DIGITAL TRANSFORMATION ACCELERATOR

Technical Report of the Probe. From Lab to Field: Assessing the Scalability of Lysiphen lysimeters in Guatemala's Dry Corridor (2025)

Authors: Óscar Estrada[1], Gresia Ramos[2], Miguel Lizarazo[3] and Daniel Jiménez[4]

1. Abstract

This technical report presents the results of a probe designed to evaluate the operational feasibility and accuracy of four automated gravimetric lysimeters ("Lysiphen"), originally developed by the Bean Physiology Program of the Alliance Bioversity International and CIAT. The objective was to validate whether this technology, successful in controlled environments, could be scaled to determine the water requirements of common bean (*Phaseolus vulgaris*) under field conditions in the semi-arid region of Chiquimula, Guatemala. The devices were deployed at the Digital Agroclimatic Plot in collaboration with the Centro Universitario de Oriente (CUNORI) of the Universidad de San Carlos de Guatemala (USAC).

Analysis of the collected time series revealed critical limitations in system robustness when operating outside its original design environment. Severe data integrity issues were identified, including excessive load-cell noise in and anomalous irrigation volume readings, attributed primarily to Wi-Fi connectivity instability and the lack of "offline" or edge-based operational mechanisms. While environmental sensors exhibited stable performance, the water-balance system failed to generate consistent data for agronomic modeling. Consequently, in its current configuration, the technology lacks the level of maturity required for remote field deployment without continuous specialized technical supervision. Re-engineering focused on enhancing operational autonomy is therefore recommended prior to any future scaling attempts.

2. Introducción

In Guatemala, a reduction in the number of rainy days has been observed, accompanied by an increase in the intensity of precipitation events. In addition, the mid-summer drought —locally known as *canícula*, a dry period that typically occurs between July and August and lasts on average 10 to 15 days— can extend to 30 or even 50 days under the influence of the positive phase of the El Niño–Southern Oscillation (ENSO). This extension results in a marked seasonal water deficit, primarily affecting departments located in the country's semi-arid zone, known as the Dry Corridor, including Zacapa, Chiquimula, and El Progreso (INSIVUMEH, 2018).

Under this context, the production of staple crops —particularly maize and beans— which largely depends on smallholder farmers, is seriously threatened by recurrent drought events. A critical example was the meteorological drought that occurred in 2012, when rainfall deficits during June and July caused losses of up to 70% in maize and bean crops in the departments of Jutiapa, El Progreso, Chiquimula, Zacapa, and

1,2,3,4: Researchers at the Alliance of Bioversity International and CIAT.

Baja Verapaz, negatively affecting household food reserves and prolonging the seasonal period of food insecurity (SESAN, 2012).

Given this scenario and considering that water is an essential resource for agricultural production, acces to accurate and timely information is crucial for reducing the vulnerability of agricultural production systems. In this regard, four lysimeters provided by the Alliance of Bioversity International and CIAT were evaluated in a probe, with the objective of generating crop water demand curves for bean cultivation. Although it is generally recognized that beans require at least 400 mm of water over their growing cycle (Villordo-Pineda et al., 2015), detailed information on the distribution of this demand across the different phenological stages of the crop remains limited. Such information is essential to enabling farmers and technical adivisors to make more precise irrigation decisions and reduce production losses.

During the study, the performance of the equipment was variable, and behaviors different from those observed under the controlled greenhouse conditions at CIAT campus. Although lysimeters may perform adequately under specific conditions, their performance can be significantly affected when transferred to environments with different geographic, climatic, and infrastructural characteristics. In this sense, the experience generated in the Digital Agroclimatic Plot represents a valuable starting point for the improvement and contextual adaptation of these devices, particularly for deployment under conditions outside Colombia.

3. Materials and Methods

3.1. Study area

The Digital Agroclimatic Plot is in Guatemala's Dry Corridor, in the eastern region of the country, within the department and municipality of Chiquimula, at the geographic coordinates 14.803055, -89.528888 (decimal degrees). The Plot is situated at an altitude of approximately 360 meters above sea level. This department lies within the "Eastern Valleys" agroclimatic region, which is characterized by chronic rainfall deficits and is the driest region in the country, with average annual precipitation ranging from approximately 700 to 1,300 mm (INSIVUMEH, 2018).

3.2. Description of the Lysiphen

Lysiphen is an IoT-based lysimeter that measures crop transpiration and integrates multiple sensors to enable automated irrigation based on crop water requirements. It also offers remote and wireless connectivity, allowing crop water-use dynamics to be monitored through a web-based platform. These devices were evaluated under greenhouse conditions at the campus of the International Center for Tropical Agriculture (CIAT) campus, and their performance has demonstrated potential scalability to other crops. It is worth highlighting their affordability, durability, and waterproof design, which make them a valuable tool for agricultural research (Pineda-Castro et al., 2024).

3.3. Lysiphen installation

The lysimeters were installed for operation at the Digital Agroclimatic Plot. The units were transferred from the CIAT Campus and installed under field conditions. Installation included sensor positioning, system leveling, and the configuration of data transmission protocols to enable continuous monitoring of crop transpiration and irrigation requirements.

3.4. Lysiphen calibration

- The lysimeters were calibrated using the web application of each unit, accessing the system with the corresponding username and password. Subsequently, the calibration option was selected (Figure 1a), and the *"calibration mode"* was activated (Figure 1b), ensuring beforehand that no objects were placed on the lysimeters. During this phase, each unit recorded measurements to establish a zero-weight baseline reference.
- Once this step was completed, a known weight of 20 kg was placed on each lysimeter and entered in the *"Known weight value"* field, followed by clicking the *"Save"* button (Figure 1c). At the end of the calibration process, the calibration mode switch was automatically turned off, indicating that the lysimeter had been successfully calibrated (Figure 1d). Immediately after calibration, a pot containing seeds of the ICTA Chortí bean variety, adapted to the agroclimatic conditions of the region, was placed on the lysimeter.

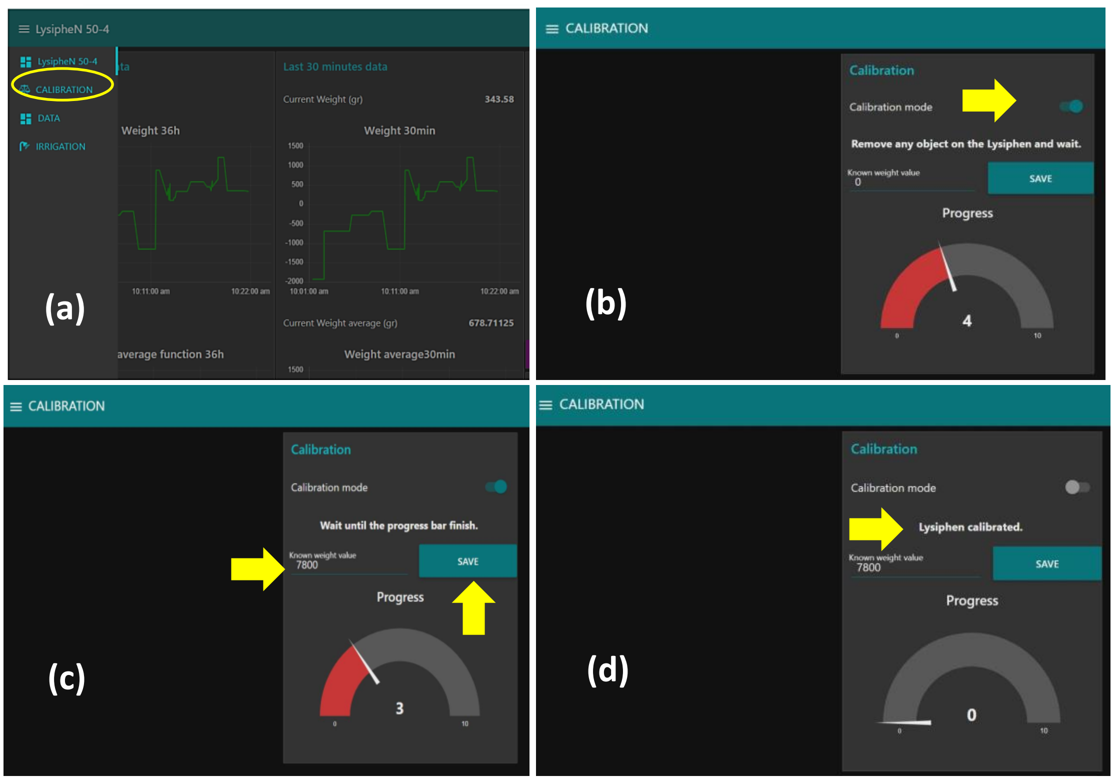

Figure 1. Evaluated lysimeters. (a) Calibration option; (b) Calibration mode on; (c) Calibration with a known weight value; (d) Lysimeter calibrated.

3.5. Irrigation scheduling

After completion of the Lysiphen calibration process, the irrigation schedule was programmed through the corresponding digital platform (Figure 2). Irrigation management was based on a criterion of 100% replacement of crop water losses, as estimated by the lysimeters.

During the vegetative growth stage, corresponding to the first 25 days after sowing (DAS), irrigation was scheduled once per day. For the reproductive stage, irrigation frequency was increased to two irrigation events per day, maintaining the same 100% water-replacement criterion. The irrigation events were scheduled at 08:00 h and 16:00 h, respectively, to ensure adequate soil moisture availability during periods of peak crop water demand.

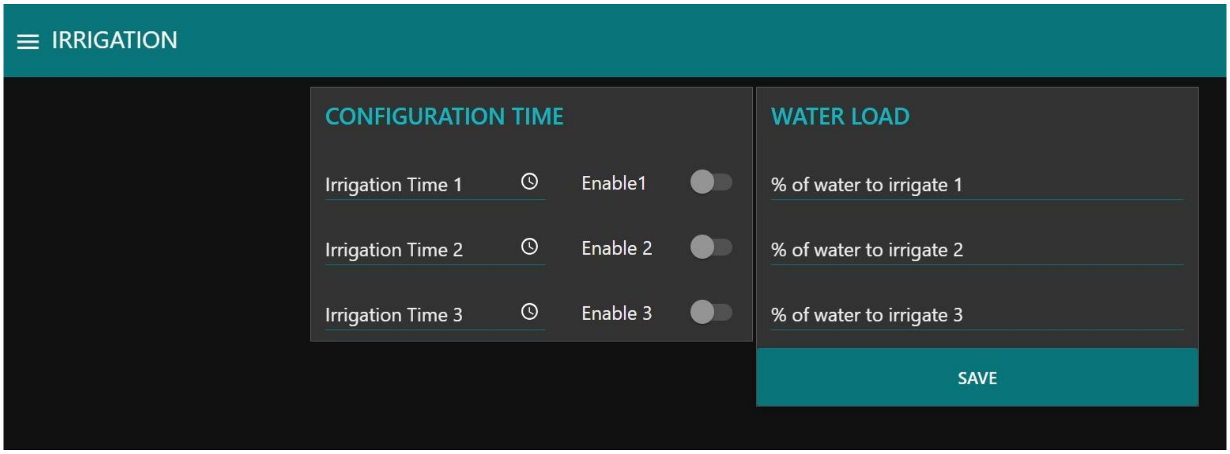

Figure 2. Irrigation scheduling

3.6. Crop establishment

The ICTA Chortí bean variety was used, given its adaptation to the agroclimatic conditions of the region. Sowing was carried out by direct seeding into plastic pots with a capacity of 20 kg. A total of six pots were planted: four were installed on the lysimeters, while two pots were established as a control treatment and managed under manual irrigation estimated (Figure 2). In all pots, two plants were established per pot, with a spacing of 10 cm between plants.

Figure 3. Lysiphens and pots

3.7. Agronomic Management

Three granular fertilization applications incorporated into the soil and one foliar fertilization application was carried out during the crop cycle. The first granular fertilization was applied on the day of sowing, the second at 10 days after sowing (DAS), and the third at 20 DAS. Foliar fertilization was performed on 25 DAS.

Regarding granular fertilization, 4 g of urea (46% N) per pot were applied at sowing, while 6 g per pot of a commercial fertilizer with an 18-10-12 formulation was applied during the second and third fertilization events. Foliar fertilization was conducted using an inorganic liquid fertilizer at a dose of 40 mL per 10 L of water, applied uniformly to the plants using a manual sprayer.

Weed control was performed manually through weekly monitoring to avoid competition for water and nutrients. For pest management, deltamethrin was applied at a rate of 5 mL per 1 L of water using a backpack sprayer to control whitefly (*Bemisia tabaci*) and leaf beetle (*Diabrotica spp*).

In addition, a detailed activity log was maintained for all field operations that added weight to the system (e.g., fertilization, irrigation, or handling). This log was used to correct the data recorded by the Lysiphen units by subtracting the added weight according to the corresponding date and time, thereby ensuring the accuracy of the measurements.

4. Results and Discussion

The analysis of the time series recorded by the four lysimeters (Lysiphen) at the CUNORI Digital Agroclimatic Plot reveals critical discrepancies between the device's theoretical operating principles and its actual performance under field conditions outside its original development site at CIAT, Colombia.

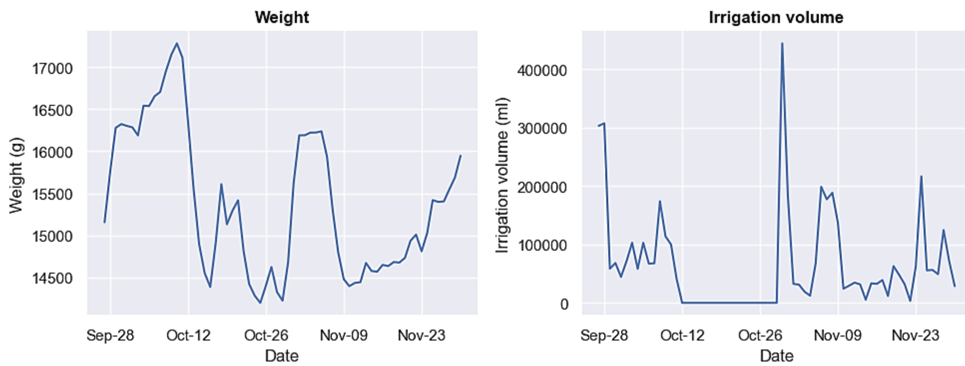

Figure 4. Weight and irrigation volume values generated by lysimeter 1

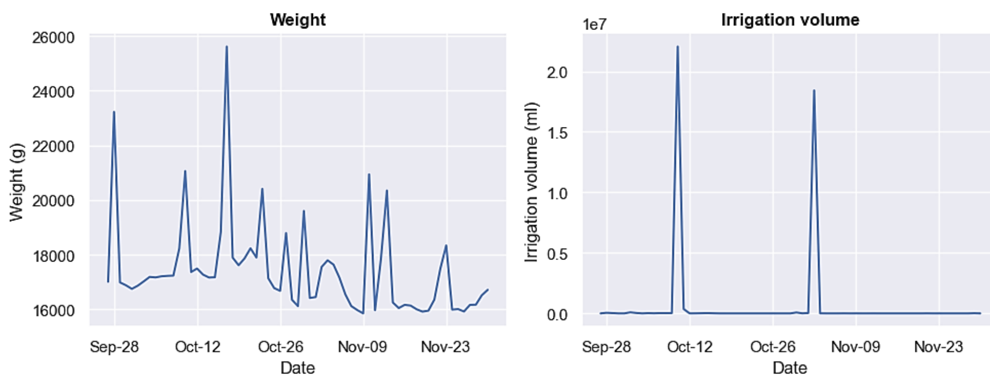

Figure 5. Weight and irrigation volume values generated by lysimeter 2

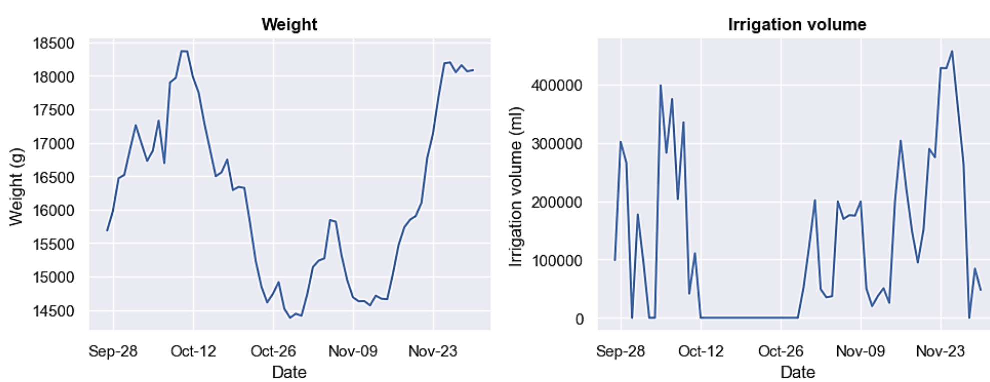

Figure 6. Weight and irrigation volume values generated by lysimeter 3

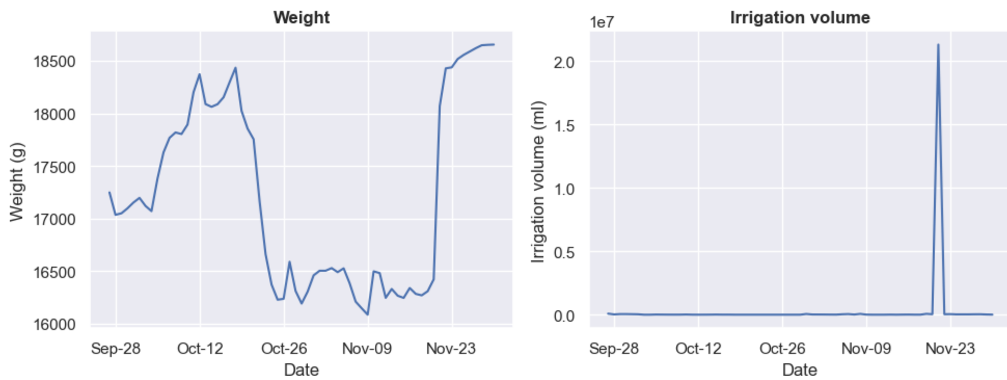

Figure 7. Weight and irrigation volume values generated by lysimeter 4

4.1. Analysis of Weight and Irrigation Volume Variables.

Observing the Weight time-series graphs for Lysimeters 1, 2, 3, and 4 (Figures 4–7), the data exhibit high signal instability (noise) and abrupt fluctuations that do not correspond to natural biological (transpiration) or physical (evaporation) processes. Specifically:

- Lysimeters 1 and 3: Show erratic daily oscillations with weight losses and gains that failed to follow the expected gradual drying pattern of a bean crop.
- Lysimeters 2 and 4: Display periods of apparent data loss (flat lines) followed by vertical weight spikes, suggesting failures in the load-cell sensor communication or data transmission.

Even more critical is the behavior recorded in the Irrigation Volume variable. In Lysimeters 2 and 4, peaks of physically implausible magnitude were observed (values approaching 2.0 X 10^7 ml, i.e., 20,000 liters in a single event). This indicates a severe failure in the digital control loop. It suggests that connectivity loss or network latency generated erroneous commands to the actuators (peristaltic pumps), either logging theoretical irrigation volumes that did not physically occur or tiggering irrigation uncontrollably (figure 8), thereby invalidating the calculated water balance.

Figure 8. Lysimeter applying excessive irrigation

4.2. Limiting Factors in Field Conditions. Unlike the controlled greenhouse tests at the CIAT campus, the deployment in Guatemala's Dry Corridor exposed the devices to multiple unmitigated field-level factors, including:

- Connectivity Instability: The system's reliance on a continuous Wi-Fi connection for data transmission and irrigation execution proved to be a critical weakness. Instability in the wireless network connection led to intermittent data loss, preventing the generation of continuous crop water demand curves.
- Hardware Robustness: Exposure to extreme environmental conditions combined with limited specialized technical personnel on-site for corrective maintenance (such as constant load-cell recalibration) resulted in data drift. The technology lacked the necessary robustness to operate autonomously without recurrentt technical intervention.

In summary, while the environmental sensors (temperature and relative humidity) showed relatively stable performance, the core system components (lysimetry and automated irrigation) failed to generate consistent or reliable data aligned with the study's agronomic objectives.

5. Conclusions and Recommendations

The execution of this probe leads to the conclusion that, in its current configuration, the Lysiphen lysimeters are not viable for generating crop water-demand curves under remote field conditions in the Dry Corridor of Guatemala.

Three main conclusions are highlighted:

- Operational Scalability Failure: The transition from a controlled environment (research-center greenhouse) to a real-world field environment in a different region revealed that the prototype does not possess sufficient technological maturity (TRL) to operate without constant expert supervision.
- Compromised Data Integrity: Issues with wireless connectivity and electronic system instability resulted in fragmented data series and extreme outliers, making the data unsuitable for agronomic modeling or precise irrigation decision-making.
- Logistical Dependency: The need for specialized technical intervention to resolve hardware and software failures makes the deployment logistically and economically unsustainable for local organizations lacking dedicated engineering capacity.

Based on the findings of this probe the following is recommended:

- Do Not Use Collected Data for Prescription: It is strongly advised against using the data generated in this experiment to determine bean crop water requirements in the region, given the high degree of experimental error and systemic failures.
- Re-engineering for "Offline" Operation: For future developments, it is imperative that the system includes local data storage capabilities (physical datalogger/SD card) and "edge computing" control logic that does not depend on cloud connectivity to execute critical functions like irrigation.
- Validation of Robustness (Hardening): Before any new field deployment, devices must undergo environmental and electrical stress tests simulating Dry Corridor conditions to ensure component protection and load cell stability against thermal variations.
- Focus on Local Capabilities: Any future implementation of IoT technologies must be accompanied by a technical training program for local personnel (partners like CUNORI) to ensure installed capacity for first-level diagnosis and troubleshooting.

6. References

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