

UNIVERSITY OF PUERTO RICO  
RIO PIEDRAS CAMPUS  
DEPARTMENT OF ENVIRONMENTAL SCIENCES  
UNDERGRADUATE PROGRAM

**PRECIPITATION AND DRIP IRRIGATION EFFECTS ON SOIL WATER DYNAMICS  
IN A SEMI-ARID AGROSYSTEM OF PUERTO RICO**

**Yeishmary Michelle Soto Muñiz**

Senior Thesis Investigation  
presented as part of the requirements  
for the degree of Bachelor of Science  
with a specialization in  
Environmental Sciences

Approved by:



---

Mentor: Elvira Cuevas



---

Co-mentor: Solimar Pinto-Pacheco

---

Jess K. Zimmerman  
Director  
Department of Environmental Sciences

May 16<sup>th</sup>, 2025

## **Dedicatory**

I dedicate this project, and the time I invested in it, to my late grandfather, Ricardo “Risco”

Muñiz Lorenzo.

A proud jíbaro who began working in the sugar cane fields at a young age, he later emigrated to New York in search of a better life. He dreamed of becoming a professional baseball player and remained a devoted fan of the game throughout his life. His love for baseball and trio music lives on through my mother. He passed away just before the summer of 2022, before I began my first-ever internship. Although I never had the chance to share my milestones with him, I believe he would be proud to see where I am today, preparing to begin my master’s degree at the University of Michigan.

Que en paz descanses, Abuelo Risco.

## **Acknowledgments**

I want to express my gratitude to the Laboratory of Processes and Functions of Tropical Ecosystems (EcoLab) Team, including Dr. Elvira Cuevas, Dr. Solimar Pinto, and Larry Díaz, for their continued guidance and support throughout my research and during my time at the lab. I also appreciate the funding provided by the NSF Centers of Research Excellence in Science and Technology Postdoctoral Research Program (CREST-PRP), Award Number #2329343. A special thanks goes to Finca Atabey, our study site, and its owners, Dr. Josefina Arce and Dr. Betzaida Ortiz, for accommodating our research needs. Additionally, I would like to acknowledge the Puerto Rico - Louis Stokes Alliance for Minorities Participation (PR-LSAMP) and the Research Opportunities for Undergraduate Students in STEM (ROUSS) Program for their contributions to my academic goals during my final year of studies. Lastly, I would like to thank my friends and family who have witnessed my undergraduate journey and have accompanied me until today.

## **Abstract**

Water deficit threatens plant productivity and growth, especially in semi-arid regions. In Puerto Rico, 53.5% of fruit and vegetable production occurs in the south, where a semi-arid climate limits water availability and agricultural productivity. This research is conducted at Finca Atabey, Santa Isabel, on the southern coast of Puerto Rico, characterized by high temperatures, low pulsing precipitation, high evapotranspiration, and frequent droughts. Crops at our study site rely almost exclusively on drip irrigation. Here, we investigate the impact of drip irrigation and pulse precipitation on soil water content in avocado stands grown in two distinct soil series: Jacaguas and San Antón. We hypothesized that effective precipitation would have an additive effect on soil water content, which depends on drip irrigation. Additionally, we hypothesized that soil type would determine the extent to which precipitation influences soil water content. For one-year, meteorological data were collected with an on-site weather station, as well as soil profile data with soil sensors, which measured water content at three depths: a) 0 – 15 cm, b) 15 – 30 cm, and c) 35 – 50 cm. Results validate semi-arid conditions at our site. Pulsing precipitation events are the norm, with effective precipitation ( $P > ET_0$ ) occurring in only 54 days. Results also indicate differences in water content between soil types. Soil water content at the Jacaguas site was mostly below the wilting point (23.4%), except for some values in the 15–30 cm depth. In San Antón, the 35–50 cm depth had no available water, while the 0–15 cm and 15–30 cm depths exceeded the wilting point (27.9%). ANOVA results show significant soil series and depth effects on water content ( $p\text{-value} > 0.0001$ ). This study contributes to knowledge on soil water dynamics in semi-arid regions and provides relevant information for water-use and crop resilience, especially under projected drier conditions due to climate change.

*Keywords: soil water content, drip irrigation, pulsing precipitation, semi-arid region*

## Introduction

Human-caused climate change has contributed to an increase in ecological droughts due to rising temperatures and evapotranspiration, making arid and semi-arid tropical areas more prone to heightened risks and vulnerabilities (IPCC, 2023). Agriculture in the semi-arid tropics is facing multiple and complex challenges, including the degradation of natural resources (Rathore et al., 2019). Drought events in these regions negatively impact crop productivity and limit plant growth (El-Beltagy & Madkour, 2012). Among the critical factors for plant growth are soil water content and temperature (Wang et al., 2000), and any significant shifts in these parameters can have profound effects on plant development and ecosystem stability. Soil nutrient and water management are important to maintain the sustainability of agricultural lands (Kim & Park, 2024).

Semi-arid regions are characterized by low and erratic rainfall, high wind velocity, and intense solar radiation. They cover about 41 percent of the earth's terrestrial surface and are home to more than a third of all human beings (Mortimore et al. 2009). In addition, they are characterized by single rainfall events that usually cause brief pulses of soil moisture with limited infiltration depth (Chesson, 2004). In these ecosystems, high year-long potential evapotranspiration leads to an increase in plant water consumption (Modarres & Rodrigues da Silva, 2007; Rathore et al., 2019, as cited in Begizew, 2021). Understanding the effects of combined precipitation pulsing events and irrigation dynamics is crucial for effective water management in semi-arid agricultural regions.

Irrigation is highly significant for global agricultural production as 20% of the world's semi-arid irrigated crops produce 40% of harvested products, doubling land productivity within these regions (Fernández Cirelli et al. 2009). An agrosystem is defined as a complex and

multidimensional landscape governed by combined natural phenomena and processes, and human influence (Tittonell, 2023). In these systems, drip irrigation is widely used and crucial for the efficient management of water resources (Ouédraogo et al., 2021). Drip irrigation is a low-pressure, low-volume system that delivers water directly to plant roots from above or below the surface through a network of valves, pipes, and emitters, conserving water and nutrients (Karishma, 2021). This management practice is recognized as a high-efficient water-saving irrigation technology around the world and has been widely used in semi-arid areas (Wang, et al. 2022).

As of 2021, Latin America and the Caribbean had a total of 6,603,895 square meters of agricultural land, with Puerto Rico accounting for 1,689 square meters (World Bank, 2021). Thus, there is a need for further research to assess the long-term effects of climate change on agriculture (Moraes et al., 2023). Recurrent droughts across the island of Puerto Rico, particularly in the southwestern semi-arid region, have highlighted the agricultural vulnerability and the increasing need for adaptation mechanisms such as effective management practices to support agricultural production (PRCC, 2022). The southern region of the island is characterized by a semi-arid climate with pulsing and infrequent precipitation that limits water availability. This region, which includes the municipality of Santa Isabel, accounted for 53.34% of Puerto Rico's fruit and vegetable cultivation land in 2018, the highest among all regions of the island (Agricultural Census, 2017), highlighting its vital role in the island's food security.

The substrate of Santa Isabel is characterized by alluvial mollisols rich in organic matter with high infiltration rates of 119.4 mm/hour (Lugo-López et al., 1968). At our study site, Finca Atabey, these soils are highly fertile and characterized by a thick, dark-colored surface horizon, elevated organic carbon levels, and high base saturation (Muñoz et al., 2018). The clay-loam and

clay soils at our study site are subdivided into two series, San Antón (Sa): fine-loamy, mixed, superactive, isohyperthermic Cumulic Haplustolls (National Cooperative Soil Survey, 2006), and Jacaguas (Jg): loamy-skeletal, mixed, superactive, isohyperthermic Fluventic Haplustolls (National Cooperative Soil Survey, 2000), respectively. San Antón soils have a water transmission capacity ( $K_{sat}$ ) of 0.37–3.75 cm/hr (moderately low to moderately high), while Jacaguas soils range from 1.50–5.23 cm/hr (moderately high to high) (USDA NRCS, 2023). The available water capacity is 20.8% for San Antón and 21.6% for Jacaguas (Lugo López, 1952).

Due to pulsing and infrequent rainfall, high temperatures and evapotranspiration, and high soil infiltration rates, crops in the southern agricultural region of Puerto Rico are almost exclusively dependent on drip irrigation (Kuniansky et al. 2004). For this project, we studied the environmental effects of pulsing precipitation and drip irrigation on the soil water dynamics of avocado crops, as understanding the impacts of the dynamics of combined precipitation pulsing events and drip irrigation is highly relevant for managing water in semi-arid agricultural regions.

Based on this, we have established the following questions: 1. How does the quantity, intensity, and frequency of pulsing precipitation determine the water content in the soil profile? and 2. Does soil type affect water availability in the agrosystem? We hypothesized that effective precipitation would have an additive effect on the water content of soils that depend on drip irrigation. In addition, we hypothesized that soil type would determine the effectiveness of precipitation in influencing soil water content.

## Methods

### A. Study site

This investigation was conducted at Finca Atabey, Santa Isabel, P.R. ( $17^{\circ}59'46''$  N  $66^{\circ}24'36''$  W) (Figure 1B). We studied the environmental effects of drip irrigation and pulsing precipitation on water content dynamics in Jacaguas and San Antón with avocado crops.



Figure 1A. highlights **Santa Isabel**, Puerto Rico, and Figure 1B. **Finca Atabey** (images based on ©Google Earth, 2024).

### B. Experimental design

We monitored meteorological variables, including air temperature ( $^{\circ}\text{C}$ ), precipitation (mm), solar radiation ( $\text{W}/\text{m}^2$ ), and reference evapotranspiration (mm), from March 2024 to 2025, at 15-minute intervals using an ATMOS 41W meteorological station installed at the site. Soil profile data was collected from March 2024 to February 2025 using METER Group TEROS 12 sensors to measure water content. These sensors were installed based on the rooting depths of avocado and pumpkin crops: a) 0–15 cm, b) 15–30 cm, and c) 35–50 cm, respectively. The soil sensors were connected to METER ZL6 loggers with data collected at 1-hour intervals.

Dry days were established by the Cuevas & Medina (1986) equation:

$$\text{Rainfall (mm)} - \text{Evapotranspiration (mm)} \leq 0$$

### *C. Statistical treatment of data*

Statistical analyses were carried out using JMP® 18 and R Studio packages. Descriptive and parametric analyses were carried out. Box plots, time series, line and dot graphs, and one-way ANOVA were performed based on the questions analyzed.

## **Results**

### *Monthly Rainfall Trends*

Monthly and yearly rainfall patterns were observed at Finca Atabey (Table 1). In May 2024, the region experienced the highest rainfall, indicating a period of intense precipitation. In contrast, November featured the most wet days along with frequent rain pulses, although these events were characterized by lower intensity. Notably, evapotranspiration exceeded rainfall on 14 of the 22 rainy days in November, highlighting a moisture deficit during that month. January 2025 stood out as the driest month, recording the highest number of dry days along with the lowest precipitation levels.

### *Relationship Between Climate Variables*

An examination of the relationship among daily precipitation, mean air temperature, and reference evapotranspiration reveals interesting trends. High rainfall periods, such as in May 2024, correlated with decreases in both air temperature and evapotranspiration (Figure 2). Conversely, during periods of low rainfall, an increase in these variables was observed. However, these patterns are not uniform, as factors like cloud cover and various climatological variations—including humidity, wind, and solar radiation—also exert significant influence. The months from November to February showed a seasonal decrease in temperature and evapotranspiration, aligning with the drier months experienced in Puerto Rico.

### *Dry Days and Precipitation Patterns*

The visual representation of dry days and precipitation pulses illustrates the semi-arid conditions on Finca Atabey (Figure 3). During most days, there is little to no precipitation, confirming the trend seen in Table 1, where the frequency of zero precipitation days is high. Rainfall events tend to be intense and sporadic, creating noticeable peaks on specific dates. This data supports the conclusion that dry days are predominant, reinforcing the observation of low precipitation consistency.

### *Soil Water Content Comparisons*

In exploring soil water content, it becomes clear that the San Antón soil series exhibited significantly higher water contents compared to the Jacaguas series at both 0 – 15 cm and 15 – 30 cm depths (Figure 4). The 35 – 50 cm depth yielded the lowest water content for both soil series. Within the Jacaguas series, the water content peaked at 15 – 30 cm ( $23.4 \pm 2.1$ , Table 2), followed by a lower measurement at 0 – 15 cm ( $17.3 \pm 2.7$ , Table 2). In contrast, average water contents in San Antón consistently exceeded 30% at the shallower depths (Max of 37.9, Table 3), while Jacaguas' values largely fell below the wilting point (23.4%), except for some measurements at 15 – 30 cm. Notably, San Antón showed no available water at 35 – 50 cm but maintained values exceeding the wilting point in the upper soil layers (27.9%).

### *Temporal Variations in Soil Water Content*

Analyzing changes in volumetric water content over time reveals the significant impact of climate events and irrigation practices. Notably, a peak in soil water content coincided with Tropical Storm Ernesto (Figure 5), reinforcing the hypothesis that significant climatic events have cumulative effects on water retention. The extensive rainfall in November, recognized as

the wettest month, also played a role in maintaining elevated water levels. The different capacities of the two soil types to retain water were confirmed, supporting the second hypothesis surrounding these soil series. During the irrigation phase, small peaks in soil water content corresponded with irrigation events. In December, San Antón exhibited minimal variability in water content, likely influenced by various meteorological factors, including cloud cover. This, in turn, creates a more stable environment for moisture retention.

#### *Statistical Analysis of Soil Water Content*

A statistical analysis presented in Table 4 indicates the results of the one-way ANOVA conducted in R Studio for the two soil series, Jacaguas and San Antón. The extremely small p-values (0.0001) indicate that both depth and soil series, along with their interactions, significantly influence water content. This analysis underscores the importance of understanding different soil characteristics in managing water resources effectively.

#### **Discussion**

Semi-arid conditions were validated throughout this study. Low precipitation, high solar radiation, elevated temperatures, and high reference evapotranspiration rates characterize Finca Atabey's climate. This site experiences bimodal and pulsed precipitation patterns, such as those known to occur in Puerto Rico (Medina & Cuevas, 1990; Govender et al., 2013). Crop production in semi-arid areas is highly influenced not only by the amount of rainfall but also by its extreme variability, with high intensities, few events, and poor spatial and temporal distribution (Rockström et al., 2010; Oweis & Hachum, 2006). This research confirms that precipitation in Santa Isabel is highly erratic, highlighting crops' critical dependence on irrigation in these regions, as soil water content tends to fluctuate mainly in response to significant rainfall

events. In these environments, drip irrigation plays a central role in managing limited water resources efficiently (Ouédraogo et al., 2021).

Our results indicate that the site experiences mostly dry days. However, when precipitation does occur, it increases soil moisture, strengthens surface–air interactions that promote evaporation, and reduces daily maximum temperatures (Pyrgou et al., 2019). In our study, significant rainfall events, such as those from Tropical Storm Ernesto, noticeably enhanced soil water content. This observation is consistent with findings from Beijing’s mountainous forestlands, where a single 164.4 mm rainfall event led to a substantial increase in soil moisture (Wu et al., 2015), and from the southern Appalachian Mountains, where storm events across diverse landscapes consistently affected soil moisture levels based on soil depth and topography (Vose et al., 2022). This result supports our initial hypothesis and reflects the broader patterns identified in the study, emphasizing the close relationship between climatic variables and water availability for avocado crops.

Soil types vary in their ability to retain water, with factors like texture, such as clay and clay loam, playing a significant role in water availability. Wilting points—the moisture level at which plants can no longer absorb enough water to survive—vary by soil type due to differences in texture and structure. Texture and structure determine the distribution of pore sizes within the soil, which directly impacts how much water is available to plants by influencing key moisture levels like saturation, field capacity, and the wilting point (Lugo López, 1952; O’Geen, 2013). In Finca Atabey, soil water content varies between the soil series, with San Antón showing higher water retention in the shallower depths than Jacaguas. This was expected and confirms our second hypothesis, which stated that soil types would exhibit differences in water content.

Temporal weather variability also influenced water content. In colder months like December, there was lower variation in water content in San Antón, possibly due to the influence of increased cloud cover, lower temperatures, and reduced evapotranspiration. As a result, the water content during this period was fairly similar to that observed during significant rainfall events. Our findings are consistent with those Pyrgou et al. (2019), who identified cloud cover, soil moisture, precipitation, and solar radiation as key factors influencing the diurnal temperature range, with cloud presence shown to reduce daytime highs and raise nighttime lows by limiting incoming sunlight and trapping heat.

In the future, we intend to study additional parameters such as soil conductivity and temperature. Furthermore, we plan to compare how soil water content in avocado crops responds to rainfall and irrigation, in contrast with pumpkins, an annual crop that is also a predominant crop at our study site. This will allow for comparing irrigation and precipitation inputs, ultimately enhancing our understanding of water use efficiency. In line with this approach, Zarai et al. (2023) emphasize that smart irrigation strategies—especially those involving real-time monitoring of soil water and salt content—are crucial for enhancing irrigation efficiency and promoting sustainable agriculture in semi-arid regions. Implementing effective irrigation management will help us optimize the depth and timing of water application to satisfy crop needs while minimizing losses and conserving water resources (Datta et al., 2017).

Our work incorporates various ecohydrological variables to provide an ecosystem-level approach in a semi-arid agricultural system where the frequency, intensity, and timing of brief climatic events, and crop and water management, dictate the dynamics between soil and received water. This investigation reveals that crops in semi-arid regions heavily rely on irrigation, as soil

water content appears to be influenced primarily during significant rainfall events. Future studies should consider other variables impacting water retention and availability, such as cloud cover, lower temperatures, and lower evapotranspiration rates.

The results of this study can help deepen our understanding of agricultural ecohydrology, especially in systems where climatic and anthropogenic factors influence water availability. There is very little data on soil water dynamics in the southern agricultural region of Puerto Rico; therefore, our ongoing study will continue to provide highly relevant information for water use and crop resilience, especially under projected drier conditions due to climate change. Understanding long-term climatic shifts is critical for developing adaptive strategies in agriculture, as highlighted by Moraes et al. (2023). This underscores the need for ongoing research into the lasting impacts on crop productivity and resource management.

## References

1. Ahmad, G., & Khan, A. A. (2019). Pumpkin: Horticultural importance and its roles in various forms; A review. *International Journal of Horticulture & Agriculture*, 4(1), 1-6. <https://doi.org/10.15226/2572-3154/4/1/00124>
2. Begizew, G. (2021). Agricultural production system in arid and semi-arid regions. *International Journal of Agricultural Science and Food Technology*, 7(2): 234-244. <https://doi.org/10.17352/2455-815x.000113>
3. Carr, M. K. V. (2013). The Water Relations and Irrigation Requirements of Avocado (*Persea americana* Mill.): A REVIEW. *Experimental Agriculture*, 49(2), 256–278. doi:10.1017/S0014479712001317
4. Chesson, P., Gebauer, R. L. E., Schwinning, S., Huntly, N., Wiegand, K., Ernest, M. S. K., Sher, A., Novoplansky, A., & Weltzin, J. F. (2004). Resource pulses, species interactions, and diversity maintenance in arid and semi-arid environments. *Oecologia*, 141, 236–253. <https://doi.org/10.1007/s00442-004-1551-1>
5. Cuevas, E., & Medina, E. (1986). Nutrient dynamics within Amazonian Forest ecosystems: I. nutrient flux in fine litter fall and efficiency of nutrient utilization. *Oecologia*, 68, 466-472. <https://doi.org/10.1007/BF01036756>

6. El-Beltagy, A., & Madkour, M. (2012). Impact of climate change on arid lands agriculture. *Agriculture & Food Security*, 1(3), Article 3. <https://doi.org/10.1186/2048-7010-1-3>
7. Fernández Cirelli, A., Arumí, J. L., Rivera, D., & Boochs, P. W. (2009). Environmental effects of irrigation in arid and semi-arid regions. *Chilean Journal of Agricultural Research*, 69(Suppl. 1), 27-40. <https://doi.org/10.4067/s0718-58392009000500004>
8. IPCC, 2023: Summary for Policymakers. In: Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II, and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001
9. Karishma, S. (2021). Drip Irrigation System. *Irrigation and Drainage Systems Engineering*, 10(6), 277.
10. Kim, H. N., & Park, J. H. (2024). Monitoring of soil EC for the prediction of soil nutrient regime under different soil water and organic matter contents. *Applied Biological Chemistry*, 67(1). <https://doi.org/10.1186/s13765-023-00849-4>
11. Kuniatsky, E.L., Gómez-Gómez, F., & Torres-González, S, 2004, Effects of aquifer development and changes in irrigation practices on ground-water availability in the Santa Isabel area, Puerto Rico: U.S. Geological Survey Water-Resources Investigations Report 03-4303, 56 p.
12. Lugo López, M. A. (1952). Available water capacity of the surface layer of various soils from the arid and semiarid region of Puerto Rico. *The Journal of Agriculture of the University of Puerto Rico*, 36(2), 134–140. <https://doi.org/10.46429/jaupr.v36i2.12793>

13. Lugo López, M. A., Juárez, J., & Bonnet, J. A. (1968). Relative Infiltration Rate of Puerto Rican Soils. *The Journal of Agriculture of the University of Puerto Rico*, 52(3), 233–240. <https://doi.org/10.46429/jaupr.v52i3.11510>
14. Modarres, R., & Rodrigues da Silva, V. de P. (2007). Rainfall trends in arid and semi-arid regions of Iran. *Journal Arid Environments*, 70, 344-355.  
<https://doi.org/10.1016/j.jaridenv.2006.12.024>
15. Moraes, F. D. S., Ramseyer, C., & Gamble, D. (2023). The effects of projected climate change on crop water availability in the U.S. Caribbean. *Journal of Water and Climate Change*, 14(4), 1176–1191. <https://doi.org/10.2166/wcc.2023.398>
16. Mortimore, M., Anderson, S., Cotula, L., Davies, J., Facer, K., Hesse, C., Morton, J., Nyangena, W., Skinner, J., & Wolfangel, C. (2009). Dryland opportunities: A new paradigm for people, ecosystems, and development. IUCN, IIED, & UNDP.
17. Muñoz, M. A., Lugo, W. I., Santiago, C., Matos, M., Ríos, S., & Lugo, J. (2018). Taxonomic classification of the soils of Puerto Rico, 2017 (Technical Report). University of Puerto Rico. <https://hdl.handle.net/20.500.11801/817>
18. National Cooperative Soil Survey. (2000). *Official series description – Jacaguas series*. U.S. Department of Agriculture.  
[https://soilseries.sc.egov.usda.gov/OSD\\_Docs/J/JACAGUAS.html](https://soilseries.sc.egov.usda.gov/OSD_Docs/J/JACAGUAS.html)
19. Natural Resources Conservation Service. (2006). *Official series description – San Anton series*. U.S. Department of Agriculture.  
[https://soilseries.sc.egov.usda.gov/OSD\\_Docs/S/SAN\\_ANTON.html](https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SAN_ANTON.html)

20. Ouédraogo, S. K., Marcel Kébré, B., & Zougmore, F. (2021). Water dynamics under drip irrigation to properly manage water use in arid zone. *Journal of Agricultural Chemistry and Environment*, 10(01), 57-68. <https://doi.org/10.4236/jacen.2021.101004>
21. Puerto Rico Climate Change Council (PRCCC). (2022). Puerto Rico's State of the Climate 2014-2021: Assessing Puerto Rico's Social-Ecological Vulnerabilities in a Changing Climate. Puerto Rico Coastal Zone Management Program, Department of Natural and Environmental Resources, NOAA Office of Ocean and Coastal Resource Management. San Juan, PR.
22. Rathore, V. S., Tanwar, S. P., Kumar, P., & Yadav, O. P. (2019). Integrated Farming System: Key to sustainability in arid and semi-arid regions. *The Indian Journal of Agricultural Sciences*, 89(2), 181–192. <https://doi.org/10.56093/ijas.v89i2.86982>
23. Tiftonell, P. (2023). Structure, Functions and Diversity of Agroecosystems. In: *A Systems Approach to Agroecology* (pp. 79-115). Springer, Cham. [https://doi.org/10.1007/978-3-031-42939-2\\_3](https://doi.org/10.1007/978-3-031-42939-2_3)
24. USDA, (2012). Agricultural Census. National Agricultural Statistics Service. Retrieved from: <https://www.nass.usda.gov/AgCensus/>
25. U.S. Department of Agriculture, Natural Resources Conservation Service (USDA NRCS). (2023). Custom soil resource report for Ponce Area, Puerto Rico Southern Part: Finca Atabey (pp. 13-14). U.S. Department of Agriculture.
26. Wang, D., Shannon, M. C., Grieve, C. M., & Yates, S. R. (2000). Soil water and temperature regimes in drip and sprinkler irrigation, and implications to soybean emergence. *Agricultural Water Management*, 43(1), 15-28. [https://doi.org/10.1016/s0378-3774\(99\)00057-8](https://doi.org/10.1016/s0378-3774(99)00057-8)

27. Wang, H., Wang, N., Quan, H., Zhang, F., Fan, J., Feng, H., Cheng, M., Liao, Z., Wang, X., & Xiang, Y. (2022). Yield and water productivity of crops, vegetables and fruits under subsurface drip irrigation: A global meta-analysis. *Agricultural Water Management*, 269, 107645. <https://doi.org/10.1016/j.agwat.2022.107645>
28. World Bank. (2021). *Agricultural land (sq. km) – Latin America and the Caribbean*. World Bank. Retrieved October 3, 2024, from [https://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=ZJ&name\\_desc=false](https://data.worldbank.org/indicator/AG.LND.AGRI.K2?locations=ZJ&name_desc=false)
29. Datta, S., Taghvaeian, S., & Stivers, J. (2017). *Understanding soil water content and thresholds for irrigation management (BAE-1537)*. Oklahoma Cooperative Extension Service. <https://extension.okstate.edu/fact-sheets/print-publications/bae/understanding-soil-water-content-and-thresholds-for-irrigation-management-bae-1537.pdf>
30. O'Geen, A. T. (2013). Soil water dynamics. *Nature Education Knowledge*, 4(5), 9. <https://www.nature.com/scitable/knowledge/library/soil-water-dynamics-103089121/>
31. Oweis, T., & Hachum, A. (2006). Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management*, 80, 57–73.
32. Pyrgou, A., Santamouris, M., & Livada, I. (2019). Spatiotemporal analysis of diurnal temperature range: Effect of urbanization, cloud cover, solar radiation, and precipitation. *Climate*, 7(7), 89. <https://doi.org/10.3390/cli7070089>
33. Rockström, J., Karlberg, L., Wani, S. P., Barron, J., Hatibu, N., Oweis, T., Bruggeman, A., Farahani, J., & Qiang, Z. (2010). Managing water in rainfed agriculture—the need for a paradigm shift. *Agricultural Water Management*, 97, 543–550.

34. Vose, J. M., Ford, C. R., Laseter, S. H., Luce, C. H., & Elliott, K. J. (2022). Soil moisture responses to storm events in southern Appalachian forested watersheds. *USDA Forest Service Research Note*. <https://research.fs.usda.gov/treearch/63156>
35. Wu, Y., Zhang, J., Liu, Q., Liu, L., Liu, X., & Wang, C. (2015). Soil moisture dynamics under extreme rainfall events in mountainous forestland in Beijing, China. *Journal of Forestry Research*, 26(1), 171–180. <https://doi.org/10.1007/s11676-015-0160-7>
36. Zarai, B., Khaskhoussy, K., Zouari, M., & others. (2023). Smart control of soil water and salt content for improving irrigation management of tomato crop field: Kairouan area. *Environmental Monitoring and Assessment*, 195, 1408. <https://doi.org/10.1007/s10661-023-12019-6>
37. Medina E, Cuevas E. Propiedades fotosintéticas y eficiencia de uso de agua de plantas leñosas del bosque decíduo de Guánica: Consideraciones generales y resultados preliminares. *Acta Científica*. 1990; 4:25-36
38. Govender Y, Cuevas E, Sternberg LD, Jury MR. Temporal variation in stable isotopic composition of rainfall and groundwater in a tropical dry forest in the northeastern Caribbean. *Earth Interactions*. 2013;17(27):1-20

## Tables and Figures

**Table 1. Quantity, Intensity, And Frequency of Precipitation Pulses by Month**

<b>Month-year</b>	<b>Quantity (mm)</b>	<b>Intensity (mm/day)</b>	<b>Frequency (pulses/month)</b>	<b>Dry days per month</b>	<b>Wet days per month</b>
<b>Mar-24</b>	13.1	0.2-5.1	7	21	2
<b>Apr-24</b>	66.9	0.02-22.9	16	25	5
<b>May-24</b>	207.8	0.05-71.6	11	25	6
<b>Jun-24</b>	63.6	0.03-19.9	13	24	6
<b>Jul-24</b>	55.8	0.02-23.3	17	28	3
<b>Aug-24</b>	58.1	0.05-30.8	9	12	4
<b>Sep-24</b>	65	0.05-25.0	15	25	5
<b>Oct-24</b>	111.5	0.1-42.8	22	24	7
<b>Nov-24</b>	99.6	0.02-27.8	22	22	8
<b>Dec-24</b>	43.1	0.05-25.8	14	27	4
<b>Jan-25</b>	8.4	0.02-4.3	11	30	1
<b>Feb-25</b>	16.2	0.2-8.0	7	26	2
<b>Mar-25</b>	26.9	0.2-24.8	5	22	1
-	Total: 836.1	-	Total: 169	Total: 311	Total: 54
-	Average: 64.3	-	Average: 13	Average: 23.9	Average: 4.2
-	SD: 53	-	SD: 5.4	SD: 4.4	SD: 2.3

**Table 2. Descriptive statistics for Jacaguas**

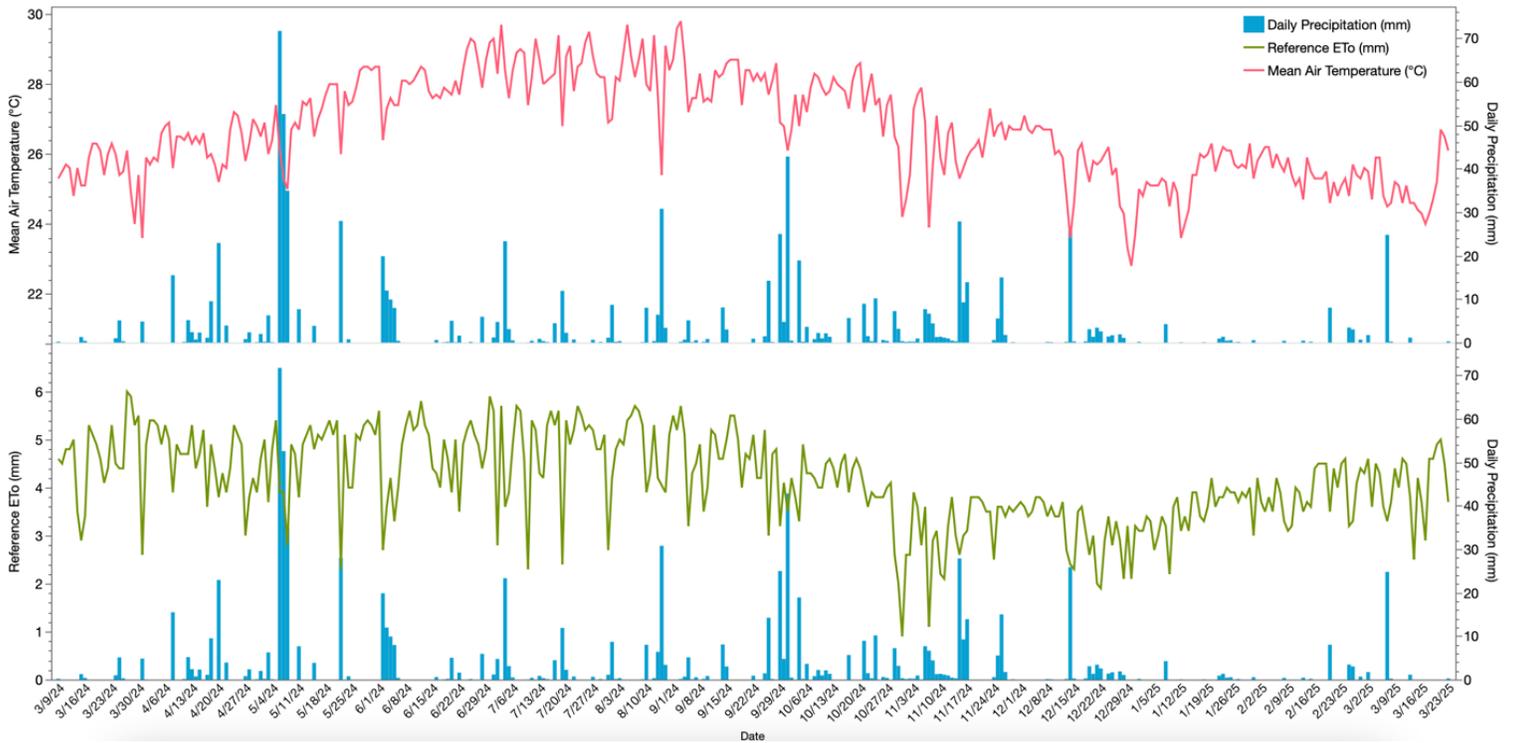
<b>Depth (cm)</b>	<b>Mean</b>	<b>SD</b>	<b>Min</b>	<b>Max</b>
<b>0-15</b>	17.32	2.74	10.4	28.4
<b>15-30</b>	23.40	2.05	16.2	33.4
<b>35-50</b>	17.95	1.25	13.4	24.5

**Table 3. Descriptive statistics for San Antón**

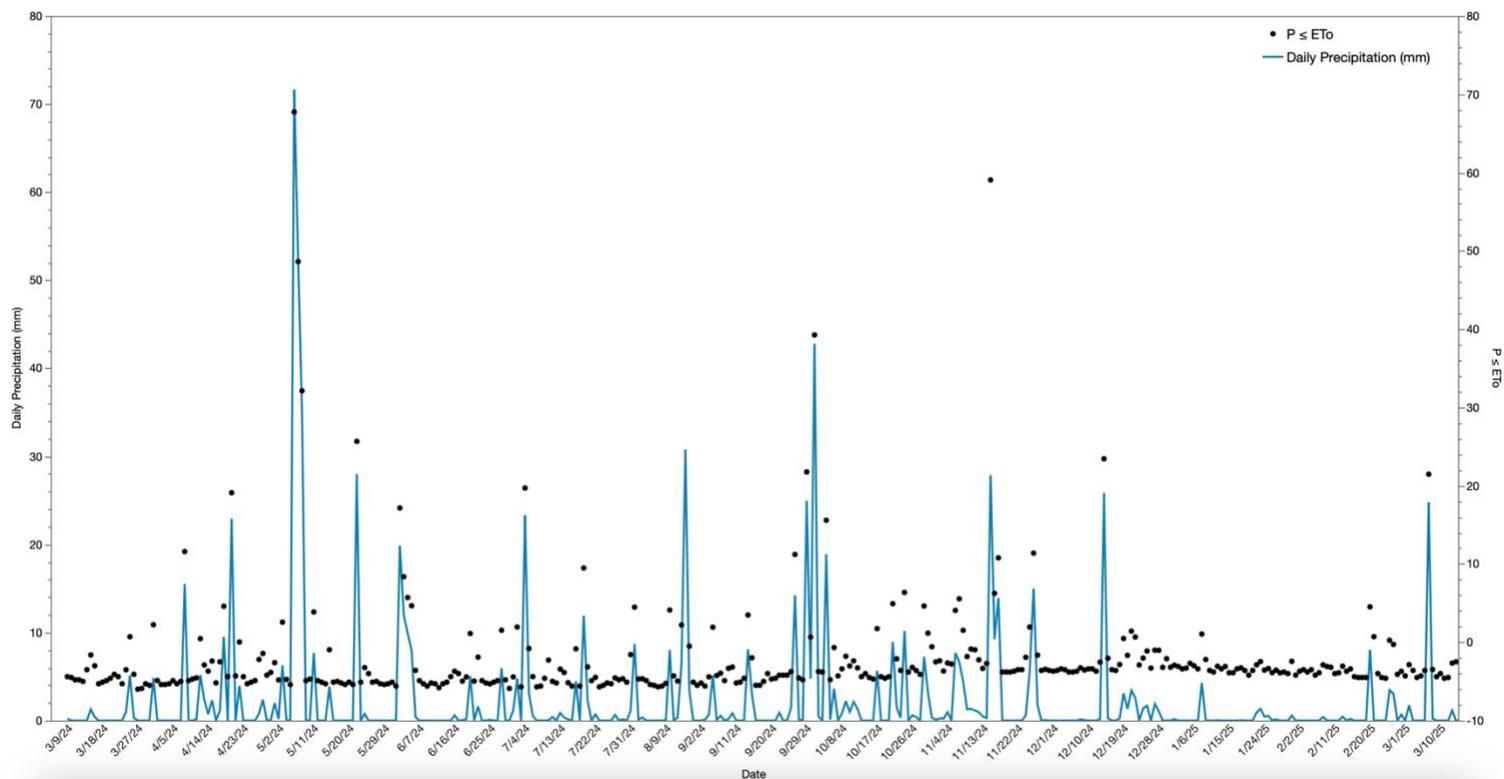
<b>Depth (cm)</b>	<b>Mean</b>	<b>SD</b>	<b>Min</b>	<b>Max</b>
<b>0-15</b>	29.23	4.72	14.2	37.9
<b>15-30</b>	30.68	2.43	21.8	36.2
<b>35-50</b>	18.46	1.85	12.7	27.8

**Table 4. One-way ANOVA for both Soil Series (Jacaguas and San Antón)**

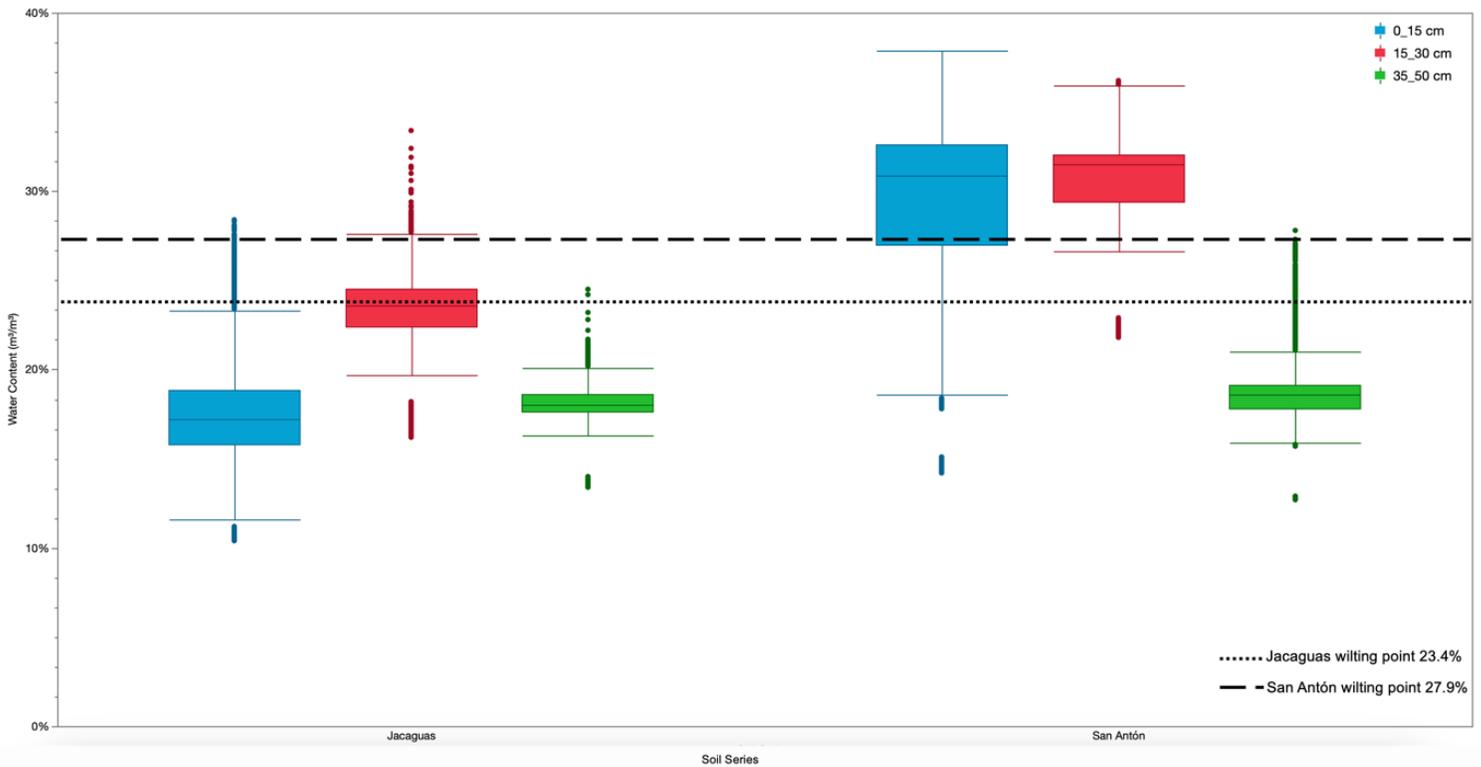
<b>Depth (cm)</b>	<b>DF</b>	<b>Prob &gt;  t </b>	<b>Prob &gt; t</b>
<b>0-15</b>	13,066.89	0.0001	0.0001
<b>15-30</b>	15,816.85	0.0001	0.0001
<b>35-50</b>	14,271.02	0.0001	0.0001



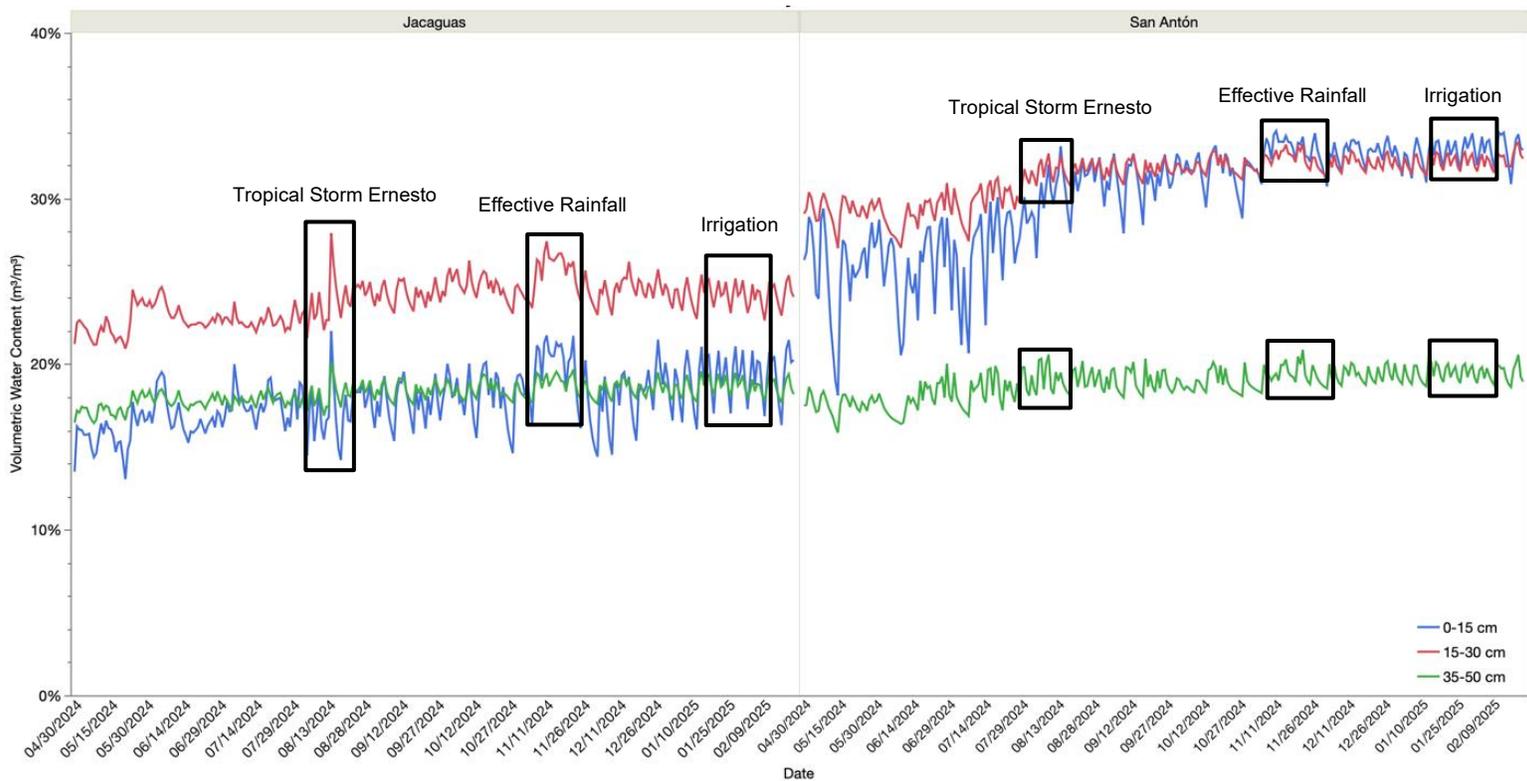
**Figure 2. Comparison Between Daily Precipitation, Mean Air Temperature, and Reference Evapotranspiration over Time.** Oposing trends between rainfall and the other variables highlight seasonal dynamics and climate-driven variability.



**Figure 3. Dry Days and Precipitation Pulses over Time.** The blue line represents rainfall, and the dots represent dry days. The site experiences mostly dry days ( $P \leq ET_0$ ) and low and erratic precipitation.



**Figure 4. Volumetric Water Content by Soil Series.** San Antón soils maintain higher moisture levels than Jacaguas, with upper layers (0–15 cm and 15–30 cm) remaining above the wilting point. In contrast, Jacaguas soils fall mostly below their wilting point at all depths.



**Figure 5. Volumetric Water Content by Soil Series Over Time.** Three major patterns are highlighted in this figure: tropical storm Ernesto, an effective rainfall event, and irrigation.

Disclaimer: Data can be provided upon request. The contact people are Dr. Elvira Cuevas and Dr. Solimar Pinto.