Sensor-Based Furrow Irrigation System (SBFIS) for Sunflower (*Helianthus annuus L.*) Production

Roldan T. Quitos[1]*, Wendy C. Mateo[2], Carolyn Grace G. Somera[3], Von Quiel S. Quitos[4], Leslie E. Gacho[5], Jonathan R. Nicomedez[6], Benedicto D. Pagaduan[7], Armando N. Espino Jr.[8]

[1,7]Crops and Resource Research and Development Center, Central Luzon State University, Science City of Munoz, Nueva Ecija, Philippines

[2,3,4,5,6,8]Department of Agricultural and Biosystems Engineering, Central Luzon State University, Science City of Muñoz, Nueva Ecija, Philippines

*Corresponding author**

DOI: https://doi.org/10.51244/IJRSI.2024.11120042

Received: 10 November 2024; Revised: 20 November 2024; Accepted: 21 November 2024; Published: 14 January 2025

ABSTRACT

The need to constantly monitor over-irrigation was one of the many challenges farmers confronted in their daily farming activities. Frequently, the farmer must travel a considerable distance to access their fields and irrigation pumps. This study further developed the feedback mechanism and program of the Central Luzon State University -Automated Furrow Irrigation System (CLSU-AFIS). The performance of the sensor-based furrow irrigation system (SBFIS) was determined in this study through the growth and yield of the sunflower. The study considered four treatments which were sensor-based furrow irrigation system with mulch (T1), sensor-based furrow irrigation system without mulch (T2), conventional furrow irrigation system with mulch (T3), and conventional furrow irrigation system without mulch (T4).

The CLSU sunflower variety named CLSF-1 was used in this study. Results showed a significant difference between sensor-based and conventional furrow irrigation. Growth and yield parameters of the sunflower in a sensor-based furrow irrigation system with mulch obtained the highest value with average plant height of 74.14 cm, leaf number of 22.82, sunflower head weight of 184.87 g, sunflower head diameter of 17.23 cm, and yield of 80.14 kg. Mulch also reduced the irrigation frequency.

Thus, it used less water but obtained the highest yield, increasing water productivity. The water productivity of using SBFIS without mulch in comparison with Conventional was found 54% higher while in SBFIS with mulch in comparison to Conventional with mulch was 72% higher. The water productivity of using SBFIS with mulch compared to SBFIS without mulch was found 39% higher while the Conventional with mulch compared to Conventional without mulch was also found 39% higher.

Keywords: sensor-based furrow irrigation, mulching, sunflower, LoRa transceiver, water productivity

INTRODUCTION

Furrow irrigation is a relatively inexpensive and probably low-technique method of surface irrigation. It requires little capital investment but involves a lot of labor and low application efficiency. Mulching is done to retain moisture, prevent weed growth, control soil temperature, and enhance plant health in general. Surface irrigation systems are considered inefficient, with an average efficiency of about sixty percent (60%). This means that only sixty percent (60%) of delivered water is retained in the soil's top layer, where crop roots can extract it for beneficial purposes. The remaining forty percent (40%) escapes the field via deep percolation beneath the root zone or surface runoff at the field's end. However, efficiency can be significantly increased by performing precise land grading, controlling inflow, optimizing irrigation timing, and reusing surface runoff Taghvaeian, 2017). Water is lost to surface runoff, groundwater, and evaporation when employing furrow irrigation, and it can be difficult to have water equally distributed across a whole field. The challenge of increasing plant growth while lowering expenses necessitates justifying the development of an automated irrigation system that will reduce water waste while also lowering labor and monitoring costs (Leroux & Raghavan, 2005). The study aims to design, fabricate and evaluate the performance of a sensor-based furrow irrigation system for sunflower production to determine the performance gaps and to improve the system of the AFIS for the development of field practice in the Philippine agriculture industry.

MATERIALS AND METHODS

The design of the sensor-based furrow irrigation microcontroller was inspired by the Central Luzon State University Automated Furrow Irrigation System (CLSU-AFIS). This study enhanced the system's feedback mechanism by incorporating a broader transceiver to facilitate efficient data transmission and reception between slave and master microcontrollers. To ensure system reliability, a program was developed to automatically restart the system in response to errors detected during data transmission. This functionality is reinforced by the inclusion of a reset pin, which is electrically connected to a digital pin on the microcontroller. This connection enables the system to trigger the reset pin and automatically restart itself when errors are encountered, ensuring uninterrupted operation. Moreover, Figure 1 presents the microcontroller assembly with the automatic restart feature, including the role of the reset pin and its connection to the digital pin. The figure illustrates when the system identifies transmission errors, activates the reset pin via the digital pin, and resumes normal operation seamlessly. This integration significantly improves the system's fault tolerance and operational efficiency. The sensor-based irrigation system provided significant benefits, including reduced farm labor and the prevention of excessive water runoff. It also optimized irrigation timing by adapting to soil intake variability, using end-of-row and within-field sensors.

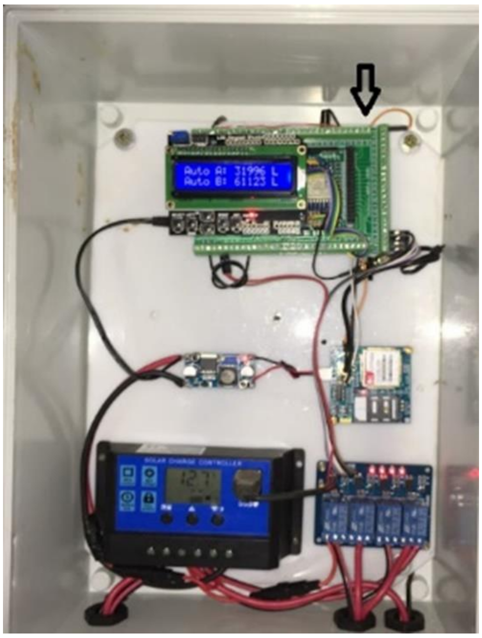

Figure 1. Master Microcontroller Assembly Reset Pin

The system was tested on sunflower crops to evaluate its performance based on sunflower yield and growth. The Sensor-based Furrow Irrigation System (with and without mulch) was compared to a conventional furrow irrigation system (with and without mulch) in terms of agronomic performance, including the effects on crop growth, yield, and water productivity. Soil moisture sensors were strategically placed at the front, middle, and end of the hill to monitor soil moisture at different locations. Additionally, shut-off sensors were placed at the end of the furrows to ensure uniform water distribution. The actual field layout is shown in **Figure 2**.

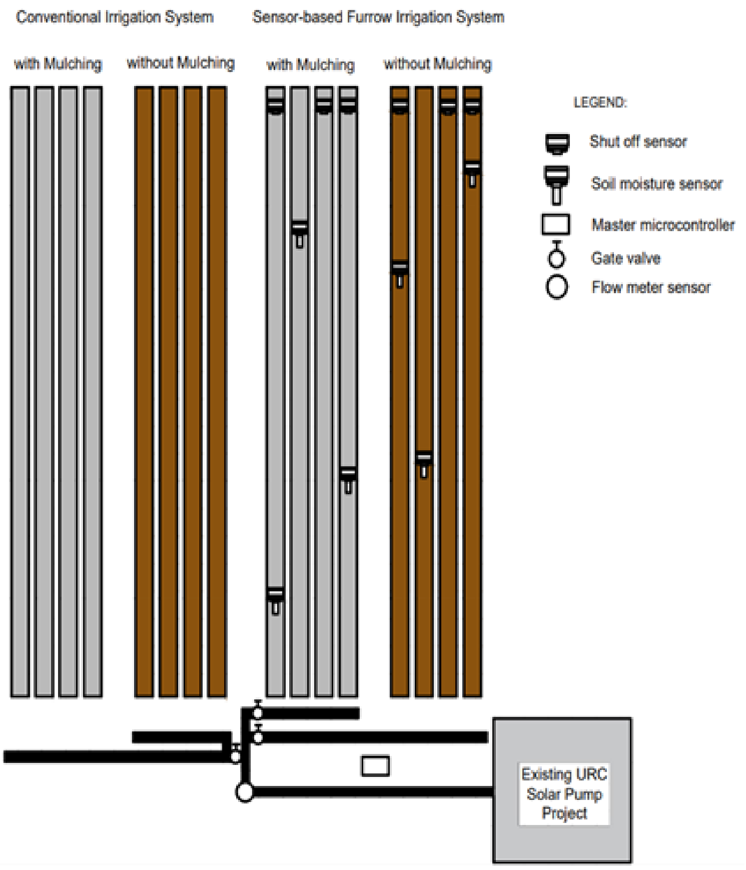

Figure 2: Actual Field Layout

A. Design of Major Components Soil Moisture Sensor Assembly

The system was composed of a solar panel, charge controller, battery, Arduino Nano, and soil moisture sensor which were same with components of CLSU-AFIS. The SBFIS was equipped with a long range (LoRa) transceiver which made the system receive and transmit data and utilize the antenna for a wider distance for better feedback mechanism. It also has step down buck converter to regulate the operating voltage of the system.

B. Shutoff Sensor Assembly

The system was composed of a solar panel, charge controller, battery, Arduino Nano, and soil moisture sensor which were same with components of CLSU-AFIS. The SBFIS was equipped with a LoRA Transceiver which made the system receive and transmit data and utilize the antenna for a wider distance for better feedback mechanism. It triggered the irrigation termination by sending a signal to the master microcontroller to close the automated gate valve. The shut-off sensor used a water level sensor float switch. This sensor was assembled with flat bar to elevate from certain level of water during irrigation.

C. Master Microcontroller Assembly

The master microcontroller composed of solar panel, charge controller, battery, LoRA transceiver, LCD, relay module and Arduino mega which worked together to gather, process, manipulate, and transmit data to and from sensors and other input/output peripherals. For this study, the master microcontroller controls the opening and closing of the improvised gate valve depending on the data transmitted by the soil moisture sensors and shut off sensor. It also requested information from the soil moisture sensor regarding the water content of the soil in the field during the transmission period and data from the shutoff sensor.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue XII December 2024

D. Fabrication of Automated Gate Valve

The system consisted of a check valve and an actuator which worked together to control the water flow and gather data on usable irrigation. The valve opened when a voltage was applied to the coil, allowing liquid to pass through and with a size of 2 ½ inches.

E. Determination of Growth Parameters for Sunflower

Both systems, namely sensor-based furrow irrigation system and conventional irrigation system were under treatments of with and without mulching of sunflowers, and arranged with equal areas of irrigation land, the same number of furrows, and planted sunflowers.

F. Determination of Water Productivity

Water productivity is the ratio of yield and total applied irrigation water and is expressed as follows (Ali, Hoque, Hassan, & Khair, 2007):

$$WP = \frac{Y}{W_{irri}} \quad (1)$$

where:

$WP = water\ productivity$

$Y = Yield, kg\ ha^{-1}$

$W_{irri} = irrigation\ applied, m^3 ha^{-1}$

RESULTS AND DISCUSSION

The implementation of the Sensor-Based Furrow Irrigation System (SBFIS) demonstrated a significant impact on various sunflower growth parameters and yield. The study considered four treatments: sensor-based furrow irrigation system with mulch (T1), sensor-based furrow irrigation system without mulch (T2), conventional furrow irrigation system with mulch (T3), and conventional furrow irrigation system without mulch (T4). The results, illustrated in **Figure 3**, highlight the superiority of SBFIS, particularly when combined with mulch, in enhancing sunflower performance. Treatment 1 (T1) achieved the greatest mean plant height (74.14 cm), followed closely by T2 (73.54 cm), while T4 recorded the shortest mean height (66.21 cm). This finding underscores the role of precise irrigation scheduling in improving plant growth, with mulch further enhancing moisture retention and reducing water loss. Similarly, the number of leaves, depicted in **Figure 4**, was highest in T1 (22.82), compared to the lowest count in T4 (19.53). The data suggest that SBFIS effectively supports vegetative growth, with mulch providing an added advantage.

Figure 3: Plant Height

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue XII December 2024

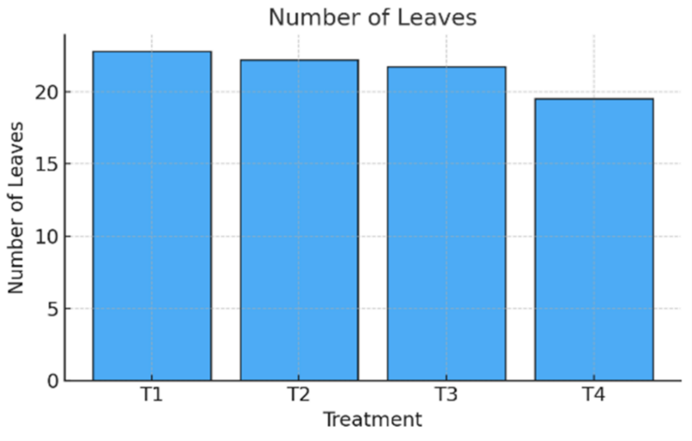

Figure 4: Number of Leaves

Figure 5 shows that T1 also produced the largest mean sunflower head diameter (17.23 cm), whereas T4 exhibited the smallest (13.04 cm). Additionally, as presented in **Figure 6**, the mean sunflower head weight was significantly higher in T1 (184.87 g) compared to T4 (75.52 g). These results indicate that sensor-based irrigation, particularly with mulch, facilitates better biomass distribution to the sunflower head, which is a key determinant of yield potential.

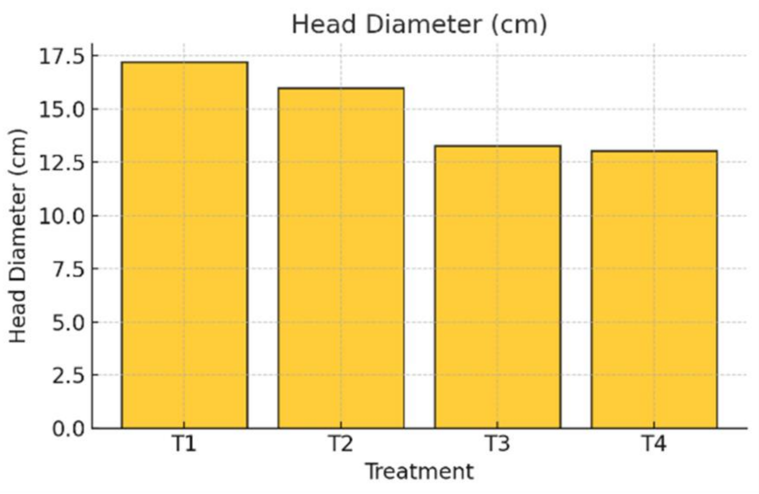

Figure 5: Sunflower Head Diameter

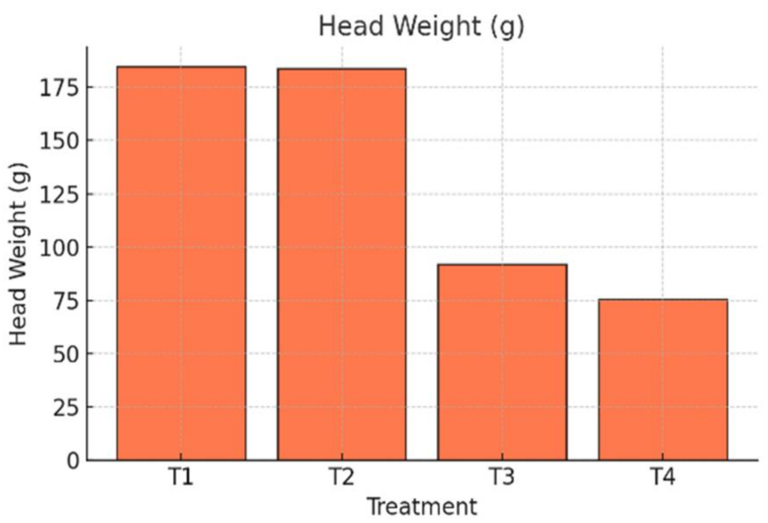

Figure 6: Sunflower Head Weight

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XI Issue XII December 2024

Finally, the total yield is illustrated in **Figure 7**, where T1 recorded the highest yield (80.14 kg), while T4 yielded only 36.86 kg. This stark contrast highlights the critical role of efficient irrigation and mulch in enhancing crop productivity. The consistent trends across all figures demonstrate that SBFIS, especially with mulch, improves water use efficiency and sunflower performance, offering a sustainable and effective irrigation strategy.

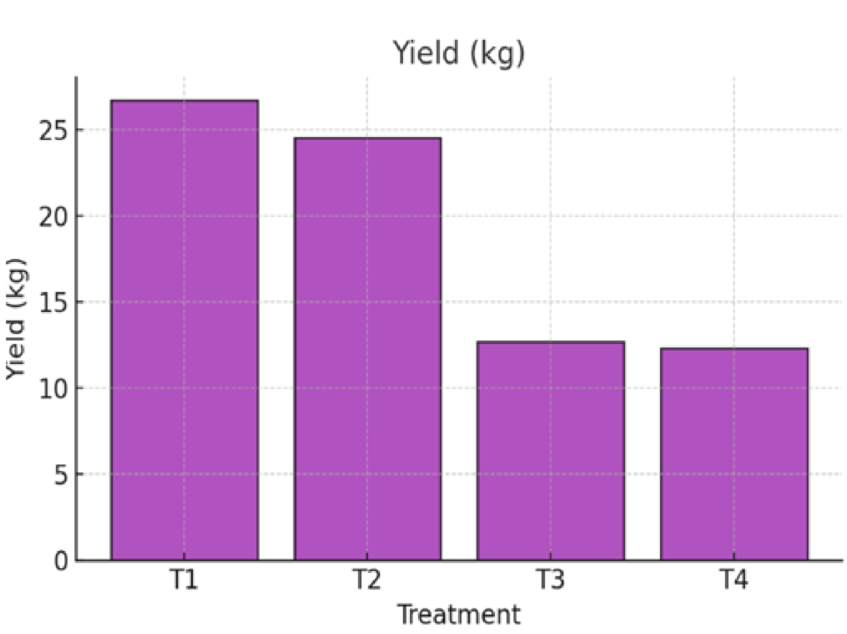

Figure 7: Sunflower Yield

Water productivity

The water consumption per treatment were determined through the flow meter sensor which was connected to master microcontroller. The total volume of irrigation per treatment were shown in Table 6. Based on the data collected it showed that the SBFIS with mulch has the highest water productivity among the four (4) treatment with value of 1.14 kg m^{-3}, followed by SBFIS without mulch with 0.69 kg m^{-3}, then CFIS with mulch which was 0.52 kg m^{-3}, and lastly the CFIS without mulch which had a water productivity of 0.32 kg/ m^3. This result showed that the sensor-based furrow irrigation system with mulching produced higher yield at a lower consumption of water due to its ability to irrigate at the right time and conserve moisture content in soil. Garcia et al. (2016) found that the adoption of suitable irrigation methods led to a rise in agricultural productivity.

This was attributed to a reduction in water stress and mitigation of heat stress during the flowering phase, as well as an increase in water productivity. The water productivity of using SBFIS without mulch in comparison with Conventional was found 54% higher while in SBFIS with mulch in comparison to Conventional with mulch was 72% higher. The water productivity of using SBFIS with mulch compared to SBFIS without mulch was found 39% higher while the Conventional with mulch compared to Conventional without mulch was also found 39% higher.

Table 6. Total water consumption

Treatment	**Total Water Consumption (m^3)**
Sensor-based furrow irrigation with mulching	70.1
Sensor-based furrow irrigation w/o mulching	106.8
Conventional furrow irrigation with mulching	72.3
Conventional furrow irrigation w/o mulching	114.1

Table 7. Total sunflower yield

Treatment	Sunflower Yield (kg)
Sensor-based furrow irrigation with mulching	80.14
Sensor-based furrow irrigation	73.57
Conventional furrow irrigation with mulching	37.86
Conventional furrow irrigation	36.86

Table 8. Water productivity

Treatment	Water productivity (kg m^{-3})
Sensor-based furrow irrigation with mulching	1.54
Sensor-based furrow irrigation	1.01
Conventional furrow irrigation with mulching	0.52
Conventional furrow irrigation	0.32

CONCLUSIONS

The design of the sensor-based furrow irrigation system was applicable for the study and made feasible to function all the microcontrollers and slaves without encountered power interruption. The fabrication of SBFIS was successfully installed and worked the whole duration of the study and proved that the system was a great help to ease the work of farmers. The performance evaluation of the SBFIS was proved that the system had a positive effect on the sunflower growth and yield, it showed that the sunflowers on SBFIS with mulch has the greatest yield. This study showed that the SBFIS reduced the stress in sunflower which result in greater yield and mulch conserved soil moistures that result in decreased irrigation frequency, thus the greater yield with less water had a high-water productivity.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the following individuals for their assistance in making this humble piece of work possible. To Dr. Armando N. Espino, Jr., Vice President of Research Extension, for his shared practical knowledge. To the Department of Agricultural and Biosystems Engineering of CLSU for their support and encouragement.

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