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TECHNICAL NOTE

Simulation of hydroponic production using rainwater and brackish water

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Abstract: Food production is the most water-demanding activity in the world. Thus, the need for using cultivation techniques that mitigate water scarcity is increasing. Hydroponics is a production system usually used under protected environments, providing significant water savings and high crop yields. Considering the importance of developing alternatives for agricultural production, the objective of this work was to develop a model that allows the use of rainwater or rainwater combined with brackish water for hydroponic crops. Rainfall data were used to determine the daily water balance in the model. A spreadsheet was developed to facilitate the use of the model, enabling the determination of the rainwater tank volume required to maintain the electrical conductivity level tolerated by hydroponic crops. Three case studies on coriander and lettuce production, conducted in Juazeiro, Senhor do Bonfim, and Cruz das Almas, BA, Brazil, were presented. The model was evaluated based on the main input variables. The model for an annual tank volume was more sensitive to variations in evaporation. The model for a multiannual tank volume was more sensitive to the number of annual crop cycles. Both water volumes presented less sensitivity to variations in the catchment area.

Keywords: Hydrographer, protected environment, soilless cultivation, salinity.

Introduction

Water is an essential natural resource for several sectors, mainly food production, which is the most water-demanding activity (Ferreira, 2011). Therefore, the use of rainwater is an alternative for a rational use of water resources (Macedo et al., 2018), since rainfall is a free source of good quality freshwater (Pôjo et al., 2020).

Furthermore, drilling wells is a widely used alternative to meet water demands. However, many drilled wells have water with high salt contents (Bezerra et al., 2019). Brackish water or even wastewater can be used for food production (Pereira et al., 2003), but they require a proper management to be viable for this purpose.

In this context, hydroponics can be an advantageous option for crop production, as the tolerance of plants to salinity in this

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system can be higher than that in conventional crop systems (Freitas et al., 2021; Silva et al., 2024). In addition, hydroponics allows the combination of water from different sources and qualities. Moreover, the combined use of brackish water and rainwater (collected through storage tanks) can reduce the effects of irregular rainfall (Furtado et al., 2017).

Considering that the obtaining of tank volumes based on annual and multiannual regimes is the main challenge for balancing water availability, the objective of the present study was to develop a model for using rainwater by designing a rational water storage system using rainwater or rainwater combined with brackish water for hydroponic crops.

Materials and Methods

A simulation model was developed to determine the daily water balance, using the continuity equation.

The model enables the obtaining of storage tank volumes for collecting rainwater in a protected environment, which totally or partially contributes to the rainwater catchment area and allows the combined use of rainwater and water with high salt concentrations.

The daily water balance was determined based on rainfall data, brackish water, and crop water demands. Figure 1 shows the schematics of the crop production systems developed, which can be used based only on the rainwater catchment area or rainwater combined with brackish water, or including an extra rainwater catchment area for hydroponic vegetable production.

The study was developed in three different phases; the first consisted of developing a model to determine the volumes of rainwater storage tanks (Figure 2); the second consisted of developing a spreadsheet with the data; and the third consisted of evaluating the model based on comparative analysis of different scenarios and application of tests to determine the sensitivity of the model to the main input variables.

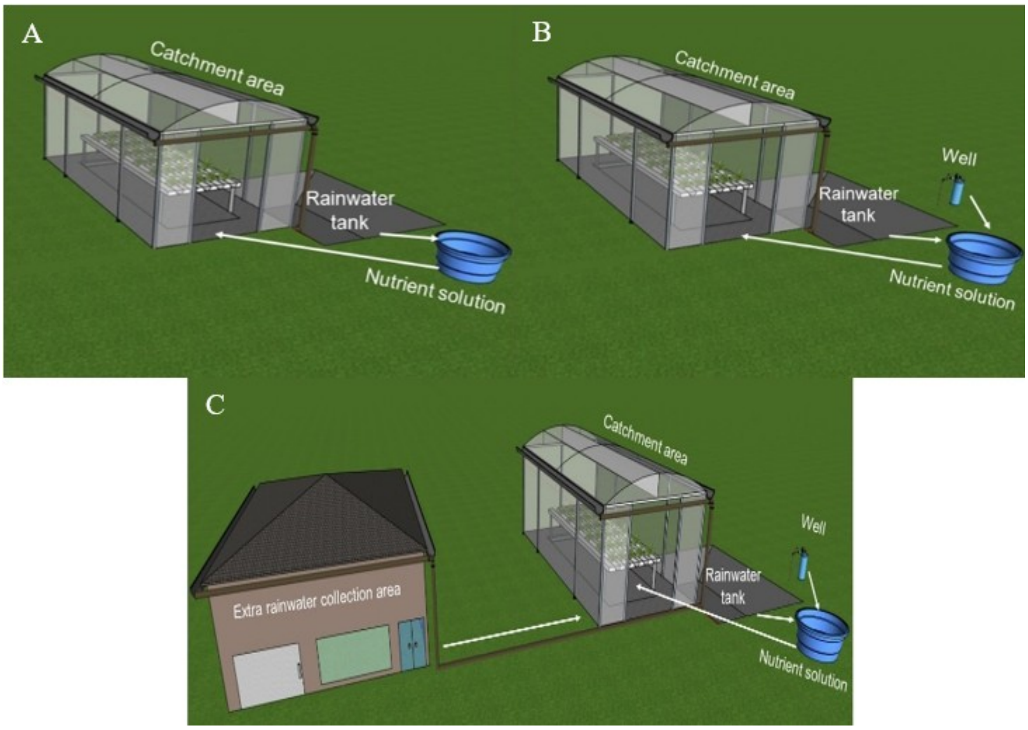

Figure 1: Schematics of crop production systems with a collection of rainwater (A), rainwater combined with brackish water (well) (B), and rainwater combined with brackish water using an extra rainwater collection area (C).

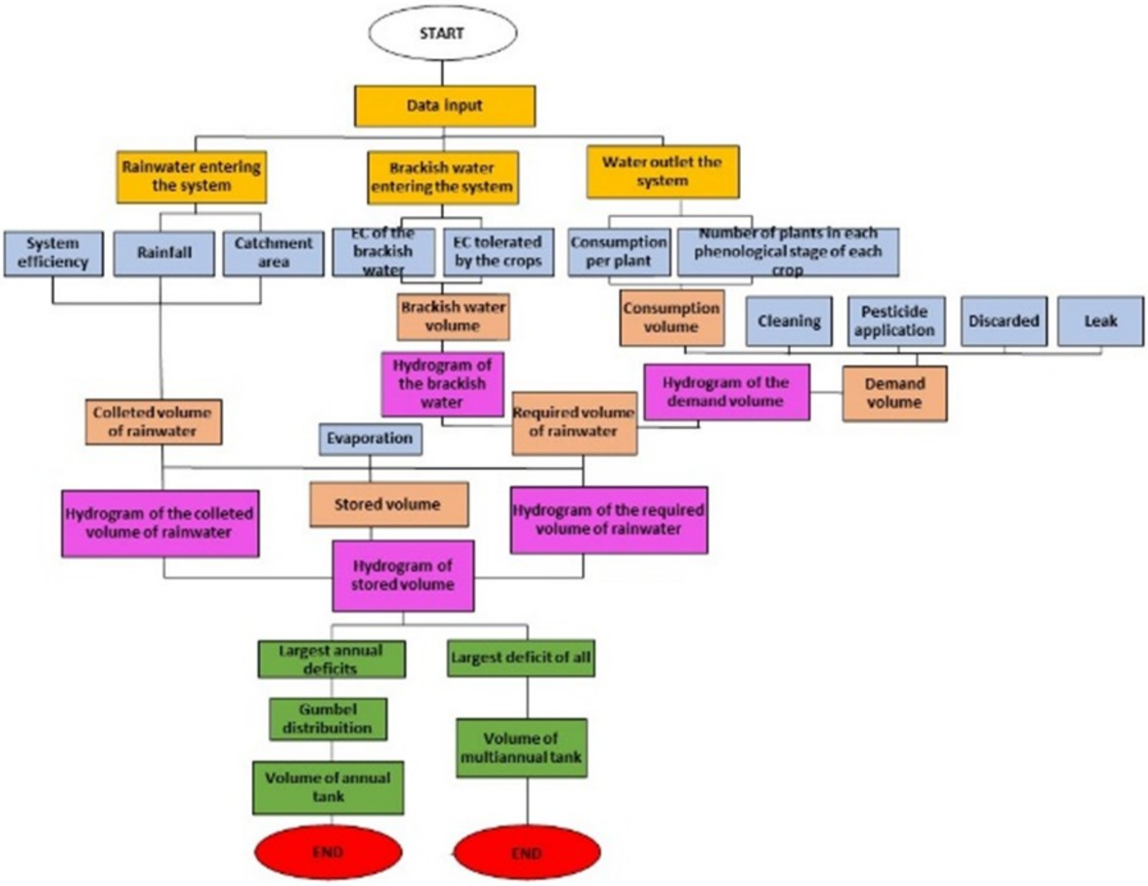

Figure 2: Model development flowchart.

The model was based on simulations, with the daily water balance determined using the continuity equation. This model was developed to design rainwater storage tanks that totally or partially meet the water demand of the hydroponic production system and determine the rainwater tank volume that contributes to the rainwater catchment area of the hydroponic system. The analysis of the tanks focused on determining water overflow and supply contents close to zero.

Conditions for using the rainwater tank

Condition 1: collected rainwater meets demand.

- Condition 1.1: when the collected rainwater volume is sufficient to meet the demand, the tank use starts at its maximum volume and is refilled to the maximum whenever it is empty.

Condition 2: collected rainwater does not meet demand.

- Condition 2.1: when the collected rainwater volume is insufficient to meet the demand, the tank use still starts at its maximum volume and is refilled to the maximum volume whenever it is empty.
- Condition 2.2: alternatively, the tank use can start with a water volume corresponding to the mean annual difference between the collected rainwater and the required volume, and it is refilled with this difference.

Contour conditions

The model was developed considering, as standard, a covered tank with no losses by evaporation. However, the tank cover area can contribute as a rainwater catchment area, but evaporation can also be considered. Controlling evaporation has costs that should be considered in the decision making; however, this economic analysis was not considered in the present study.

Crop water consumption varies according to local micrometeorological conditions external to the crop environment and dimensions and cover materials of the protected environment; however, these factors were not simulated. Water consumption data can be included to find more adequate conditions. The model includes the expected water consumption found in the studies of Soares et al. (2007) and Silva et al. (2020) for lettuce and coriander, respectively.

The spreadsheet includes only the osmotic effect of salinity and not the specific effects of salinity. The plant responses to waters with the same electrical conductivity (EC) can vary depending on the ion chemical species. The model simulates yield losses; however, the limits can be changed.

A methodology for a tank with a trapezoidal section drilled in the loam soil was proposed for systems that include rainwater catchment by the tank structure, using a tank depth of 3.5 m, base of 10 m (for annual or multiannual regimes), and slope of 1:1 (Marangon, 2017).

The constant EC tolerated by lettuce crops considered in the present study was 4.03 dS m^{-1} (Soares et al., 2007). The nutrient solution should present an EC of 2.00 dS m^{-1} (Furlani et al., 1999); thus, the waters were combined, reaching an EC of 2.03 dS m^{-1}. Water combinations for coriander crops were carried out to reach a maximum EC of 2.41 dS m^{-1} (Silva et al., 2023).

The model was developed considering that the grower has intermediate information and discards the nutrient solution every three production cycles. These data can also be adjusted for each situation.

The system dimensioning was carried out for a minimum 10-year period with daily rainfalls (Rodriguez et al., 2016). The daily rainwater volume collected was considered as the product between the rainfall depth and the catchment area.

The model can be applied to any hydroponic crop. The crop water consumption varies according to the plant's developmental stage and climate conditions, requiring a varying water flow over time. In addition, the planting density should be considered, i.e., the number of plants in the production environment.

The daily total water demand in the production system was calculated by the product between the number of plants and the water consumption per plant in each phenological stage of each crop, plus the water consumption for cleaning and pesticide application and the discarded water.

Coriander and lettuce crops were evaluated for the validation of the model. The collection area of 817.42 m^2 (sum of the coriander and lettuce system areas) was defined based on actual projects of a hydroponics company in Brazil. The number of plants under germination in each bench of four nurseries (only for lettuce) and each one of the four final growth benches for each crop was determined using pre-defined dimensions for the production systems. Lettuce has three production stages and a 51 days crop cycle, and coriander has a 35 days crop cycle with two production stages.

Daily water consumption per plant of coriander and lettuce crops under a protected environment were estimated for the study locations (Juazeiro, Senhor do Bonfim, and Cruz das Almas) (Soares et al., 2007; Silva et al., 2020) to assess the volumes demanded by the protected systems.

The benches and other structures of the hydroponic system were cleaned at the end of each cycle as a prophylactic measure. When using water combinations, the water with lower quality should be used for cleaning. Water used for discarding, pesticide application, and leaks were also considered.

The defined water leak volume was 5%, considering the actual data of a hydroponics company. The water volume used for pesticide application was determined considering that applications were carried out every seven days using a 20-L manual backpack sprayer.

The daily brackish water volume required was calculated using the Equation 1.

$$V_{BWi} = \left(\frac{EC_{limit} - EC_{NS}}{EC_{BW}} \right) x\ V_{WD} \quad (1)$$

Where: V_{BWi} is the volume of brackish water to be used in the day i, in m^3; EC_{limit} is the highest water electrical conductivity tolerated by the crops, in dS m^{-1}; EC_{NS} is the electrical conductivity of the nutrient solution, 2.0 dS m^{-1} (Furlani et al., 1999); EC_{BW} is the electrical conductivity of the brackish water, in dS m^{-1}; V_{WDi} is the total water volume demand of the production system on the day i, in m^3 day^{-1}.

The calculated brackish water volume enabled to plot hydrograms. Thus, the daily water rainfall volumes required for the production systems were determined by the difference between the demanded volume and the brackish water volume.

The dimensioned tank stores only rainwater. Brackish water is combined in the nutrient solution tank.

The daily water volume stored in the tank was determined using the Equation 2, determining the volume stored on day i and plotting hydrograms of stored volume.

$$V_{Wi} = V_{Pi} - V_{RACi} - V_E \quad (2)$$

Where: V_{Wi} is the water volume stored in the day i, in m^3 day^{-1}; V_{Pi} is the rainwater volume collected in the day i, in m^3 day^{-1}; V_{RACi} is the rainwater volume demanded by the crops on day i; in m^3 day^{-1}; VE is the water volume evaporated from the tank in the day i (product between the daily evaporation and the open tank area).

Dimensioning of tank volumes for annual and multiannual regimes

The tanks were dimensioned for annual and multiannual regimes, following the method of maximum accumulated differences, which establishes that the regularized flow corresponds to the flow on the tank (Barbosa Júnior et al., 2005).

The tank volumes were determined considering the transfer of deficit and surplus for the next years for the multiannual regime and by the Gumbel distribution for the annual regime. The sensitivity of the main input variables considered in the model was determined according to the methodology proposed by Nearing et al. (1990) using the Equation 3.

$$S_M = \frac{\dfrac{V_{T1} - V_{T2}}{V_{T12}}}{\dfrac{I_1 - I_2}{I_{12}}} \quad (3)$$

Where: SM is the model sensitivity to the input variable; V_{T1} is the tank volume obtained by the model for the lowest input value; V_{T2} is the tank volume obtained by the model for the highest input value; V_{T12} is the mean tank volume obtained with the input values; I_1 is the lowest input value of the analyzed variable; I_2 is the highest input value of the analyzed variable; I_{12} is the mean input value of the analyzed variable.

Case studies

The methodology was applied to the rainfall conditions of three cities: Juazeiro, Senhor do Bonfim, and Cruz das Almas, in state of Bahia, Brazil. The simulations were carried out considering the same production demand of coriander and lettuce crops for the three locations.

Juazeiro

Juazeiro, in the northern state of Bahia (9° 24’ 50” S and 40° 30’ 10” W) (IBGE, 2011), has a Bswh semiarid climate, according to the Köepen classification, with mean annual rainfall between 380 and 760 mm in the rainy season, high temperatures, and high evaporation rates (Leitão et al., 2013).

Aquifers in Juazeiro are fractured or karst (Figure 3A). Wells in Juazeiro were surveyed through the SIAGAS platform of the Mineral Resource Research Company (CPRM, 2021), according to the Resolution no. 357 of the Brazilian National Environment Company (CONAMA); the results showed 194 wells: 186 (95.88%) with brackish water and only eight (4.12%) with freshwater (Figure 3B).

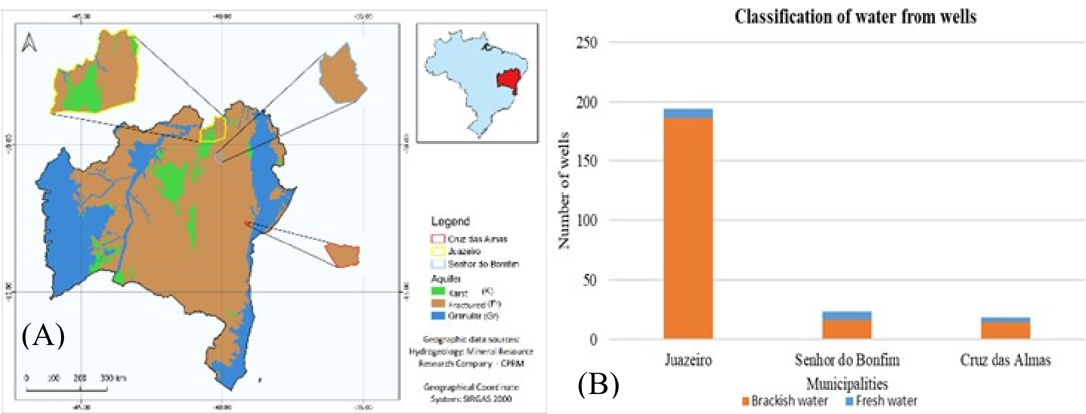

Figure 3: Hydrogeology map of the state of Bahia, Brazil, with the municipalities of Juazeiro, Senhor do Bonfim, and Cruz das Almas (A), and classification of water from wells, according to Brazilian National Environment Company (CONAMA) (B).

Senhor do Bonfim

Senhor do Bonfim is in the central-northern of Bahia (10° 28' 00" S and 40° 11' 00" W), in the Semiarid region of Brazil; the region presents a sub-humid dry climate, characterized by irregular rainfall, which mean annual not exceeding 800 mm (Reis and Souza, 2021). The hydrogeology of the region (Figure 3A) shows fractured aquifers. Senhor do Bonfim has 23 wells, as shown in the SIAGAS platform of the Mineral Resource Research Company (CPRM, 2021): seven (30.43%) with freshwater and 16 (69.57%) with brackish water (Figure 3B).

Cruz das Almas

Cruz das Almas, in the Recôncavo da Bahia region (12° 48' 38" S and 39° 06' 26" W), was chosen for the application of a methodology focused on diversifying the applications of the model (Cunha, 2018). It presents a hot and wet tropical climate, according to the Köppen classification, with a mean annual temperature of 24.5°C, mean annual rainfall of 1.138 mm, varying from 1,000 to 1,300 mm (Vieira et al., 2019), and fractured aquifers (Figure 3A). Although Cruz das Almas is in a relatively rainy region, 18 wells are registered in the SIAGAS platform of the CPRM: 14 (77.78%) with brackish water and four (22.22%) with freshwater (Figure 3B).

Local general information was collected from the BDMEP platform of the Brazilian National Institute of Meteorology (INMET), generating a rainfall data series of the last 10 years for Cruz das Almas (weather station code 8322), and from the Hidroweb platform of the Brazilian National Water Agency (ANA) for Juazeiro (weather station code 940024) and Senhor do Bonfim (weather station code 1040027).

Evaporation data were found for Senhor do Bonfim and Cruz das Almas in the BDMEP platform of the INMET. No data was found for Juazeiro, thus, data from Petrolina (PE) (weather station code 82983), which is close to Juazeiro, were used for the calculation in the spreadsheet.

Spreadsheet for the application of the model

A spreadsheet was developed in Microsoft Office Excel 2016 to enable the application of the developed methodology. Data on the crop, growing location, rainfall, collection area, number of plants, daily water demand in the tank, EC of the brackish water, and evaporation should be fed into the system for correct processing in the spreadsheet.

The necessary rainfall data can be supplied using daily records from INMET or synthetic data from hydrological models. Daily data from INMET provide actual recorded measurements, offering precise and historical accuracy. In contrast, synthetic data from hydrological models generate simulated records based on statistical properties and patterns, which can be useful for filling gaps or extending data series. Regardless of the source, the data series should be pre-processed to meet specific requirements.

The spreadsheet elaborate has five main worksheets and hidden worksheets reserved for basic calculations needed for the efficient functioning of the model.

Results and Discussion

Rainfall

A study on the main rainfall characteristics of the three locations studied was carried out (Figure 4).

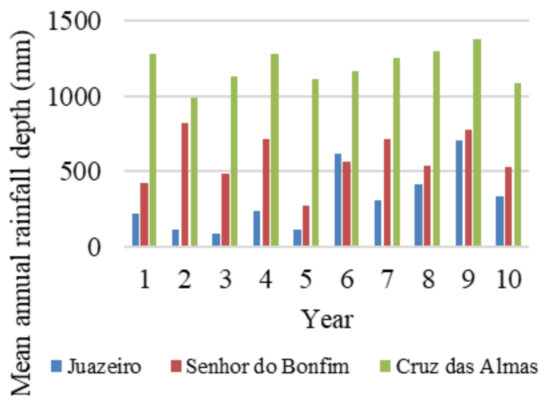

Figure 4: Mean annual rainfall in the 10 last years in Juazeiro, Senhor do Bonfim, and Cruz das Almas, Bahia, Brazil.

The mean annual rainfall calculated through the 10-year data series were 314.84 mm in Juazeiro, 585.38 mm in Senhor do Bonfim, and 1,199.93 mm in Cruz das Almas. The statistical analyses showed that the maximum EC of the brackish water for the solution to reach the full demands of the production systems were 3.22 dS m^{-1} in Juazeiro, 5.46 dS m^{-1} in Senhor do Bonfim, and 10.57 dS m^{-1} in Cruz das Almas. Therefore, regions with low rainfall depths have little capacity to dilute brackish water to the EC level tolerated by the crops.

Dimensioning of tanks considering rainfall depths in Juazeiro, Senhor do Bonfim, and Cruz das Almas

Simulations of annual and multiannual tank volumes were carried out, considering covered tanks with no losses by evaporation and a rainwater catchment area of 817.42 m^2 for Juazeiro, Senhor do Bonfim, and Cruz das Almas, disregarding the combination with brackish water (Figure 5). The tank volume increased as the rainfall depths decreased. Without the combination with brackish water, the water demands were not fully supplied in any of the locations, even in the rainiest region (Cruz das Almas).

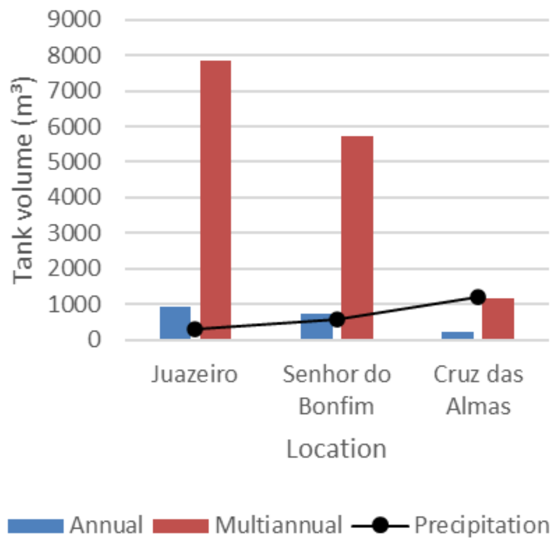

Figure 5: Volumes of tanks for annual and multiannual regimes for hydroponic lettuce and coriander crops, considering a rainwater catchment area of 817.42 m^2.

The tank volume was inversely proportional to rainfall depths, as expected.

The tank dimensioned for the multiannual volume can be 88.04% larger than that for the annual volume in Juazeiro. The different tank volumes found for the locations were also affected by the mean annual rainfall variability and rainfall seasonality over the year.

The mean annual water demand of 1,027.69 m^3 was considered for the production system, based on the contour conditions; it was constant in 9 years (1,037.24 m^3) after being lower in the first year (941.81 m^3). A longer time for the growth of plants, resulting in a lower water consumption, is expected only in the first year due to the production system rotation.

Situations in which the total rainwater volume collected is lower than the total rainwater volume required can be minimized by decreasing the number of annual crop cycles during the period, distributing a higher rainwater volume, and decreasing the relative yield through dilution, making the EC threshold to limit the production to a defined total percentage.

Rainwater catchment area

Three different situations were considered for the rainwater catchment area: the first consisted of a catchment area relative to the production system (817.42 m^2); the second consisted of a minimum extra area needed to maintain the water sufficiency of the system; and the third consisted of system with the production area combined with the extra catchment area, represented by the tank cover (Table 1).

Table 1: Tank volumes for annual (TVAR) and multiannual (TVMR) regimes with different rainwater catchment areas, considering a production system area (PSA) of 817.42 m^2, a minimum extra area (MEA), and the tank cover area (TCA)

Location	PSA		PSA + MEA		PSA + MEA + TCA	
	TVAR	TVMR	TVAR	TVMR	TVAR	TVMR
	(m^3)					
Juazeiro	940.73	7,866.50	799.76	3,011.79	774.88	2,421.89
Senhor do Bonfim	740.54	5,731.18	493.13	1,078.81	306.86	354.51
Cruz das Almas	233.35	1,175.67	207.79	536.50	180.45	332.07

Considering only the area of the production system as the rainwater catchment area, the water demands were not fully met in any of the locations studied. The minimum extra areas needed to ensure the total supply were 2,618.58 m^2 (Juazeiro), 1,030.68 m^2 (Senhor do Bonfim), and 84.58 m^2 (Cruz das Almas). Considering the tank cover area as the rainwater catchment area, the water demands were met in the three locations.

EC of the brackish water

Brackish water with high EC requires rainwater tanks with larger volumes (Figure 6).

No rainwater tank is needed when using brackish water with EC from 0 to 2.03 dS m^{-1} for lettuce, and from 0 to 2.41 dS m^{-1} for coriander. Brackish water can be used in production systems, with no need for implementation of rainwater catchment systems, when having enough flow of brackish water.

Dilution in rainwater is needed for 103 (53.09%) of the 194 wells (SIAGAS platform) in Juazeiro; for seven (30.43%) of the 23 wells in Senhor do Bonfim; and for three (16.67%) of the 18 wells in Cruz das Almas, which presented EC of 2.27, 4.30, and 17.15 dS m^{-1}, respectively.

Evaporation in the tanks

The evaporation varied between 1,496.3 and 2,568.6 mm in the 10 years considered in the present study. The mean annual evaporation, calculated using the 10-year data series, was 4,075.52 mm in Juazeiro, varying between 2,680.4 and 4,626.9 mm; 2.133.1 mm in Senhor do Bonfim, varying between 1,496,3 and 2,568,60 mm; and 1,462.4 mm in Cruz das Almas, varying between 1,155.5 and 1.698.4 mm (Figure 7).

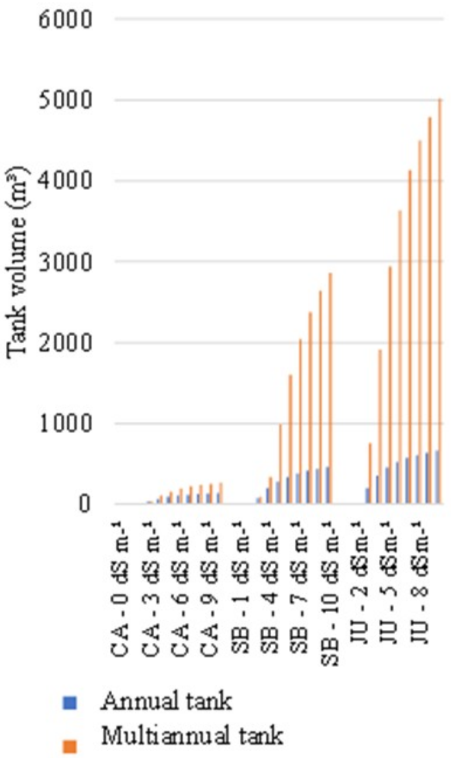

Figure 6. Volumes of annual and multiannual tanks, considering the dilution of brackish water with EC from 0 to 10 dS m^{-1}, in the three study locations: Juazeiro (JU), Senhor do Bonfim (SB), and Cruz das Almas (CA) in the state of Bahia, Brazil.

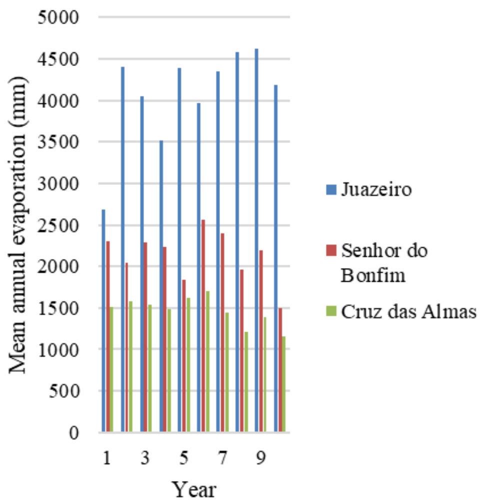

Figure 7: Annual evaporation in the 10 years considered in the study for Juazeiro, Senhor do Bonfim, and Cruz das Almas, Bahia, Brazil.

According to the simulations, losses by evaporation required increases in the tank volume of 65.78% (annual regime) and 68.22% (multiannual regime) in Juazeiro; 47.37% (annual) and 54.85% (multiannual) in Senhor do Bonfim; and 37.95% (annual) and 54.98% (multiannual) in Cruz das Almas (Table 2).

The volumes of annual and multiannual tanks were simulated for the study locations, considering normal crop conditions with no addition of brackish water, but decreasing the number of annual crop cycles from 13 to 12 for lettuce and from 15 to 14 for coriander (Table 3). Economic comparisons were disregarded.

Table 2. Tank volumes for annual (TVAR) and multiannual (TVMR) regimes with and without water losses by evaporation, in different locations in the state of Bahia, Brazil

Location	Without losses by evaporation		With losses by evaporation	
	TVAR	TVMR	TVAR	TVMR
	(m^3)			
Juazeiro	940.73	7,866.50	2,749.46	24,753.22
Senhor do Bonfim	740.54	5,731.18	1,407.14	12,694.00
Cruz das Almas	233.35	1,175.67	376.04	2,611.51

Table 3: Tank volumes for annual (TVAR) and multiannual (TVMR) regimes with different numbers of annual crop cycles, with no addition of brackish water, in different locations in the state of Bahia, Brazil

Location	28 cycles			26 cycles		
	TVAR (m^3)	TVMR (m^3)	Full supply	TVAR (m^3)	TVMR (m^3)	Full supply
Juazeiro	940.73	7,866.50	No	870.08	6,833.01	2,421.89
Senhor do Bonfim	740.54	5,731.18	No	694.97	4,679.80	354.51
Cruz das Almas	233.35	1,175.67	No	226.14	379.69	332.07

The full or partial supply of the systems were affected by decreases in the number of annual crop cycles only in Cruz das Almas. The tank volume for the annual and multiannual regimes in Cruz das Almas decreased 3.09% (annual tank) and 32.30% (multiannual tank). The rainier the location, the higher the decrease in the multiannual tank volume, and the opposite for the annual tank volume.

Decreases in relative yield

The water EC thresholds required to maintain the relative production in 75% was established as 6.32 dS m^{-1} (Soares et al., 2007) for lettuce and 4.89 dS m^{-1} for coriander. Thus, volumes of annual and multiannual tanks were simulated for the study locations focused on assessing the effect of a 25% production decrease on the tank volume decrease; economic viability analyses were disregarded (Table 4).

Table 4. Tank volumes for annual (TVAR) and multiannual (TVMR) regimes, considering decreases in relative yield, in different locations in the state of Bahia, Brazil

Location	Relative yield of 100%			Relative yield of 75%		
	TVAR (m^3)	TVMR (m^3)	Full supply	TVAR (m^3)	TVMR (m^3)	Full supply
Juazeiro	940.73	7,866.50	No	734.23	5,768.63	No
Senhor do Bonfim	740.54	5,731.18	No	535.25	3,615.81	No
Cruz das Almas	233.35	1,175.67	No	157.97	307.63	Yes

The production system was affected by decreases in relative yield only in Cruz das Almas. The annual and multiannual tank volumes were affected by decreases in production, reaching 32.30% (annual) and 73.83% (multiannual) decreases in Cruz das Almas.

Senhor do Bonfim was the second most affected in both regimes, after Cruz das Almas, and followed by Juazeiro, showing that the rainier the region, the higher the decrease in the tank volume due to decreases in production.

Discarding the nutrient solution

The frequency of nutrient solution discarding was simulated to be carried out every 1, 3, and 6 cycles. Changes in discarding frequency did not ensure the full water supply in all simulations, but there were decreases, mainly in the multiannual tank volume.

Choice of tank

Regarding the choice of the best tank for annual and multiannual regimes in each location, the results found showed:

- Juazeiro: annual tank for an EC of 3.00 dS m^{-1} in Condition 1.1 and multiannual tank for EC between 4.00 and 10.00 dS m^{-1}, which presented no significant differences in water collection for Juazeiro in none of the simulations. The overflow was slightly higher for Condition 2.2 in the annual tank.

- Senhor do Bonfim: annual tank with EC between 3.00 and 5.00 dS m^{-1} in Condition 1.1 and multiannual tank with EC from 6.00 to 10.00 dS m^{-1} in Condition 2.1.
- Cruz das Almas: annual tank for any EC of brackish water in Condition 1.1.

Sensitivity of the model to the main input variables

Table 5 shows the sensitivity indexes of the model to the annual and multiannual tank volumes, considering the main input variables of the model: rainfall depth, rainwater catchment area, brackish water electrical conductivity, evaporation, variations in the number of annual crop cycles, variations in relative yield, and the number of cycles of nutrient solution discarding.

Table 5: Sensitivity of the model to the main input variables

Variable	I_1	I_2	Annual volume (m^3)			Multiannual volume (m^3)		
			VR_1	VR_2	S_M	VR_1	VR_2	S_M
RD	314.84	1,199.93	940.73	233.35	-1.03	7,866.50	1,175.67	-1.27
CA	817.42	3,436.00	940.73	799.76	-0.13	7,866.50	3,011.79	-0.73
EC	3.00	10.00	196.38	660.72	1.01	750.48	5,020.54	1.37
E	14,673.00	40,880.00	376.04	2,749.46	1.61	2,611.51	24,753.22	1.72
NC	26.00	28.00	870.08	940.73	1.05	6,833.01	7,866.50	1.90
RY	75.00	100.00	734.23	940.73	0.86	5,768.63	7,866.50	1.08
D	1.00	6.00	1,013.69	921.92	-0.07	8,609.12	7,681.74	-0.08

RD = rainfall depth; CA = rainwater catchment area; EC = electrical conductivity of the brackish water; E = evaporation; NC = variations in the number of annual crop cycles; RY = changes in relative yield; D = number of cycles of nutrient solution discarding; I_1 = lowest input value of the analyzed variable; I_2 = highest input value of the analyzed variable; V_{R1} = tank volume obtained by the model for the lowest input value; V_{R2} = tank volume obtained by the model for the highest input value; S_M = the model sensitivity to the input variable.

A sensitivity index with a negative sign denotes that increases in variables that affect the tank volume imply decreases in this volume. Regarding the annual tank volume, the calculation simulations showed that the model was more sensitive to variations in evaporation, followed by variations in the number of annual crop cycles, rainfall depth, EC of the brackish water, decrease in relative yield, rainwater catchment area, and frequency of nutrient solution discarding. Regarding the multiannual tank volume, the model was more sensitive to variations in the number of annual crop cycles, evaporation, EC of the brackish water, rainfall depth, relative yield, rainwater catchment area, and frequency of nutrient solution discarding; the three latter variables was the same found for the annual tank.

Conclusions

The model proposed is a fast and easy alternative for determining the required volume of tanks used in hydroponic systems.

The water balance was negative only when using rainwater, in the three simulated situations.

The model for calculating the volume of annual regime tanks showed greater sensitivity to variations in evaporation.

The model for calculating the volume of multiannual regime tanks showed greater sensitivity to variations in the number of annual crop cycles.

The development of the model provided multiple results that can be used as a basis for further studies, mainly in semiarid regions.

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