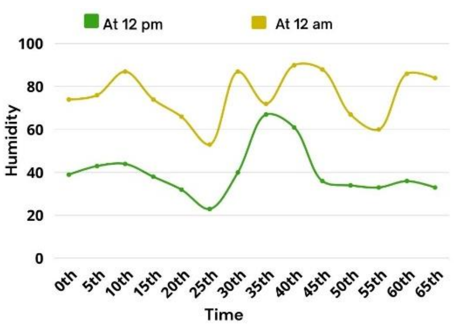

Figure 12. Weather records of humidity, % (own results)

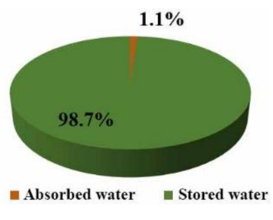

Figure 13. Water capacity of *Luffa cylindrica* (own results)

Table 5. Water capacity of *Luffa cylindrica*

1st stage absorption by Luffa's fibre			2nd stage storing in Luffa's structure				L_t, %
L_d, g	L_w, g	L_f, %	X, g	V_l, ml	V_f, ml	L_s, %	
226	1340	492.9	1.2	687.2	147	45016.7	45509.6

L_d – weight of dry *Luffa cylindrica*; L_w – wight of wet *Luffa cylindrica*; $L_f = \frac{Lw - Ld}{Ld}$ 100% – water capacity of Luffa's fibre by weight; X – weight of an average *Luffa cylindrica*; V_l – volume of an average *Luffa cylindrica*; V_f – volume of an average Luffa's fibre; $L_s = \frac{Vl - Vf}{X}$ 100% – water kept in the empty space by weight; $L_t = L_f + L_s$ – total capacity.

Soil moisture

The initial observation indicated that the field was submerged to a depth of 0.02 m, allowing the stick to penetrate the mud at a depth of 0.039 – 0.041 m. As time progressed, the water level gradually receded, permitting the stick to penetrate the soil to a depth of approximately 0.02 m within a span of 3 hours. Soil moisture tension, in conjunction with gravity, initially facilitated rapid soil moisture absorption. However, after 15 hours, the rate of soil moisture increase decelerated, indicating a saturation point (Table 6).

In the 15th hour, the maximum depth the stick could penetrate in the field without *Luffa cylindrica* was 0.282 m, while in the field with *Luffa cylindrica*, it took an additional 12 hours to reach the highest depth of 0.304 m. Subsequently, it was observed that the field without *Luffa cylindrica* dried significantly quicker compared to the field with *Luffa cylindrica*. By the 39th hour, the field without *Luffa cylindrica*, along with the surrounding fields, had dried sufficiently for irrigation. In contrast, it took an additional 18 hours for the field with *Luffa cylindrica* to reach a similar level of soil dryness. Moreover, the rate of water seepage from the soil was notably slower than the rate of water infiltration, indicating enhanced water retention in the presence of *Luffa cylindrica* (Figure 14).

Total water

Due to frequent power outages, the pump struggled to extract enough water to adequately irrigate the field to the recommended level. Consequently, the irrigation frequency exceeded the optimal threshold to achieve the desired outcome. Additionally, more water was required to fill the field containing *Luffa cylindrica* compared to the one without, as the dry *Luffa cylindrica* needed to be saturated as well. Despite these challenges, utilizing *Luffa cylindrica* resulted in an estimated water saving of 26.97% (Table 7).

The table outlines water usage in two fields over 65 days, one with *Luffa cylindrica* plants and one without. It shows the number of irrigations, water volume used per irrigation, and calculates water usage per square meter. Despite challenges like power outages and the need to saturate *Luffa cylindrica* plants, using *Luffa cylindrica* saved approximately 27% of water (Figure15).

Table 6. Soil moisture by stick depth (17 – 20 March 2024)

Time, hour	Soil moisture measured by a stick							
	Field without *Luffa cylindrica*				Field With *Luffa cylindrica*			
	Spot A, m	Spot B, m	Spot C, m	Avg depth, m	Spot A, m	Spot B, m	Spot C, m	Avg depth, m
0	0.039	0.034	0.040	0.0377	0.042	0.039	0.041	0.0400
3	0.172	0.165	0.180	0.1720	0.208	0.197	0.205	0.2033
6	0.221	0.217	0.234	0.2250	0.262	0.269	0.266	0.2623
9	0.266	0.261	0.268	0.2650	0.273	0.277	0.277	0.2757
12	0.272	0.271	0.272	0.2717	0.279	0.281	0.279	0.2797
15	0.283	0.282	0.283	0.2827	0.280	0.288	0.286	0.2840
18	0.280	0.278	0.277	0.2783	0.282	0.293	0.291	0.2886
21	0.265	0.262	0.269	0.2653	0.303	0.310	0.311	0.3080
24	0.245	0.248	20.47	0.2467	0.299	0.308	0.306	0.3043
27	0.214	0.213	0.211	0.2127	0.292	0.303	0.301	0.2987
30	0.186	0.184	0.184	0.1847	0.272	0.273	0.276	0.2736
33	0.109	0.114	0.111	0.1113	0.250	0.254	0.231	0.2450
36	0.072	0.075	0.072	0.0730	0.227	0.214	0.208	0.2163
39	0.039	0.041	0.040	0.0400	0.208	0.206	0.193	0.2023
42	–	–	–	–	0.187	0.181	0.172	0.1800
45	–	–	–	–	0.158	0.160	0.159	0.1590
48	–	–	–	–	0.142	0.145	0.139	0.1420
51	–	–	–	–	0.121	0.122	0.117	0.1200
54	–	–	–	–	0.078	0.080	0.074	0.0773
57	–	–	–	–	0.059	0.061	0.055	0.0583

Table 7. Total water used and saved (1st 65 days)

Days	Water level, mm	Field without *Luffa cylindrica*				Field with *Luffa cylindrica*				E, m^{-2}
		N	M, L	A, m^2	m, $L \cdot m^{-2}$	N	M, L	A, m^2	m, $L \cdot m^{-2}$	
1 – 25	15 – 25	15	27.4	1.055	389.57	10	134.4	4.77	281.76	26.97%
26 – 46	20 – 35	11	34.5		359.7	8	170		285.1	
47 – 65	30 – 45	18	43		733.6	12	224		516	
				Total T1 = 1482.87				Total T2 =1082.86		

N – number of irrigation; M – weight of the water each time; A – area of the study area; m = $\frac{N \cdot M}{A}$ – water used; E = $\frac{(T1 - T2)}{T2}$ 100% – water saver.

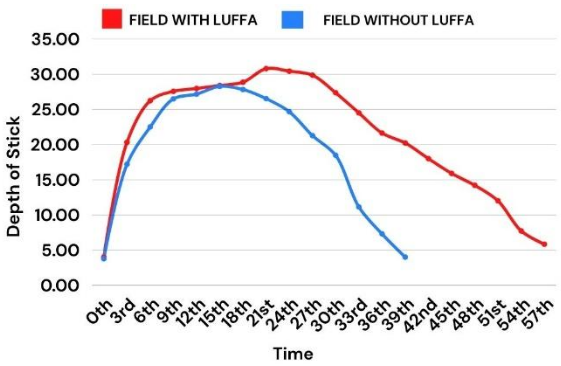

Figure 14. Soil moisture (own results)

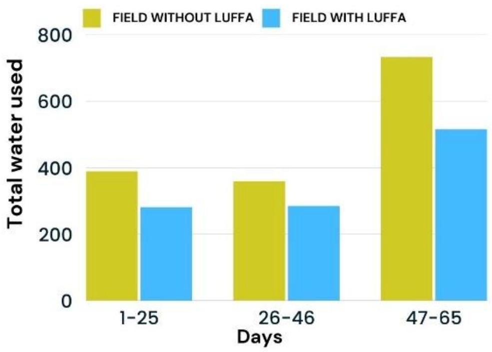

Figure 15. Total water used in 1st 48 days (own results)

DISCUSSIONS

The sponge gourd, also known as *Luffa cylindrica*, native to South Asia, possesses a myriad of properties that render it well-suited for tackling water management challenges in agriculture. Its fibrous composition, comprising a central core enveloped by hollow tubes and an outer layer of densely packed fibres, creates an optimal environment for storing water within the soil. Illustrated in the accompanying images, this two-step water retention process showcases how *Luffa cylindrica* acts as a miniature aquifer, efficiently holding water for nearby plants (Figure 16, 17).

Figure 16. Luffa working as a mini aquifer

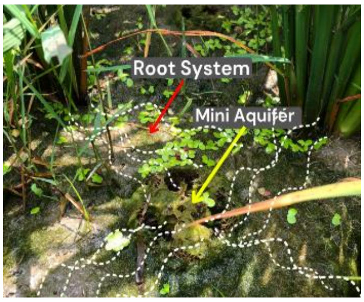

Figure 17. Root system developing inside *Luffa cylindrica*

The root system of paddy plants gradually extends, enveloping the fibres of *Luffa cylindrica* as it retains moisture during periods of soil dryness. Simultaneously, bacteria, snails, algae, and other microorganisms establish a habitat around the *Luffa cylindrica* due to its water content, providing sustenance and oxygen, essential elements for various life forms (Figure 18, 19).

Figure 18. Root system of paddy surrounding *Luffa cylindrica*

Figure 19. *Luffa cylindrica* working as a habitat

Comparing fields with and without *Luffa cylindrica* reveals a notable contrast in water storage capacity. Initial observations suggest that integrating *Luffa cylindrica* into paddy fields improves water retention, thereby reducing losses attributed to evaporation and seepage. Utilizing the equation for water loss

journal homepage: https://www.teiee.net/

depicted earlier, calculations demonstrate the significant decrease in water losses and the consequent savings attained through the adoption of *Luffa cylindrica*.

Calculation on water reduction

The seepage rate (μ) was found to be influenced by soil density (d), soil type, and gravity, with the relationship described as follows:

$$\mu \propto \frac{1}{d}1. \quad (1)$$

Whereas, the vaporization rate (β) was found to be influenced by sunlight density, temperature, and humidity, with the relationship expressed as:

$$\beta = \frac{K\,(\alpha \cdot T)}{q}, \quad (2)$$

where K is a constant; α is sunlight density; T is temperature; q is humidity.

In the field without *Luffa cylindrica*, it was observed that the soil dried out more rapidly compared to the field where *Luffa cylindrica* was present. *Luffa cylindrica* acts as a reservoir for water, retaining moisture within its structure. When the surrounding soil experiences a decrease in moisture content, the soil moisture tension prompts the release of water stored within the *Luffa cylindrica*, thereby keeping the soil consistently moist for extended periods. This mechanism helps prevent rapid soil drying and maintains a moist and conducive environment for plant growth (Figure 20, 21).

Figure 20. Dried field without *Luffa cylindrica*

Figure 21. Muddy field with *Luffa cylindrica*

Availability of *Luffa cylindrica*

In the context of Bangladesh, where water scarcity is increasingly prevalent, the presence of *Luffa cylindrica* offers a promising solution. Its resilient nature, as discussed earlier, suggests that *Luffa cylindrica* could be effectively cultivated across various regions, thereby contributing to water conservation efforts. Additionally, being native to South Asian countries, *Luffa cylindrica* grows abundantly in village areas with minimal care. However, for large-scale implementation, farmers should consider cultivating *Luffa cylindrica* during the winter season when conditions are favourable for growth. Cultivating *Luffa cylindrica* along riverbanks or other water bodies can ensure sufficient water supply for the plants. Furthermore, the adoption of hybrid *Luffa cylindrica* varieties can enable farmers to cultivate larger quantities of *Luffa cylindrica*, meeting both vegetable demand and providing additional income through market sales. Any surplus *Luffa cylindrica* can be dried and utilized in the fields, further maximizing its utility and sustainability (Figure 22, 23).

Figure 22. Native small sized luffa

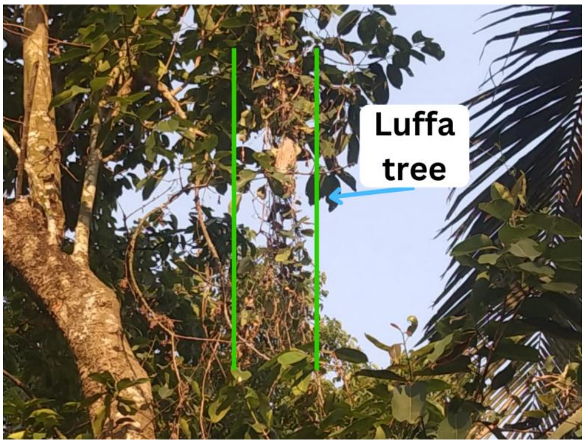

Figure 23. Wild *Luffa cylindrica* tree

Eco-Friendly and Cost-Effectiveness

Moreover, the eco-friendliness and cost-effectiveness of *Luffa cylindrica* underscore its potential as a sustainable solution for water management. By offering benefits such as natural fertilization and water conservation simultaneously, *Luffa cylindrica* represents a holistic approach to agricultural sustainability. Since *Luffa cylindrica* is readily accessible to farmers, cultivation requires minimal costs. Farmers would primarily incur labor expenses, which are outweighed by the benefits. Additionally, for large-scale operations, machinery could be employed instead of manual labor, further reducing overall costs.

Cost Analysis

Cost analysis shows the economic viability of switching to *Luffa cylindrica* cultivation for farmers, with significant savings in irrigation costs. Previous Boro (HYV) rice cultivation incurred 89,129 – 96,886 BDT per hectare or 810 – 880 USD per hectare (Chanda et al., 2019), with 34 – 43% spent on irrigation (Mim et al., 2021). Transitioning to *Luffa cylindrica* could save 35,807 BDT or 325 USD per hectare in irrigation costs alone. Moreover, *Luffa cylindrica* requires 27% less water and reduces fertilizer needs, further cutting costs.

Quality Analysis

Quality analysis underscores Luffa's added benefits, particularly its capacity to foster beneficial microbial communities and supply essential nutrients to plants post-decomposition (Figure 24). Luffa's fibre composition, consisting of cellulose, hemicellulose, lignin, and other components, serves as a food source for numerous microorganisms. These microorganisms break down the fibre content, releasing nitrogen-rich by-products crucial for the growth of rice plants (Figure 25). The gradual release of nutrients not only enriches soil fertility but also sustains it over time.

Figure 24. Luffa's fertilization properties

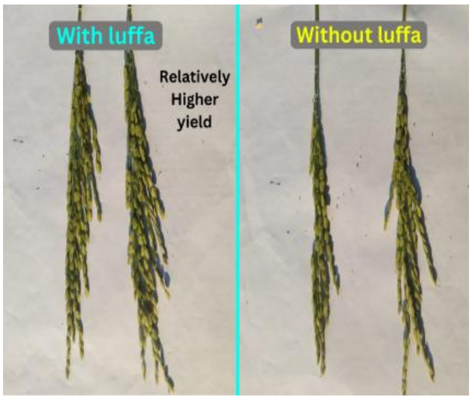

Figure 25. Relatively higher yield

Advantages

Luffa cylindrica offers dual benefits in agriculture:

1) natural fertilizer: *Luffa cylindrica* plants naturally enrich soil fertility by absorbing and accumulating nutrients as they grow. When incorporated back into the soil, they release these nutrients gradually, promoting better plant growth and improving soil structure. The decomposition of *Luffa cylindrica* biomass also enhances microbial activity, further boosting soil fertility over time;

2) water-saving mechanism: Luffa's extensive root systems allow it to access moisture from deeper soil layers, reducing the need for frequent irrigation. Additionally, its dense foliage creates a natural canopy that retains soil moisture by minimizing evaporation. Using *Luffa cylindrica* as part of a water-saving strategy helps minimize water wastage, optimize irrigation practices, and increase farming resilience in water-stressed regions.

Future research

However, there is a need for future research to optimize implementation methods and evaluate the long-term effects of *Luffa cylindrica* on soil fertility and crop productivity. Through conducting additional studies in these domains, we can enhance and broaden the potential applications of *Luffa cylindrica* in agricultural practices, thereby advancing sustainable water management strategies for the future. The implementation method used in this project is based on trial and error so the best method to use *Luffa cylindrica* in agriculture is yet to be find out.

Additionally, the *Luffa cylindrica* specimens utilized in this study were sourced from native plants known for producing small-sized fruits. Employing larger *Luffa cylindrica* varieties could potentially extend the intervals between irrigation, thereby reducing water usage and losses. Further research on implementation methods is warranted to identify optimal techniques that are practical and more beneficial for farmers.

CONCLUSION

The utilization of *Luffa cylindrica*, a native plant with versatile properties, presents a promising solution to address the pressing issue of water scarcity in agriculture. Through meticulous experimentation and analysis, this study has demonstrated the efficacy of *Luffa cylindrica* in reducing water consumption and enhancing soil moisture retention in paddy fields. By leveraging the fibrous structure of dry *Luffa cylindrica*, water losses due to evapotranspiration and seepage were significantly mitigated, resulting in substantial water savings and cost reduction for farmers.

Moreover, the implementation of *Luffa cylindrica* not only conserves water but also promotes ecological balance and soil health. The symbiotic relationship between *Luffa cylindrica* and beneficial microorganisms creates a conducive environment for plant growth while minimizing reliance on artificial fertilizers. Additionally, *Luffa cylindrica* natural decomposition process enriches the soil with essential nutrients, further enhancing its fertility over time.

The eco-friendly and cost-effective nature of *Luffa cylindrica* underscores its potential as a sustainable water management solution for agricultural practices. Its accessibility and ease of cultivation make it a viable option for farmers, with minimal investment required to implement this method on a larger scale. Cost analysis reveals significant savings in irrigation expenses, coupled with the reduction in fertilizer usage, thus offering economic benefits to farmers.

However, further research is warranted to optimize implementation methods and assess the long-term impact of *Luffa cylindrica* on soil fertility and crop productivity. By refining and expanding upon the current findings, we can unlock the full potential of *Luffa cylindrica* in revolutionizing agricultural water management practices. Future endeavours should focus on exploring diverse cultivation techniques, including hybrid *Luffa cylindrica* varieties and mechanized farming, to maximize the efficiency and scalability of *Luffa*-based water conservation methods.

Acknowledgement

We extend our heartfelt gratitude to all those who have supported us throughout this research project.

First and foremost, we express our gratitude to our uncle, Pabul Sikder, a respected farmer whose invaluable insights and guidance were instrumental in refining our methods. We are especially thankful to him for providing us with access to a section of his paddy field, which enabled us to conduct our experiments.

Our sincere appreciation goes to our father, Kabul Sikder, whose support in building systems and prototypes greatly facilitated our research efforts. We are also grateful for his significant contribution towards funding this study project.

We would like to express our boundless gratitude to our mother, Panna Aktar, for generously allowing us to utilize her kitchen as a laboratory and providing us with the necessary tools for experimentation. Her encouragement, albeit sometimes in the form of stern words, served as a driving force behind this study.

Lastly, we thank our younger cousin brother, Sajid Sikder, for his unwavering assistance, from carrying tools to tending to the plants and keeping us informed about the weather conditions. His support was invaluable throughout the duration of this project.

Author's statements

Contributions

The authors contributed equally to all aspects of the current study and preparation of the manuscript.

Declaration of conflicting interest

The authors declare no competing interests.

Financial interests

The authors declare they have no financial interests.

Funding

Not applicable.

Data availability statement

No data were used for the current study.

AI Disclosure

The authors declare that generative AI was not used to assist in writing this manuscript.

Ethical approval declarations

Not applicable.

Additional information

Publisher's note

Publisher remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

The initial version of the research manuscript was published as a preprint:

https://doi.org/10.13140/RG.2.2.29429.59367.

REFERENCES

Anastopoulos, I., & Pashalidis, I. (2020). Environmental applications of Luffa cylindrica-based adsorbents. *Journal of Molecular Liquids*, 319, 114127. https://doi.org/10.1016/j.molliq.2020.114127.

Attwater, R., Anderson, L., & Derry, C. (2016). Agricultural risk management of a peri-urban water recycling scheme to meet mixed land-use needs. *Agricultural Water Management*, 176, 266–269. https://doi.org/10.1016/j.agwat.2016.05.025.

Chanda, S. C., Ali, M. A., Haque, M. E., Abdullah, M. R., & Sarwar, A. G. (2019). Cost of production and cost benefit analysis of different rice in Sirajganj district. *Asian Journal of Crop, Soil Science and Plant Nutrition*, 1(1), 7–14. https://doi.org/10.18801/ajcsp.010119.02.

FAO. (2017). Water for Sustainable Food and Agriculture: A report produced for the G20 Presidency of Germany. Rome. Available: http://www.fao.org/publications.

Gurjar, A. K., Kulkarni, S. M., Joladarashi, S., & Doddamani, S. (2024). Investigation of mechanical properties of luffa fibre reinforced natural rubber composites: Implications of process parameters. *Journal of Materials Research and Technology*, 29, 4232–4244. https://doi.org/10.1016/j.jmrt.2024.02.133.

Han, Y., Shi, M., Lee, S., Lin, R., Wang, K. J., & Wang, X. Y. (2024). Application of porous luffa fiber as a natural internal curing material in high-strength mortar. *Construction and Building Materials*, 455, 139169. https://doi.org/10.1016/j.conbuildmat.2024.139169.

Ibarrola-Rivas, M. J., Kastner, T., & Nonhebel, S. (2016). How much time does a farmer spend to produce my food? An international comparison of the impact of diets and mechanization. *Resources*, 5(4), 47. https://doi.org/10.3390/resources5040047.

International Rice Research Institute (IRRI). (2024). Water Management in Rice Fields. In Step-by-Step Production: Growth. Available: http://www.knowledgebank.irri.org/step-by-step-production/growth/water-management.

Mim, T. T., Sheikh, M. H., Chowdhury, S., Akter, R., Khan, M. A. A., & Habib, M. T. (2021). Deep learning based sponge gourd diseases recognition for commercial cultivation in Bangladesh. *In Artificial Intelligence and Industrial Applications: Smart Operation Management* (pp. 415–427). Springer International Publishing. https://doi.org/10.1007/978-3-030-51186-9_29.

Psarra, E., & Papanicolaou, G. C. (2021). Luffa Cylindrica as a durable biofiber reinforcement for epoxy systems. Composites Science and Technology, 203, 108597. https://doi.org/10.1016/j.compscitech.2020.108597.

Rahaman, K. M., Ahmed, F. R. S., & Nazrul Islam, M. (2016). Modeling on climate induced drought of north-western region, Bangladesh. *Modeling Earth Systems and Environment*, 2, 1–21. https://doi.org/10.1007/s40808-016-0089-7.

Sahayaraj, F., Muthukrishnan, M., & Jenish, I. (2023). Extraction and Characterization of Sponge Gourd Outer Skin Fiber. *Journal of Natural Fibers*, 20(2). https://doi.org/10.1080/15440478.2023.2208888.

United Nations. (2014). The United Nations world water development report Water and Energy, vol. 1, *UNESCO, Paris*, France.

Zhang, K., Weng, B., Cheng, D., Guo, Y., Chen, T., Wang, L., ... & Chen, Y. (2021). Influence of chemical treatment and drying method on the properties of cellulose fibers of luffa sponge. *International Journal of Biological Macromolecules*, 180, 112–120. https://doi.org/10.1016/j.ijbiomac.2021.03.053.