



## Effects on the agronomic development of the Dominico Hartón plantain under drought and flood conditions

### Efecto sobre el desarrollo agronómico del plátano Dominico Hartón sometido a condiciones de sequía e inundación

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#### Abstract

The study evaluated the developmental behavior of the 14-week-old Dominico Hartón cultivar (*Musa* spp.) under simulated drought and flooding water scenarios. The work was carried out at the facilities of the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM-MFL) in the area of the Ciudad de la Investigación, Innovación y Desarrollo Agropecuario (CIIDEA), located in Calceta, Bolívar canton, Manabí province. Three types of treatments were implemented: T1: control without water stress, T2: drought conditions, T3 flooding conditions. Among the results obtained, the dry root biomass ( $P < 0.001$ ), where the treatment subjected to flooding conditions (T3) increased this variable by 42% compared to the management without water stress (T1). For the pseudostem dry biomass variable ( $P < 0.001$ ) something similar occurred, where T3 reached 102% greater dry biomass in the pseudostem in relation to (T1). For the variable of dry leaf biomass ( $P < 0.001$ ), T1 and T3 had similar values, but in relation to the treatment subjected to drought (T2), they presented a biomass 59% lower than the average of the other treatments. These findings highlight that the different conditions of drought and flooding significantly affect the growth and development of banana seedlings.

**Keywords:** agricultural development, water resource management, technified irrigation, rural development, environmental sustainability.

#### Resumen

La investigación evaluó el comportamiento durante el desarrollo del cultivar Dominico Hartón (*Musa* spp.) de 14 semanas de edad, bajo escenarios simulados de estrés hídrico por sequía e inundación. El trabajo se desarrolló en la Ciudad de la Investigación, Innovación y Desarrollo Agropecuario (CIIDEA) de la Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM-MFL), ubicada en la parroquia Calceta, cantón Bolívar, provincia de Manabí. Se implementaron tres tipos de tratamientos: T1: testigo sin estrés hídrico, T2: condiciones de sequía, T3: condiciones de inundación. Entre los resultados obtenidos, la biomasa seca de la raíz ( $P < 0,001$ ), donde el tratamiento sometido a condiciones de inundación (T3) incrementó en un 42% en comparación al manejo sin estrés hídrico (T1). Para la variable de biomasa seca del pseudotallo ( $P < 0,001$ ) ocurrió algo similar, donde T3 alcanzó un 102% mayor biomasa seca en el pseudotallo con relación a T1. Para la variable de biomasa seca de la hoja ( $P < 0,001$ ), el T1 y T3 tuvieron valores similares ( $\approx 28$  g), pero con relación al tratamiento sometido a sequía (T2), este presentó una biomasa de 59% menor a la media de los otros tratamientos. Estos hallazgos destacan que las diferentes condiciones de sequía e inundación afecta de manera significativa el crecimiento y desarrollo de las plántulas de plátano.

**Palabras clave:** desarrollo agrícola, gestión de recursos hídricos, riego tecnificado, desarrollo rural, sostenibilidad ambiental.



## Introduction

At the global level, plantain is one of the most important and most consumed products, in addition to having been among the first to globalize and position itself in the international market, establishing this crop as a staple food in the daily diet of millions of people (Álvarez et al., 2020). The Observatory of Economic Complexity (OEC, 2024) platform mentioned that, in 2022, plantain was the three hundred and fifth product worldwide, with total sales of \$13.5 million, and trade in this crop represents 0.05% worldwide.

In Ecuador, according to the Ministry of Agriculture and Livestock (MAG, 2024), the historical plantain yield in the period (2019–2023) recorded an average of 6.50 t ha<sup>-1</sup>; in 2023, a planting area of 152,654 ha for export purposes was recorded and a production of 840,599 t was achieved, resulting in an average yield of 5.5 t·ha<sup>-1</sup>, which enabled foreign sales totaling USD 3,855 million for this commodity. It also stands out with a 28% share in the global market in exports, above Guatemala, Colombia, and the United States, standing out as the leading plantain exporter worldwide with a value of USD 680 million, notably considering the economic importance of this crop. Among the provinces that stand out for their production (t) are: Manabí (307,447), Guayas (135,828), Santo Domingo de los Tsáchilas (124,415), Los Ríos (104,798), Napo (30,470), and Esmeraldas (25,504) (Survey of Agricultural Area and Production (ESPAC), 2023).

In the province of Manabí, during 2023, an area of 60,000 ha planted with plantain was recorded, with a production of 307,446 t, which achieved an average yield of 6.26 t·ha<sup>-1</sup>, covering a national market of 68% and an international market of 32% with regard to this crop (National Institute of Statistics and Census (INEC), 2023). Among the cantons of Manabí, El Carmen, Chone, Portoviejo, Flavio Alfaro, and Tosagua stand out with 87, 3, 3, 2, and 1%, respectively, of the provincial share (Silvia et al., 2021).

Manabí has a climate that is beneficial for plantain cultivation, which is characterized as humid and warm: the winter season is comprised between the months of December–May, being a period of heat and the presence of precipitation due to the influence of the warm “El Niño” current; the summer season runs from the months of June to December and is less hot and with an absence of precipitation because it is influenced by the cold Humboldt Current (Piloso et al., 2020). In view of the above, it is also important to note that Manabí has been affected by both droughts and floods; Mendoza et al. (2019) pointed out that, in 2010, the province experienced a prolonged period of drought,

and Cedeño et al. (2020) stated that water stress was the most limiting abiotic factor in Musaceae due to increasing variability in rainfall and competition for water resources, which limit both commercial production and subsistence production.

Climate change is an environmental phenomenon caused by greenhouse gases (Díaz, 2012) and represents a threat to the agricultural sector due to rising temperatures, alteration of crop adaptability, increased water requirements due to a higher evapotranspiration rate, and, in turn, it also puts the planet’s water sources at risk, because as temperatures rise, water evaporates more rapidly (León and León, 2023). Both droughts and floods put food sovereignty at risk. It is estimated that by 2050 global food production will have to increase by 60% to meet the rise in demand, which necessitates the search for strategies, technologies, and tools for climate change adaptation and mitigation (Sánchez et al., 2020). Considering that climate shows high spatiotemporal variability, which has intensified with the effects of climate change (Valdivieso et al., 2021), it is expected that droughts and floods will intensify across the globe, which poses a risk to food production systems worldwide (Nelson et al., 2009).

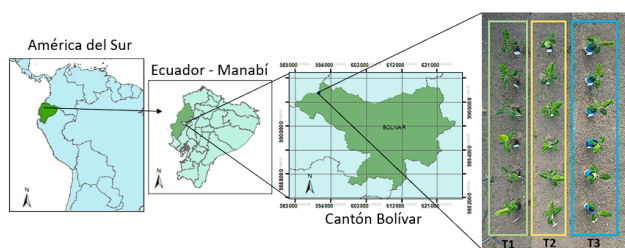
Campos and Mendoza (2018) mentioned that droughts and floods have historically affected the province of Manabí, and according to the projections of Rivadeneira (2014), temperatures are expected to increase and rainfall is expected to register anomalies, processes that will be accentuated by climate change. He also makes a projection regarding the management of the levels of the “La Esperanza” reservoir in the Carrizal River sub-basin, where the theoretical demand presented is not favorable for future scenarios, indicating that if water demand is maintained, the agricultural sector would be the most affected. According to the Ministry of Environment, Water and Ecological Transition (MAATE, 2021), it is considered that by 2025 drought will be within the ranges of moderate to high vulnerabilities.

Framed within the importance of plantain cultivation for the province of Manabí and Ecuador, as well as the climatic challenges that agricultural sustainability faces, the study of the response of Dominico Hartón plantain under water-stress conditions—flooding and drought—has been proposed, and its influence on the variables biomass, leaf area index, relative water content, and leaf emission rate. Therefore, they provide a comprehensive view of the plant’s physiological status under water-stress conditions. A study conducted by Teoh et al. (2022) recorded the response to water stress in *Musa acuminata* cv. Berangan during the initial stages of development, specifically over a controlled period of 24 days of stress; however, for

drought conditions, studies have been generated *in vitro* crops for genetic improvement (Salazar et al., 2014a; Salazar et al., 2014b; Moreno et al., 2017); nevertheless, there is no evidence indicating the exact length of time that a plantain plant (*Musa* spp.) can survive without water before dying. In addition, research indicates that drought stress physiologically affects the plant (Nansamba et al., 2022).

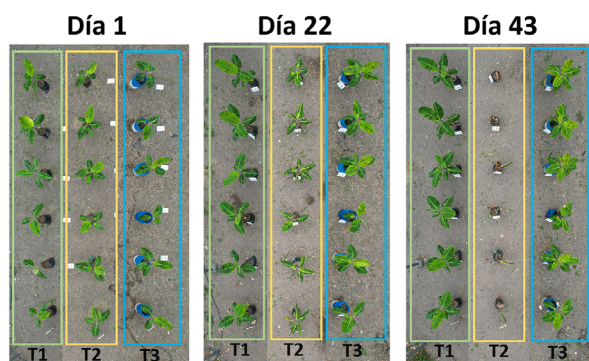
**Materials and methods**

The research was carried out at the City of Research, Innovation and Agricultural Development (CIIDEA) of the Escuela Superior Politécnica Agropecuaria de Manabí Manuel Félix López (ESPAM-MFL). The trial was located (figure 1) between the coordinates 0°49'47.6" S and 80°10'52.9" W, at an altitude of 15 m a.s.l.



**Figure 1.** Location: CIIDEA area at ESPAM-MFL. ESPAM-MFL.

For the development of the research, two water-stress scenarios were considered—flooding and drought—compared with an ideal scenario for the crop. The variables analyzed were biomass, leaf area index, relative water content, and leaf emission rate in 18 *Dominico Hartón* plantain individuals (*Musa* spp.) 14 weeks of age. The evaluation period was comprised between June 21 and August 02, 2024, with a total of 43 days evaluated (figure 2). The individuals used came from vitroplants to ensure their homogeneity and plant material.



**Figure 2.** Visual status of *Dominico Hartón* plantain plants on days 1, 22, and 43. The climatic conditions (table 1) of the months during which the experiment was conducted showed the following characteristics:

**Table 1.** Historical climate conditions data series 2012–2022, from June to August.

Month	Precipitation mm	Sunshine duration h	Maximum temperature (°C)	Minimum temperature (°C)	Relative humidity (%)	Wind speed m·s <sup>-1</sup>
Junio	28	73.68	30.26	21.80	83.90	0.49
Julio	10	70.94	29.61	21.11	83.50	0.54
August	1	100.38	30.36	20.66	81.54	0.61

Source: Estación Meteorológica ESPAM MFL.

**Field experiment**

The vitroplants used were placed in black plastic bags measuring 14 × 16 inches. A soil characteristic of the study area was selected, which was sieved to remove clods, incorporating a portion of leaf litter rich in organic matter and sand from the bank of the Carrizal River in a ‘50-25-25’ ratio; this implies that the substrate to be used contained 50% regular soil from the study area, 25% leaf litter, and 25% sand from the river bank, suitable for the needs of plantain since it allows free root expansion, favoring gas exchange, moisture, and nutrient uptake, resulting in a soil suitable for good crop development.

Prior to the start of the trial, the seedlings were subjected to a four-week acclimatization period to homogenize the individuals (figure 3), during which irrigation and fertilizer were applied based on the soil analysis (table 2). Once this stage was completed, each treatment was subjected to the particular characteristics of the design in order to simulate water-stress conditions, both drought and flooding. To ensure flooding conditions, round plastic buckets were used, with a diameter at the lower base of 30 cm and a height of 40 cm, lined on the inside with a plastic bag to ensure that the water did not drain. Similarly, for the treatment under drought conditions, the use of a plastic cover was implemented, which was placed when rainfall was present and when photosynthetic activity was lower (6:30 pm to 5:30 am), and was removed every morning before the seedlings’ photosynthetic activity began (figure 4).

Eventos claves	Adaptación del cultivo 20 de Mayo hasta el 20 de Junio			Inicio del ensayo 21 de junio		Culminación del ensayo 2 de agosto		Pesado de biomasa fresca de las plantas 5 de agosto		Pesado de biomasa seca de las plantas 15 de agosto			
	Meses	MAYO			JUNIO		JULIO		AGOSTO				
Edad de las plántulas	Semana 9	Semana 10	Semana 11	Semana 12	Semana 13	Semana 14	Semana 15	Semana 16	Semana 17	Semana 18	Semana 19	Semana 20	Semana 21
Riego													
Fertilización													
T1 Control													
T2 Déficit hídrico													
T3 Inundación controlada													
Biomasa fresca y seca													

**Figure 3.** Assay timeline

**Table 2.** Chemical analysis of the soil.

pH	Organic matter(%)	Phosphorus (ppm)	Potasio (meq·100 mL <sup>-1</sup> )	Calcium (meq·100 mL <sup>-1</sup> )	Magnesium (meq·100 mL <sup>-1</sup> )
6.9	-	42	0.87	13	4.1





**Figura 4.** On the left, seedlings under water-deficit stress covered with plastic, and on the right, seedlings in containers kept continuously flooded.

### Experimental design

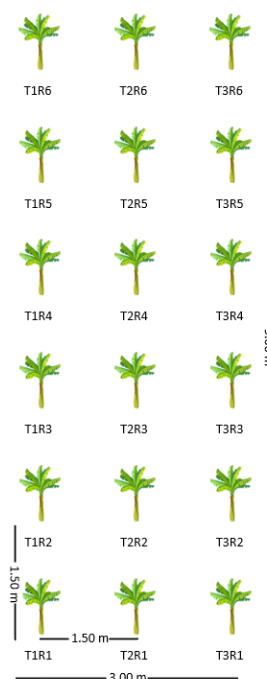
The trial followed a completely randomized experimental design (CRD), with three treatments and six replicates, for a total of 18 experimental units. Each experimental unit consisted of one plant (figure 5; table 3). The treatments were: (T1) control treatment, which consisted of management without water deficit (ideal irrigation conditions), where the soil water content was maintained between field capacity and the allowable water level (33 to 60 cbar). Treatment T2 water-stress treatment due to drought, where no water was applied throughout the entire trial. Treatment T3 water-stress treatment due to flooding, where conditions of flooding were maintained between 8 and 10 cm above the soil level.

**Table 3.** Treatments that were applied in the experiments

Description	Coding
Control	T1
Water-deficit stress	T2
Flooding stress	T3

### Statistical analysis

An analysis of variance (ANOVA) was performed at  $\alpha=0.05$  and Tukey's test at 5% to determine significant differences among treatments, and finally, correlation among the study variables was performed using InfoStat software, Student Version 2020.



**Figure 5.** Experimental design.

### Analyzed variables

#### Biomass

Biomass was calculated separately for the root, stem, and leaves of each experimental unit once the field trial ended; a precision balance was used to determine biomass, and a forced-air oven (Memmert brand, UF110 model, Schwabach, Germany) (Arias et al., 2014) was used for drying the samples.

**Root biomass (g).** To obtain this variable, it was necessary to separate the roots from the corm in order to weigh the fresh roots and determine fresh biomass; subsequently, the samples were placed in the oven at a temperature of 105 °C for 48 hours or until the biomass was constant, thus obtaining dry biomass.

**Pseudostem and leaf biomass (g).** Once the pseudostem was separated from the corm and the leaves from the pseudostem, the procedure for obtaining fresh and dry biomass was similar to that of the root, except that for the pseudostem the oven was used for 72 hours and for the leaves for 48 hours, both at 105 °C until the biomass of the sample did not vary.

### Leaf area index

For this variable, a representative leaf sample from each treatment with an area of  $10 \times 10 \text{ cm}^2$  was selected and weighed on a precision balance. Subsequently, it was placed in an oven at  $75 \text{ }^\circ\text{C}$  for 24 hours until the biomass was constant, and the known leaf area was then related to the dry biomass obtained through the biomass in grams of the leaves (Martínez et al., 2024).

### Relative water content

Relative water content in the root: to obtain this variable, the following formula proposed by Villalobos et al. (1990) was applied:

$$\text{CRAR} = (\text{Bf}-\text{Bs})/(\text{Bt}-\text{Bs}) \times 100 \quad (1)$$

Where:

Bf= fresh root biomass

Bs= dry root biomass

Bt= turgid root biomass

Turgid biomass was the fresh root biomass of T3, because this treatment was always under flooding conditions; therefore, it served as the standard to calculate the difference with the other treatments.

Water content in the pseudostem and leaves: the calculation of this variable was performed using the values obtained for dry and fresh biomass of the samples, applying the corresponding formula as indicated.

### Leaf emission rate

To obtain this variable, the emergence of each new flag leaf was observed and counted throughout the trial, thus making it possible to quantify the rate at which the plant produces new leaves and to interpret the physiological status of the crop (Carr, 2009; Douglas, 2018).

## Results and discussion

### Evolution of the variables

The analysis of variance of the treatments for the evaluated physiological variables is presented (tables 4, 5, 6, and 7), and it is observed that the means showed statistical significance in all cases; the details for each variable are presented below.

### Biomass

The analyses of variance for biomass showed significant differences among treatments for each segment analyzed of the seedlings (table 4).

**Table 4.** Determination of biomass in 14-week-old Dominico Hartón plantain seedlings subjected to water stress.

Variable	Tratamiento		
	T1	T2	T3
Fresh root biomass (g)	107.58 B	26.52 C	207.58 A
Dry root biomass (g)	18.16 B	7.28 C	25.91 A
Fresh pseudostem biomass (g)	542.42 B	167.42 C	769.70 A
Dry pseudostem biomass (g)	45.20 B	17.39 C	85.48 A
Fresh leaf biomass (g)	200.76 A	31.82 B	184.85 A
Dry leaf biomass (g)	27.50 A	11.37 B	29.76 A
Total fresh biomass (g)	850.76	225.76	1162.13
Total dry biomass (g)	90.86	36.04	141.15
Water content (g)	759.9	189.72	1020.98

### Root biomass

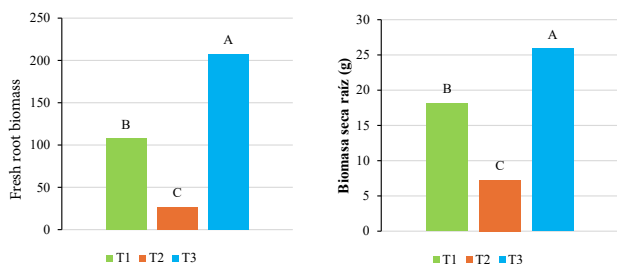
The calculation of fresh root biomass (figure 6) made it possible to identify that in T3, with a biomass of 207.58 g, there was an increase of 92.9% compared to T1, with a biomass of 107.58 g, suggesting that the controlled flooding to which the seedlings were subjected during the 43 days of treatment significantly favored biomass accumulation in the root. Meanwhile, in the case of T2, with a biomass of 26.52 g, water stress due to drought represented a 75.3% reduction in fresh biomass compared to T1, indicating that the water deficit drastically limited the development of fresh biomass in the root. These results agreed with those obtained by Teoh et al. (2022), who described that flooding induced physiological responses such as aerenchyma formation and antioxidant enzyme activity in the roots of plantain plants, promoting their increase, since these structures facilitated tissue oxygenation under hypoxic conditions (absence of oxygen in the tissues), which contributed to greater tolerance to excess water.

However, according to Gamboa (2024), excess water in the soil can result in the saturation of pore spaces, which can limit the oxygen supply to the roots, and, according to Domingues et al. (2024), a prolonged flooding process can generate anaerobic conditions that altered root respiration and favored the development of soil pathogens; neither of these statements could be validated after the 43 days of flooding evaluation..

With regard to dry biomass (figure 6), the effect of flooding water stress applied in T3, with a resulting biomass of 25.91 g, showed an increase of 43.50% compared to T1, with a biomass of 18.06 g, which, although lower than the percentage reached in fresh biomass, also indicated an increase in dry biomass, suggesting that controlled flooding during the evaluated period benefited the overall root biomass growth. Consistent with what occurred in fresh biomass, drought stress in T2, with a biomass of 7.28 g compared to T1, showed a reduction of 59.90%, which coincided with what was indicated by Nansamba et al. (2022), who pointed



out that the lack of water caused a decrease in root development, leading the plant to reduce resource consumption under extreme environmental conditions. The reduction in dry biomass in T2 also suggested that, under conditions of water scarcity, the seedlings prioritized water conservation rather than biomass production.



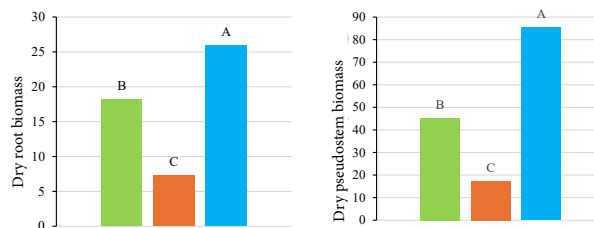
**Figure 6.** Fresh and dry root biomass content in Dominico Hartón plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) over 43 days.

**Pseudostem biomass**

The analyses of fresh and dry pseudostem biomass (figure 7) showed that it was one of the organs with the highest percentages of biomass accumulation in the seedling (table 4). The response of this organ to flooding water stress in terms of fresh biomass showed that T3, with a biomass of 769.70 g, had a 41.9% increase in biomass compared to T1, with a biomass of 542.42 g, with a lower accumulation percentage relative to the proportion of the roots; and that, in T2, with a biomass of 167.52 g, it decreased by 69.1% compared to T1, also in a lower proportion than that obtained in the roots. These results were consistent with those found by Teoh et al. (2022) for the evaluated period.

In turn, for dry biomass, T3 with 85.48 g of biomass showed an increase of 89.1% compared to T1 with 45.20 g (figure 7). Meanwhile, T2 with a biomass of 17.39 g reflected a decrease of 61.5% compared to T1; the accumulated dry biomass values were substantially lower than those obtained for fresh biomass, indicating the high water content accumulated in the pseudostem. The results also indicated that seedlings under water deficit showed lower dry biomass accumulation compared to the control and flooded treatments. This phenomenon could reflect a physiological adaptation to stress, where plants reduced water accumulation in their tissues to minimize loss through transpiration and survive under drought conditions (Ravi et al., 2013; Cedeño, 2020). The significant difference observed among

treatments underscored the importance of adequately managing the amount of water available for plantain cultivation.

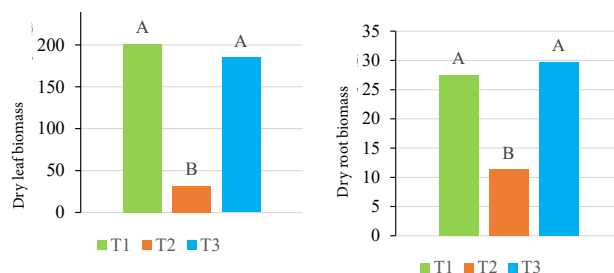


**Figure 7.** Fresh biomass and dry biomass content of the Dominico Hartón plantain pseudostem under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.

**Leaf biomass**

Significant differences were observed ( $P < 0.05$ ; figure 8), where T3 (184.85 g) was equivalent to 92% relative to T1 (200.76 g), which indicated an 8% reduction compared to T1. On the other hand, T2 (31.82 g) represented 15.85% in relation to T1 (200.76 g), which represented an 84.15% reduction in biomass due to the plant’s water deficit with regard to fresh biomass. Regarding leaf dry biomass in each seedling, T3 (29.76 g) showed an increase of 8.21% compared to T1 (27.50 g); in turn, T2 (11.37 g), compared to T1 (27.50 g), showed a reduction of 58.66%, which indicated that stress conditions negatively affected biomass accumulation in the leaves of the plantain plant.

**Figure 8.** Fresh biomass and dry biomass content in the leaf of



Dominico Hartón plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.

Studies conducted by Cedeño et al. (2022) have shown that water stress limited cell expansion and biomass accumulation in different crops. In this sense, water deficit affected both root size and aboveground biomass production, which ultimately reduced crop productivity, where clearly T2, being subjected to stress due to lack of water, presented a lower amount of both fresh and dry biomass compared to the other treatments.

The analysis of biomass contribution of the different plant components (table 5) is presented, in percentage terms, making it possible to establish the plant's development priorities under the different water-stress conditions; it is observed here that in T2 the development of biomass in the roots and leaves increases compared to normal and flooding conditions, whereas under flooding stress conditions the increase in biomass occurs in the pseudostem.

**Table 5.** Analysis of the percentage distribution of biomass among the different organs.

Treatment	Fresh biomass			Dry biomass			Water content		
	Root	Pseudostem	Leaf	Root	Pseudostem	Leaf	Root	Pseudostem	Leaf
T1	12.65%	63.76%	23.60%	19.99%	49.75%	30.27%	11.77%	65.43%	22.80%
T2	11.75%	74.16%	14.09%	20.20%	48.25%	31.55%	10.14%	79.08%	10.78%
T3	17.86%	66.23%	15.91%	18.36%	60.56%	21.08%	17.79%	67.02%	15.19%

Considering the water-retention segments, the pseudostem was the organ that stored the most water; however, it was in T2 where water retention was greater, in contrast to the leaves and roots. Because the treatment was in a state of extreme drought, evapotranspiration decreased due to stomatal closure, reducing transpiration, which was a strategy to conserve water; this affected crop development, causing the pseudostem to act as an important water reservoir, helping to maintain cellular turgor (Delgado et al., 2013). With respect to flooding conditions, the greatest water retention occurred in the roots relative to T1.

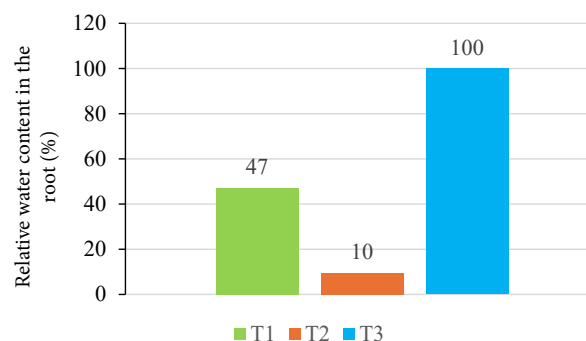
Likewise, it was observed that under normal development conditions (T1), approximately half of the percentage of biomass generated in the plant accumulated in the pseudostem and showed a 20-30% biomass distribution in root-leaves, respectively. These proportions under water-stress conditions due to deficit were relatively similar; however, in the case of flooding stress, biomass accumulation was concentrated in the pseudostem at approximately 60%, with this increased value reducing the biomass allocated to the leaf.

The analysis of the percentage of fresh biomass present in the leaves showed that water stress due to flooding and drought can lead to leaves having a lower concentration than under normal conditions, because as the plant struggled to maintain its water balance, it may not have allocated sufficient resources to grow larger leaves. Smaller leaves can further limit the plant's ability to photosynthesize effectively, creating a cycle of stress and reduced growth. According to Surendar et al. (2013), water stress led to a decrease in photosynthetic activity, which reduced the plant's ability to produce food, affecting leaf growth and the overall health of the plant.

### Relative water content

With respect to the relative water content in the root for the different treatments ( $P < 0.05$ ; figure 9; table 6) of *Dominico Hartón* plantain, it is shown that the root in T3 has the highest percentage of water content, with a value of 100%, having been

permanently subjected to flooding stress, followed by T1 with 47%, whereas the lowest percentage was recorded in T2 with 10%, which was always maintained under drought conditions. According to the reported values, the difference between management under flooding and management under drought conditions reduces the relative water content in the root by 90%; likewise, given the effects associated with low soil water content, for T3 it can be shown that the root contains the highest percentage of water, compared to T2 with lower percentages, demonstrating significance between the treatment with water deficit and flooding over time in each treatment.

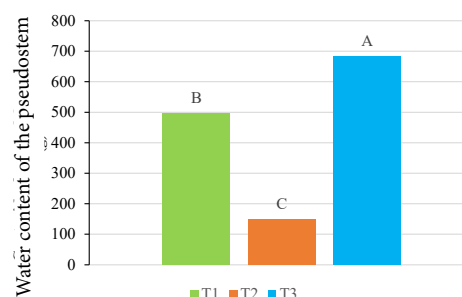


**Figure 9.** Relative water content in the root of *Dominico Hartón* plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) over 43 days.

**Table 6.** Relative water

Variable	Treatment		
	T1	T2	T3
Relative water content in the root (%)	47	10	100
Relative water content in the pseudostem (g)	497.22 B	150.03 C	684.22 A
Water content (mL) per each (cm <sup>2</sup> ) of the leaf	0.189 A	0.141 B	0.184 A

The water content of the pseudostem showed that T3, with a biomass of 684.22 g, had an increase of 37.68% compared to T1, which presented 497.22 g, suggesting that flooding conditions increased the water content in the pseudostem relative to normal conditions; in turn, T2 with 150.03 g represented 30.17% of T1, with a decrease of 69.83% (figure 10).



**Figure 10.** Water content of the pseudostem in *Dominico Hartón* plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.

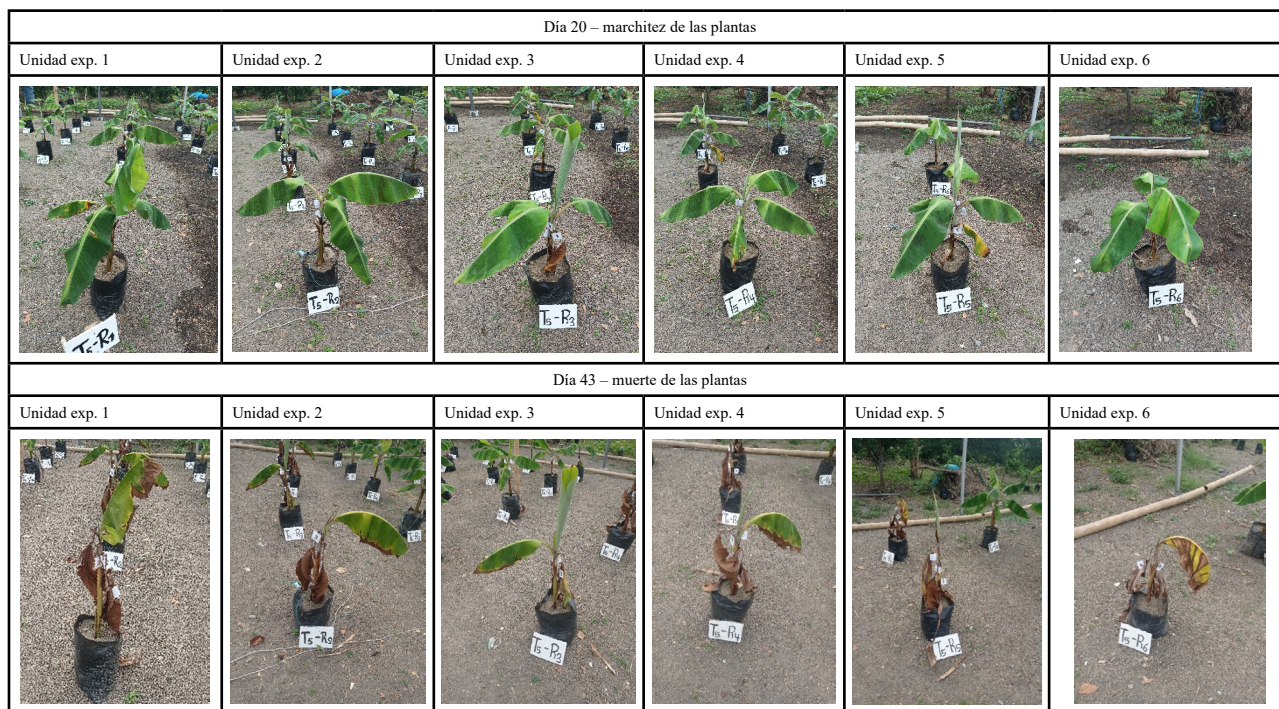


**Leaf area index**

The leaf area index is a fundamental variable for studying crop development and growth because it makes it possible to quantify crop growth and agronomic yield, considering its relationship with the interception of solar radiation, associated with photosynthesis, and with transpirational processes linked to biomass accumulation and productivity (Mendoza et al., 2017).

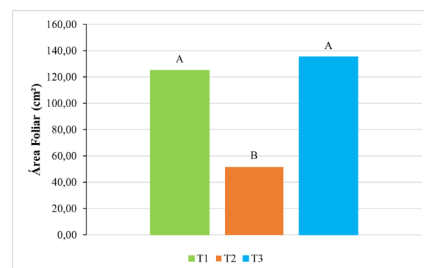
Significant differences were found ( $P < 0.05$ ; Figures 11 and 12; table 7) among the treatments, where T3 (135.26 cm<sup>2</sup>) showed an increase of 8.20% compared to T1 (125.00 cm<sup>2</sup>), whereas T2 (51.70 cm<sup>2</sup>) was equivalent to 41.36% relative to T1, showing a reduction of 58.64%, reflecting the conditions of each treatment. This coincided with studies conducted by Gamboa (2024), in

his work on water balances, showing that water deficit reduced plant growth due to the restriction of key physiological processes such as photosynthesis and nutrient uptake. It was speculated that water limitation in treatment T2 affected the water balance of the seedlings, causing a reduction in cellular turgor and the consequent decrease in root and leaf growth, which was consistent with the effects described by Muñiz (2023) in his work with plantains using the micro-corm method. Bashir et al. (2021) highlighted that drought reduced photosynthesis by decreasing carbon dioxide concentration and through stomatal closure, which would explain why the leaf area of T2 was lower, with wilting on day 20 and plant death by day 43 (figure 12); the latter was highlighted by Nansamba (2020), who mentioned that wilting was one of the symptoms shown by leaves under drought..



**Figure 12.** Wilting and death of the individuals in treatment 2.

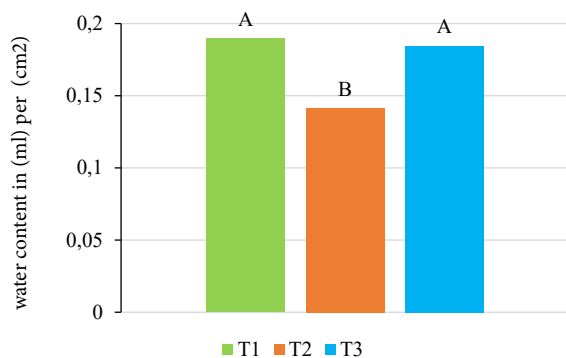
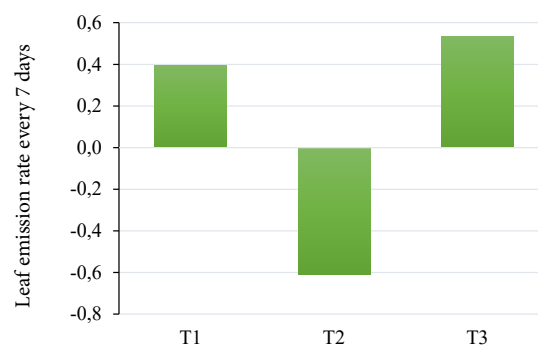
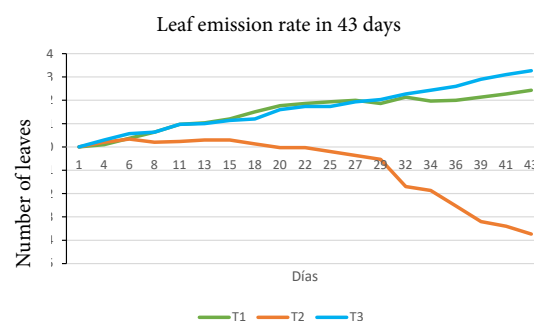
It was observed that T3 (figure 13) reached an accumulation of 0.1846 mL·cm<sup>-2</sup>, which represented 97.23% of T1 (0.1899 mL·cm<sup>-2</sup>), indicating that both treatments were associated with the water content (mL) present in each (cm<sup>2</sup>) of the leaves; in turn, T2 (0.1414 mL·cm<sup>-2</sup>) was equivalent to 74.53% of T1, which implied a reduction of 25.47% relative to T1, highlighting how water stress affected the water content (mL) present per (cm<sup>2</sup>). Comparison of the results obtained showed significant differences ( $P < 0.05$ ; figure 10) among the different treatments.



**Figure 11.** Leaf area (cm<sup>2</sup>) of Dominico Hartón plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.

**Table 7.** Leaf area index.

Variables	Tratamientos		
	T1	T2	T3
Área foliar (cm <sup>2</sup> )	125,00 A	51,70 B	135,26 A
Contenido de agua (mL) por cada (cm <sup>2</sup> ) de las hojas	0,189 A	0,141 B	0,184 A

**Figure 13.** Water content per cm<sup>2</sup> of the leaves of *Dominico Hartón* plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.**Figure 14.** Leaf emission rate every 7 days in *Dominico Hartón* plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.**Figure 15.** Leaf emission rate in *Dominico Hartón* plantain under normal conditions (T1), water deficit (T2), and controlled flooding (T3) for 43 days.

### Leaf emission rate

The results obtained on the leaf emission rate showed that T2 significantly reduced (-0.6) the emission of new leaves, which agreed with what was reported by Belalcázar (1991), mentioning that drought conditions can influence leaf emergence from the pseudostem and, in extreme cases, the death of the vegetative apex. On the other hand, T3 (0.5) showed leaf emission slightly higher than T1 (0.4), which was due to the stress conditions to which the seedlings of each treatment were subjected, where the foliar system, being the primary source of photoassimilates, varied considerably in size and plant functionality; generally, a seedling under normal conditions (T1) emitted at a frequency of one leaf·week<sup>-1</sup> in the rainy season and between 0.4 and 0.6 leaf·week<sup>-1</sup> under drought conditions (Martínez and Cayón, 2011), information that was verified in this trial. Consequently (Table 8; Figure 14), the treatments subjected to water stress, mainly T2, showed strong alterations in this parameter, sharply decreasing the emission of new leaves. T1 and T3 produced the first leaf at 11 days, the second leaf at 27 days, and T3 its third leaf at 39 days, accelerating leaf emission compared to T1 (Figure 15). Thus, T2 under drought conditions did not produce new leaves, and from day 20 onward they wilted (Figure 12).

**Tabla 8.** Leaf emission rate.

Variables	Treatment		
	T1	T2	T3
Leaf emission rate every 7 days	0,4	-0,6	0,5

### Conclusions

The trial makes it possible to understand the effects of flooding and drought conditions on 14-week-old *Dominico Hartón* plantain over 43 days of evaluation, with respect to its development and growth analyzed through biomass, leaf area index, and leaf emission rate.

The physical response of plantain to drought stress showed a reduction in plant growth and development, with a marked decrease in the generation of dry biomass by 60% compared to a healthy plant, a decrease in leaf area index of 85% compared to normal conditions, and the suspension of flag-leaf emission from day 20 without irrigation. Additionally, it is observed that under drought conditions plants prioritize water conservation in the pseudostem over the leaves, and that they maintain the biomass proportion of the structures until total wilting.

With respect to plantain plants subjected to flooding stress, an increase in dry biomass of 155% was evidenced compared to a plant under normal conditions, concentrating biomass generation mainly in the flooded roots and secondarily in the pseudostem, where the accumulation of water content is the

plant's priority. During the 43 days of evaluation, the plant showed no signs of wilting or decline in development, showing indicators higher than those of a plant under normal conditions for leaf area index, and 0.1 higher for the emission of flag leaves.

Although the trial included only 18 individuals and 43 days of evaluation, the trends found for the phenological stage analyzed were clear, and make it possible to indicate that under drought stress conditions the crop presents advanced wilting conditions and a low level of agronomic development, whereas under flooding conditions the analyzed variables exceed those of normal development conditions.

From what was analyzed, the need also emerges for flooding evaluation periods to be longer and to allow observation of the final effects of stress on other vegetative stages of development, as well as the impacts on the production and yield of Dominico Hartón plantain.

#### Conflict of interest

The authors declare that they have no conflicts of interest in the present publication at any of its stages.

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#### Declaration of contribution according to CRediT

**Loor Quijije María José:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **Leridy Mercedes Sabando Loor:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **Cristian Sergio Valdivieso López:** supervision, conceptualization, formal analysis, methodology, investigation, writing—original draft, writing—review and editing. **Myrian Elizabeth Herrera Centeno:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **Javier Alejandro Maiguashca Guzmán:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **José Luis Rivadeneira García:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **Carlos Alberto Molina Hidrovo:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing. **Jim Raphael Ochoa Ramos:** methodology, investigation, formal analysis, writing—original draft, writing—review and editing..