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Water Consumption Analysis Of An Automated Irrigation System Based On Soil Moisture Monitoring

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Abstract – This article presents the development, implementation, and evaluation of an automated irrigation system designed for cotton cultivation on clay-sandy soil. Efficient irrigation management is essential for optimizing crop yield, particularly in soils with specific water retention characteristics. The proposed system integrates soil moisture sensors, solenoid valves, and a microcontroller-based control unit using an Arduino Uno board to automate the irrigation process. The water supply is managed through a 5000-liter reservoir, which is refilled by a 370-watt pump. The system operates based on soil moisture thresholds, activating the solenoid valves when the moisture level drops below 35 percent and deactivating them when it reaches 50 percent, ensuring optimal hydration for cotton growth.

To assess system performance, experiments were conducted under different climatic conditions. The study includes a detailed analysis of soil moisture variation and water consumption in both sunny and cloudy conditions. Solar irradiation significantly influences soil evaporation, leading to differences in irrigation frequency and water usage. Under sunny conditions with a solar irradiation coefficient of 7929 watt-hours per square meter, moisture depletion occurs faster, requiring more frequent irrigation cycles. In contrast, under cloudy conditions with a reduced solar irradiation coefficient of 3172 watt-hours per square meter, soil moisture retention is prolonged, reducing water consumption.

The results demonstrate that automated irrigation based on real-time soil moisture monitoring improves water efficiency while adapting to environmental variations, making it a sustainable solution for optimizing irrigation in cotton cultivation.

Keywords – Water pump, Reservoir, Pipes, Sprinklers, Solenoid valves, Soil moisture sensors, Arduino board

1. INTRODUCTION

Efficient irrigation is crucial for maximizing cotton crop yield, especially on sandy-clay soils that have specific water retention characteristics. Automating irrigation based on moisture sensors allows for precise water supply adjustments according to the plants' actual needs while considering environmental conditions such as sunlight exposure.

2. LITERATURE REVIEW

Previous studies have demonstrated the importance of controlled irrigation for cotton. For example, Allen et al. (1998) provided guidelines for calculating crop water requirements, emphasizing the significance of precise irrigation management. Li and Bai

(2021) examined smart irrigation systems based on moisture sensors and IoT technology, highlighting their efficiency in optimizing water use. Zotarelli et al. (2011) detailed the calculation of evapotranspiration using the Penman-Monteith method, which is essential for determining crop water needs.

3. METHODOLOGIES

3.1. System Description

The electronic irrigation system is based on several essential components :

- **Soil moisture sensors** : Six sensors are evenly distributed to measure moisture levels in different areas of the field.
- **Arduino Uno board** : Processes sensor data and controls the solenoid valves.
- **12-Volt solenoid valves** : Regulate water flow to different sections of the field, controlled by IRLZ34N MOSFET transistors.
- **Cofan 360° sprinklers** : Six sprinklers ensure uniform water distribution with a flow rate of 30 liters per minute and a spraying radius of 4 meters.
- **370-Watt pump (HMT = 30 m)** : Supplies a 5000-liter reservoir, ensuring adequate pressure for irrigation.
- **Electric float switch** : Manages the water level in the reservoir, activating the pump when the level drops below 1000 liters and stopping it at 4500 liters.
- **40 mm pipes** : Ensure uniform water distribution to the sprinklers.

3.2. System Operation

The moisture sensors measure the water level in the soil. At 35% humidity, the solenoid valves open to allow irrigation, then close once 50% is reached. Management is handled by an Arduino board, which activates the valves based on sensor data. A 3-meter elevated reservoir and a pump supply the sprinkler network to ensure efficient water distribution.

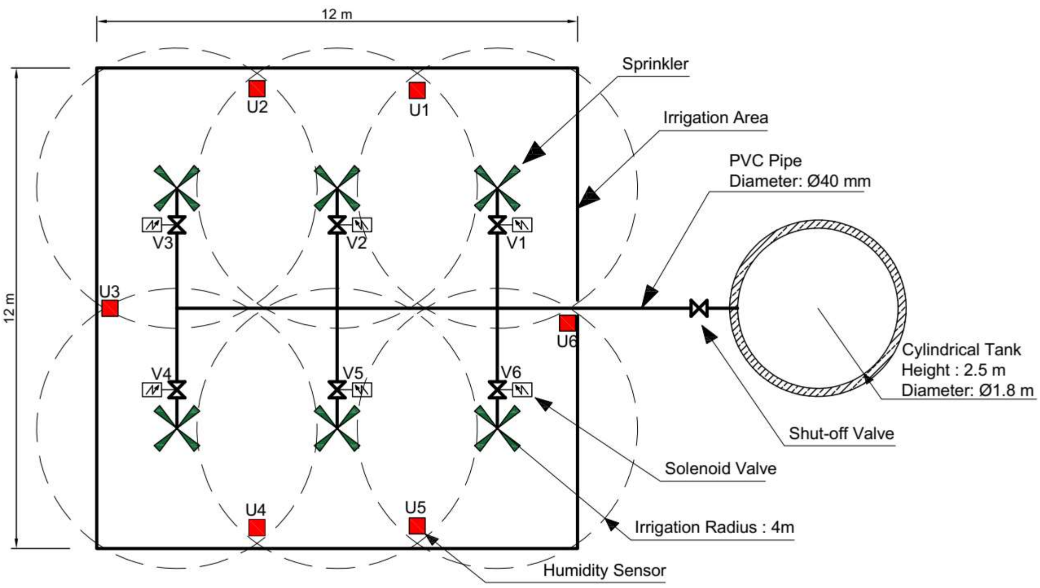

Figure 1 : Operating Diagram

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3.3. Electrical Diagram

The electrical diagram illustrates the wiring of the moisture sensors and solenoid valves connected to the Arduino board. Each sensor sends data to activate or deactivate the solenoid valves via IRLZ34N MOSFETs. A flyback diode is placed in parallel with each solenoid valve to protect the circuit. The system ensures automatic irrigation management based on soil moisture levels.

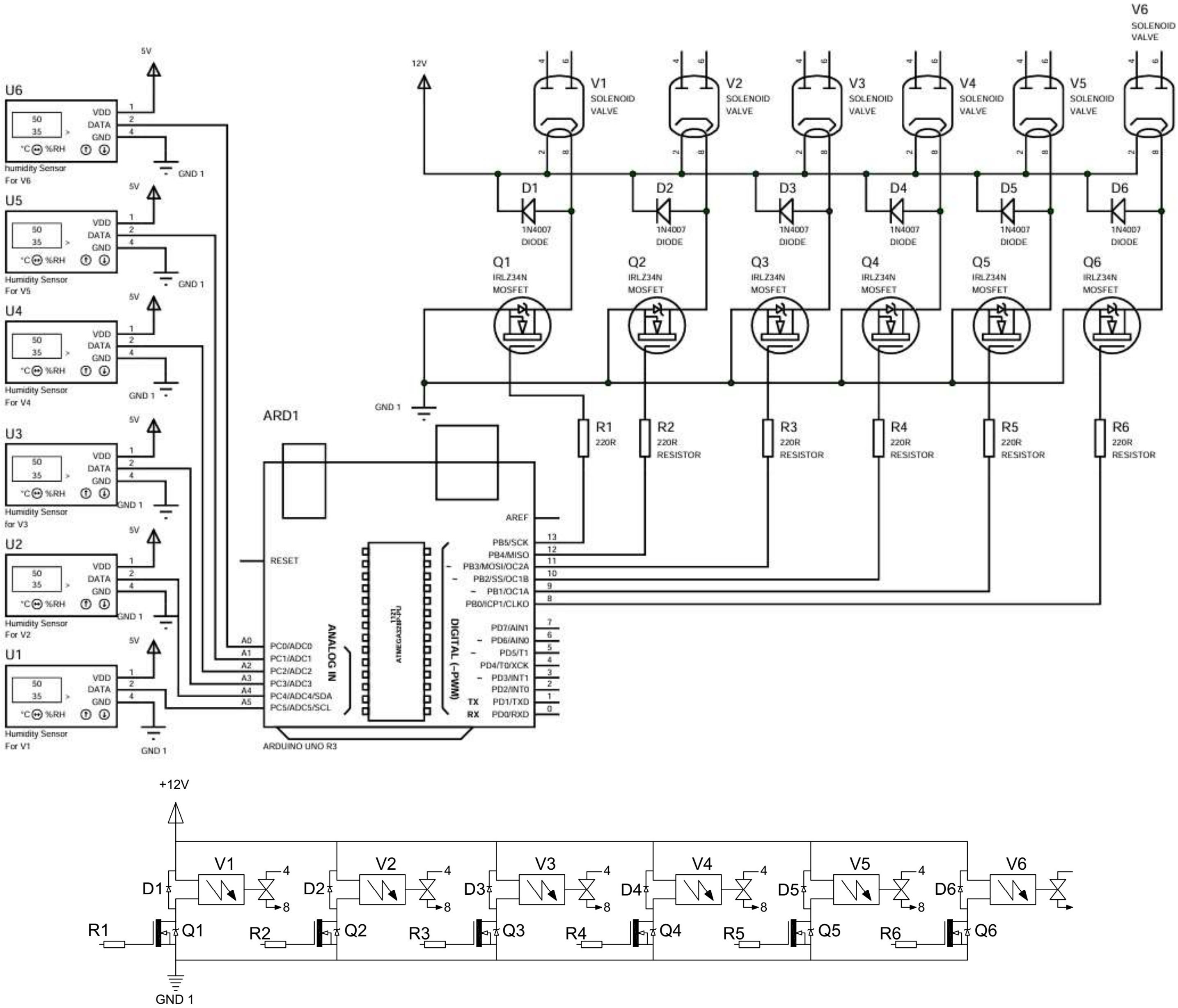

Figure 2 : Electrical Diagram

4. RESULTS

4.1. Soil Moisture and Water Consumption Over Time

Measurements were taken to observe the decrease in soil moisture and the volume of water consumed after irrigation, considering solar radiation levels during a sunny day and a cloudy day.

4.1.1. Results Obtained on a Sunny Day

The values recorded on a sunny day with a solar radiation coefficient of 7929 $\frac{Wh}{m^2}$allowed for the plotting of a curve representing the decrease in soil moisture and another curve representing the volume of water consumed after irrigation. These results show a rapid loss of soil moisture due to intense sunlight, leading to more frequent activation of the solenoid valves and, consequently, higher water consumption.

Tableau 1 : Soil Moisture and Water Consumption on a Sunny Day (7929 $\frac{Wh}{m^2}$)

Time elapsed after irrigation in hours	Soil Moisture (%)	Water Consumption (L)	State of the Solenoid Valves
0 (At 06:00 AM)	50	0	Closed
1 (At 07:00 AM)	48	0	Closed
2 (At 08:00 AM)	45	0	Closed
3 (At 09:00 AM)	42	0	Closed
4 (At 10:00 AM)	39	0	Closed
5 (At 11:00 AM)	36	0	Closed
6 (At 12:00 PM)	35 (Activation Threshold)	1440	Open
7 (At 1:00 PM)	45	1440	Open
8 (At 2:00 PM)	50	1440	Closed

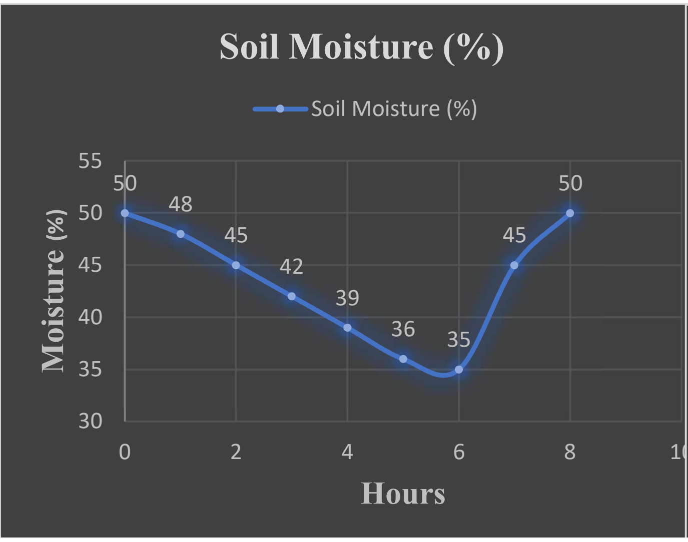

Figure 3 : Curve of soil moisture over time

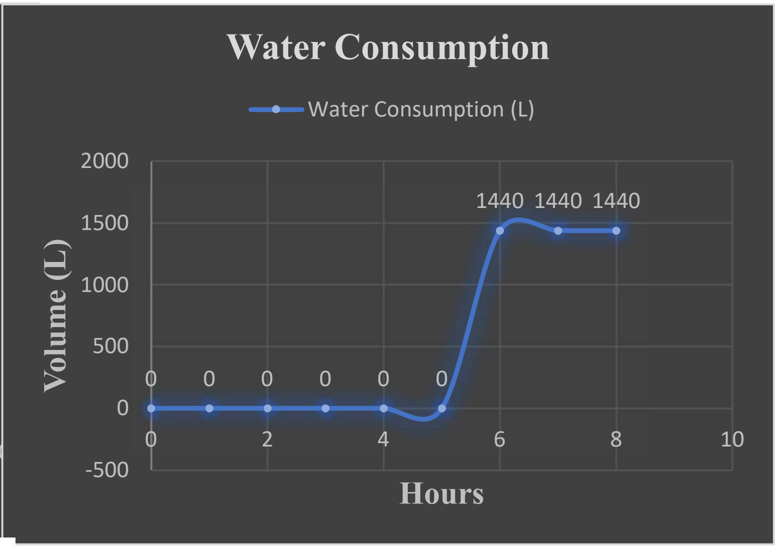

Figure 4 : Curve of water consumption over time

4.1.2. Interpretation

On a sunny day, soil moisture gradually decreases due to evapotranspiration and infiltration. When moisture reaches 35% at the 6th hour, the solenoid valves open, delivering 1440 L of water to compensate for losses and raise moisture to 50% at the 8th hour, where the solenoid valves close.

4.1.3. Results obtained on a cloudy day

In order to compare the effect of climatic conditions, we also conducted a test on a cloudy day with a reduced solar irradiation coefficient of 3172 $\frac{Wh}{m^2}$, which is approximately 40% of the coefficient on a sunny day (7929 $\frac{Wh}{m^2}$). The following table presents the values recorded in the field :

Tableau 2 : Soil Moisture and Water Consumption on a Cloudy Day (3172 $\frac{Wh}{m^2}$)

Time elapsed after irrigation in hours	Soil Moisture (%)	Water Consumption (L)	State of the Solenoid Valves
0 (At 06:00 AM)	50	0	Closed
2 (At 06:00 AM)	49	0	Closed
4 (At 06:00 AM)	47	0	Closed
6 (At 12:00 PM)	45	0	Closed
8 (At 2:00 PM)	42	0	Closed
10 (At 4:00 PM)	39	0	Closed
12 (At 6:00 PM)	36	0	Closed
14 (At 8:00 PM)	35	1440	Open
15 (At 9:00 PM)	45	1440	Open
16 (At 10:00 PM)	50	1440	Closed

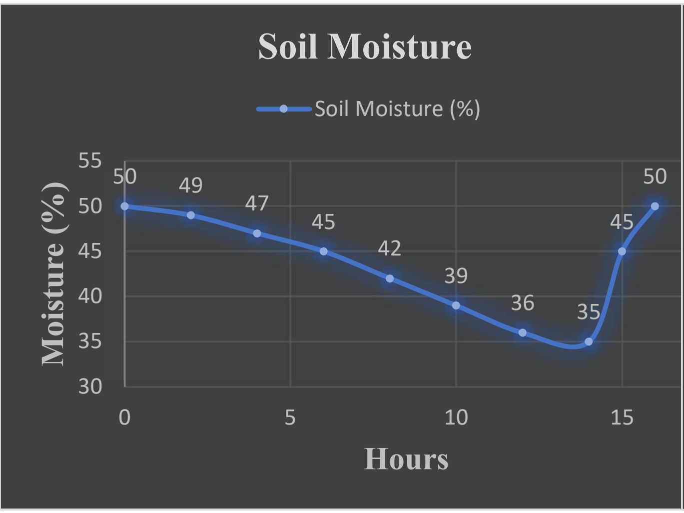

Figure 5 : Soil Moisture Curve Over Time

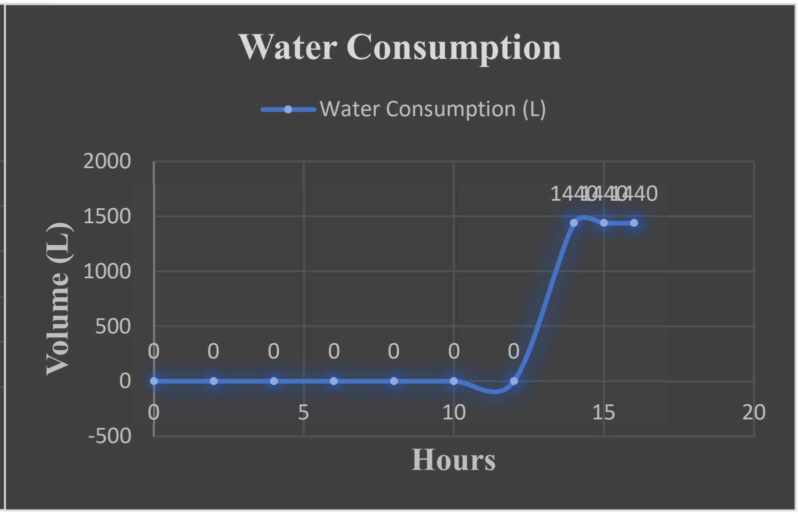

Figure 6 : Water Consumption Curve Over Time

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On a cloudy day, evapotranspiration and infiltration are reduced, slowing down the decrease in soil moisture. The solenoid valves activate at the 14th hour, delivering 1440 L of water, raising the moisture level to 50% by the 16th hour. This confirms that weather conditions directly influence the rate of water evaporation in the soil.

4.1.5. Comparisons

4.1.5.1. Comparison curves of soil moisture on a sunny day and a cloudy day

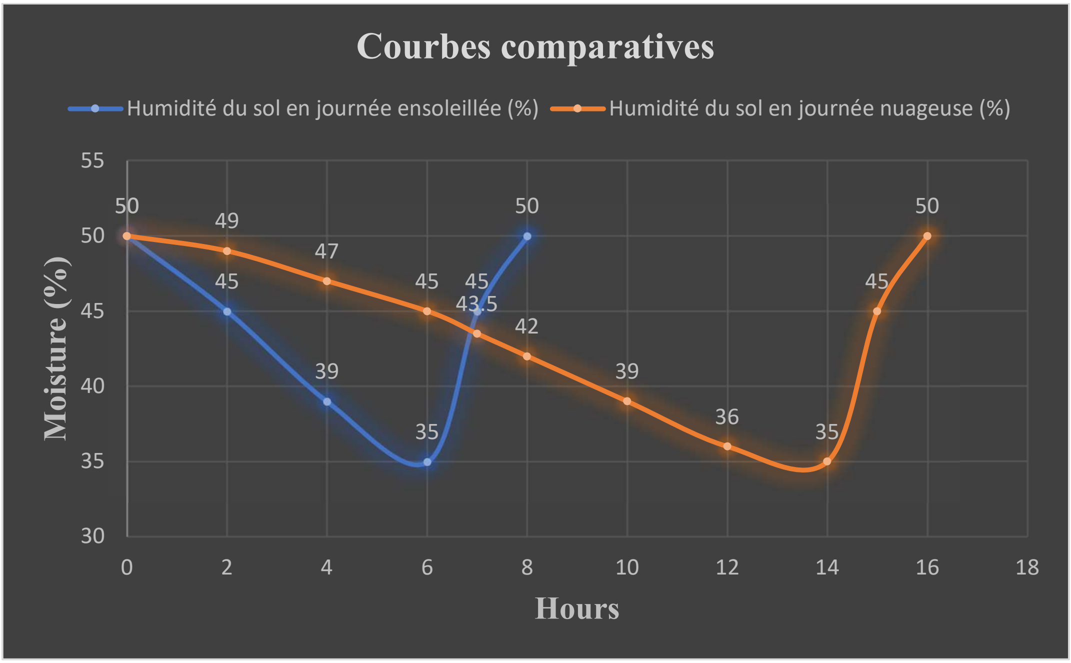

Figure 7 : Comparison curves of soil moisture over time

4.1.5.2. Interpretation

The comparative curves show that soil moisture decreases more slowly on a cloudy day than on a sunny day due to the solar irradiation coefficient being reduced to 40%. As a result, evapotranspiration is lower, delaying the activation of the solenoid valves. This difference highlights the impact of weather conditions on irrigation management and the optimization of available water.

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4.1.5.3. Comparison curves of water consumption volumes on a sunny day and a cloudy day

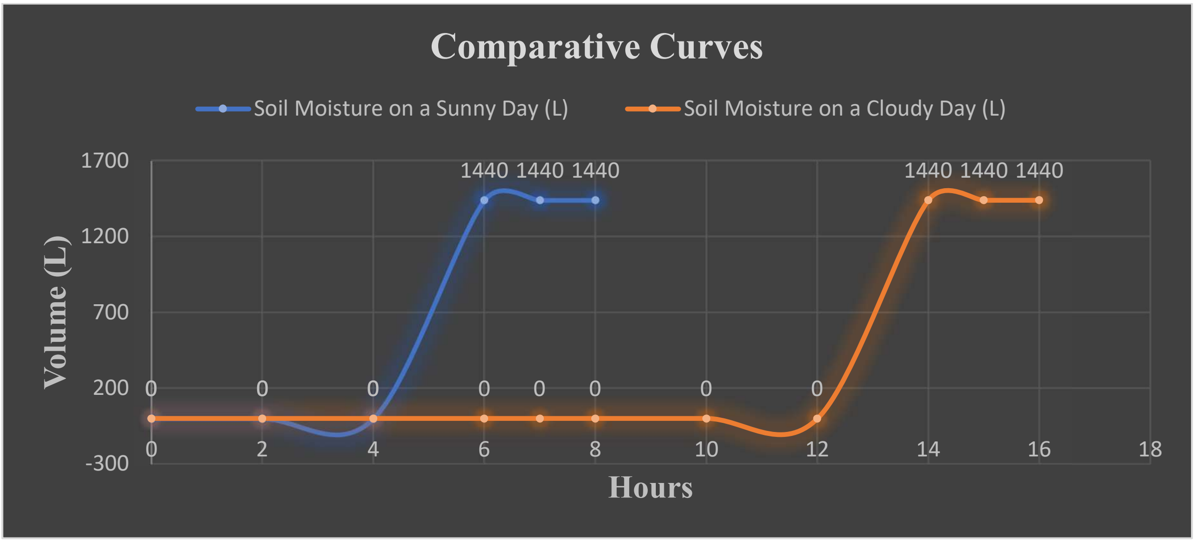

Figure 8 : Comparison curves of water consumption volumes over time

4.1.5.4. Interpretation

The results show that water consumption strongly depends on the level of sunlight. On a sunny day, the solenoid valves activate earlier (6 AM), and water is consumed quickly. On a cloudy day, consumption is delayed until 2 PM, but the water volume remains the same in both cases (1440 L per irrigation cycle)

5. DISCUSSION

The objective of this automated irrigation system was to improve water use efficiency by adjusting irrigation based on the actual needs of the soil and plants. The obtained results demonstrate effective regulation of soil moisture between 35% and 50%, which aligns with the water requirements of cotton grown on clay-sandy soil.

Comparing these results with other irrigation systems, we observe that traditional irrigation, where water is applied at fixed intervals, often leads to water wastage and periods of water stress for plants. For example, Fereres & Soriano (2007) demonstrated that controlled deficit irrigation systems can enhance water productivity by preventing periods of saturation and water stress. Similarly, Zhang et al. (2017) studied the impact of water deficit on cotton cultivation and showed that precise soil moisture management improves yield while reducing water consumption.

In terms of energy consumption, our approach optimizes pump usage based on the reservoir level, minimizing operational costs compared to systems where the pump operates continuously. Kang et al. (2002) also highlighted that scheduling irrigation based on soil moisture can reduce energy consumption without affecting crop yield.

Finally, integrating environmental factors, such as sunlight, into the analysis of soil behavior is an innovative approach that allows irrigation to be adapted to climatic conditions. Teixeira et al. (2013) emphasized the impact of climate change on water availability for agriculture, further reinforcing the need for intelligent irrigation management.

These comparisons confirm the relevance of our approach and demonstrate that automation based on soil moisture and climatic conditions optimizes irrigation, improves crop yield, and reduces water wastage.

6. CONCLUSION

The developed automated irrigation system effectively meets the specific needs of cotton cultivation on clay-sandy soil. By integrating soil moisture sensors and considering environmental conditions such as solar irradiation, it is possible to optimize water use, improve crop yield, and preserve water resources.

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