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Development of a rainwater harvesting model for broiler farms

Desarrollo de un modelo aplicado a la recolección de agua de lluvia para granjas de pollos de engorde

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Abstract

The access to water is critical in agricultural and livestock production. In the dry season, the water supply systems are under stress and have placed the region of La Mesa de Los Santos (Santander-Colombia) as susceptible to economic impacts due to water shortages, mainly caused by high demand in growth population, agriculture and the poultry production. Currently, the poultry production suffers from water shortages and has been supplied with liquid in tanker trucks during the dry season, presenting a significant added cost to the farmers. The implementation of a rainwater-harvesting (RWH) system could reduce the water stress on the poultry industrial production of the region. The main objective of this research was to develop a mathematical model to identify the numbers of poultry grown cycles that a rainwater harvesting (RWH) system could potentially feed in an average year of precipitations. The analyses performed here considered daily rainfall data ranged from 2010 to 2018 obtained from the weather stations in La Mesa de Los Santos. The results of this research can be helpful to the entrepreneurs and policymakers by evaluating the importance of water management and the opportunity to take advantage of rainwater as a resource for sustainable poultry production, currently an important alternative to the value chain in the agricultural, livestock and industrial sector of the region.

Keywords: mathematical model; poultry production; agricultural production; weather station; rainwater.

Resumen

El acceso al agua es crítico en la producción agrícola y pecuaria. En la estación seca, los sistemas de suministro de agua están bajo estrés y han colocado a la región de La Mesa de Los Santos (Santander-Colombia) como susceptible a los impactos económicos de la escasez de agua, causada principalmente por la alta demanda debido al crecimiento excesivo de la población. agricultura y la producción avícola. Actualmente, la producción avícola sufre de escasez de agua y se suministra con líquido en camiones cisterna en la estación seca, lo que representa un costo significativo para los avicultores. La implementación de un sistema de recolección de agua de lluvia (RWH) podría reducir la dependencia del "estrés hídrico" de la producción industrial avícola de la región. El objetivo principal de esta

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investigación fue desarrollar un modelo matemático para identificar la cantidad de ciclos de cría de aves de corral que un sistema de recolección de agua de lluvia (RWH) podría alimentar en el año promedio de precipitaciones. Los análisis realizados consideraron los datos de precipitación diaria entre 2010 y 2018 obtenidos de las estaciones meteorológicas en la región de estudio. Los resultados de esta investigación serían útiles para los empresarios y los encargados de formular políticas al evaluar la importancia de la gestión del agua y la oportunidad de aprovechar el agua de lluvia como recurso para la producción avícola sostenible, siendo actualmente una alternativa importante en la cadena de valor del sector agropecuario e industrial de la región.

Palabras clave: modelo matemático; aves de corral; impacto económico; producción agrícola; estación meteorológica; agua lluvia.

1. Introduction

With the increasing population and changing climate regime, water supply systems in many cities of the world are under stress. The climate variability and the shifts in rainfall patterns are bringing more uncertainty as to the availability, predictability and geographical distribution of water. It also poses major risks and unpredictability in the agricultural and livestock sector including land and water use, and many social, and sustainability impacts affecting the socio-economic development, mainly to those at the heart of the challenge in the sector, the small-scale farmers [1]–[3]. The long-term sustainable use of water resources is of growing concern. Colombia is among the world water-rich countries in terms of internal water resources and accounts for 5% of world water resources. Moreover, the water potential of Colombia is three times the average of Latin American supply and six times the world average [4], [5].

In Colombia, the water resource is not shared equally in space and time. Counting, with a wet year with 3420 mm of precipitations, and a dry year with 841 mm, resulting in an average of 1775 mm of precipitations per year. Moreover, water deficit regions are registered to the departments of Caquetá, Cauca, Tolima, Santander, Boyacá, and Cundinamarca.

The agricultural region of La Mesa de Los Santos is the selected area for this study due to its water scarcity and the high amount of agricultural and poultry production. Thus, the poultry farm denominated Villa Laury, located in this region (latitude and longitude coordinates 6.924369, -73.062591) was considered for this study.

This region is located in the Santander department and presents an extension of 446.000 m^2, and between the 300 m to 1790 m above the sea level, showing a high vulnerability in the water availability [6]. The water mismanagement has placed this region susceptible to the economic impacts of water shortages. The “water stress” of the region is due to the higher demand for water to supply the excessive growth of the population, agriculture and poultry production, representing an amount of water greater than the ecosystem can provide as natural offer and the reduction of precipitation or insufficiency in the supply infrastructure [7], [8]. Despite its current partial aridity, it is an interesting region from an economic point of view and forms one of the natural regions of the Santander department with agricultural and livestock production, mining, and tourism [9].

The poultry production is the main livestock production in the Santander department, accounting with the highest relation of installed capacity (22% of national capacity) and occupation (20% of national capacity). The poultry industry in the Mesa de Los Santos counts with approximately 370 poultry farms and generates more than 40.000 direct and 70.000 indirect jobs. It produces 340.000 tons of chicken meat and 2,900 million eggs and processes more than 1.400.000 tons of balanced feed each year [10], [11]. Accordingly to Fenavi (The National Federation of poultry farmers), due to the water scarcity in La Mesa de Los Santos, the poultry industry was forced to reduce the number of birds in the sheds of this area, of which the 60% corresponds to broiler chicken and the remaining 40% to laying birds.

Currently, the poultry production of this region suffers from shortages and is being supplied with liquid in tanker trucks (of 12 and 20 m^3 of capacity) in the dry season increasing the production cost [7], [8], [12]. Major innovation and investments in the region, and indeed nationally, are necessary to combat growing water scarcity and the phenomenon of climate change and conserve the water resources for future generations.

The main objective of this research was to develop a mathematic model to identify the numbers of poultry grown cycles that a rainwater harvesting (RWH) system could potentially feed in the average year of precipitations. Using this model, an RWH system, incorporating multiple parameters such as precipitations in the region, roof area, and water demand related to the number of animals to feed, rainwater tank sizing for the poultry houses, and other parameters were considered and assessed for a farm located in the region of La Mesa de Los Santos, Santander, Colombia.

The results of this research would be helpful to the entrepreneurs and policymakers by evaluating the importance of water management and the opportunity to take advantage of rainwater as a resource for sustainable poultry production, being currently an important alternative to the value chain in the agricultural, livestock and industrial sector of the region.

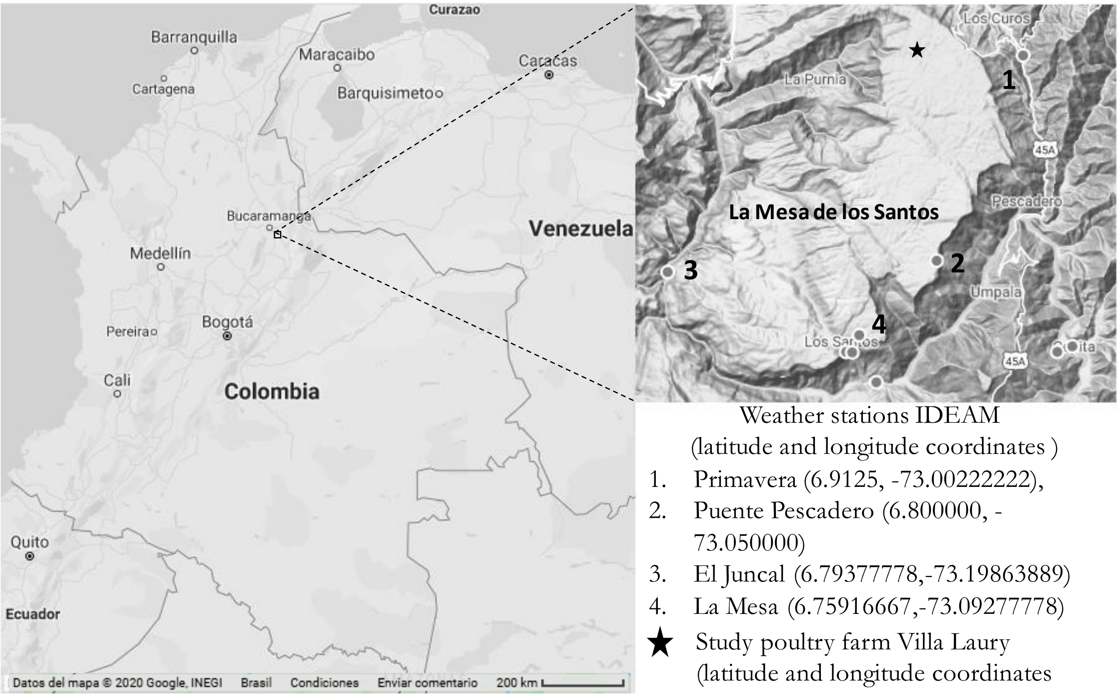
2. Methodology

The base of the research was the estimation of rainwater potential for animal consumption in the poultry production from La Mesa de Los Santos, Santander, Colombia.

The RWH system modeling developed considers the weather data for the farm's geographic location, the water management on the animal feed cycle (growth poultry cycle), and the rainwater harvested on a daily base. The analysis performed considered daily rainfall data from the weather stations with less than 25 km surrounding the study farm: 24037010 (IDEAM Primavera, latitude and longitude coordinates 6.9125, -73.00222222), 24037350 (IDEAM Puente Pescadero, latitude and longitude coordinates 6.800000, -73.050000), 2405700149 (IDEAM El Juncal latitude and longitude coordinates 6.79377778,-73.19863889) and 24060050 (IDEAM La Mesa, latitude and longitude coordinates 6.75916667,-73.09277778) [13]. These rainwater information were compared with weather station 800940 (SKGB) in the Palonegro Airport, Bucaramanga, Santander (latitude and longitude coordinates 7.126389, -73.184722) [14].

Figure 1 presents the location map of La Mesa de Los Santos region, including the weather stations and the considered study poultry farm. To consider true or applicable these weather data were acquired from the Institute of Hydrology, Meteorology and Environment Studies- IDEAM-Colombia, and corresponds to the assumption that the weather stations surrounding the La Mesa de Los Santos region could represent the average weather condition of the studio region, and thus, the condition of the study farm.

The collected data ranged from 2010 to 2018, and the stations selected were due to the availability of long-run rainfall data. Among the years 2015/2016, the large-scale atmospheric circulation over northwestern South America was influenced by extreme events of climate variability considered in this study, particularly related to the transition from La Niña to El Niño [15]–[18].



Weather stations IDEAM
(latitude and longitude coordinates)

1. Primavera (6.9125, -73.00222222),
2. Puente Pescadero (6.800000, -73.050000)
3. El Juncal (6.79377778,-73.19863889)
4. La Mesa (6.75916667,-73.09277778)

★ Study poultry farm Villa Laury (latitude and longitude coordinates 6.924369, -73.062591)

Figure1. Location map of La Mesa de Los Santos region, shows the weather stations and the poultry farm considered in this study.

The consideration of these climate variabilities corresponds to the assessment of the minimum poultry cycle that could feed with the rainwater harvesting system in the years with the dryer seasons. The considered structural and hydraulic sizing of the catchment area is the poultry house roof usually built in the Mesa de Los Santos region (zinc tiles) [19]–[22]. The runoff coefficient or system capture efficiency from a roof surface or from an impervious surface after a rain event is usually poor due to the accumulation of dust, sediments, bird and animal droppings, and leaves and debris from the surrounding areas. The selection of a roof coefficient Cf of 0.9 was accordingly to [23], [24]. Poultry house parameters consisted of house length (105.0 m), width (12.5 m), and the number of houses (1 unit) on the farm.

Daily liquid precipitation values were summed for each day to get a daily precipitation value, calculating the maximum and the minimum captured water in liters for a period of 90 days.

The considered average water demand for poultry consumption was in a poultry production cycle of 45 days, and seven cycles per year. The most common way to predict water consumption is as a function of the weight of feed consumed. The factor in this study was 1.8 g/g (grams of water/grams of feed), corresponding to the average between 1.6 to 2.0 of the weight of feed consumed daily like water usually considered in the literature and in data collected directly on-farm [21], [25], [26]. Table 1 presents the amount of feed consumed in the poultry cycle, the inventory data was collected directly on-farm, and compared with the literature information. The bird water consumption reported in this paper estimates the water consumption per cycle of broiler chickens kept under commercial conditions presented in Table 2.

Table 1. Weight of feed consumed in a poultry production cycle

	Days / Average feed per day (kg/day)						
Week	1	2	3	4	5	6	7
1	0.010	0.014	0.018	0.022	0.026	0.031	0.034
2	0.038	0.042	0.048	0.054	0.06	0.066	0.072
3	0.077	0.081	0.085	0.089	0.093	0.097	0.101
4	0.109	0.115	0.122	0.129	0.135	0.141	0.148
5	0.151	0.154	0.157	0.16	0.163	0.166	0.169
6	0.172	0.174	0.177	0,18	0.183	0.186	0.189

Table 2. Estimation of Bird water consumption

Day (range)	**Feed range (kg/day)**	**Water demand (liters/bird/day) [1]**	**Water demand (liters) [2]**
1 a 7	0.022	0.2772	4989.6
8 a 22	0.078	2.106	37908
23 a 45	0.195	8.073	145314
Total poultry cycle		104.562	188211.6

[1] Water demand (liters) in the day range per animal (liters/bird/day)

[2] Water demand (liters) per poultry house (18,000 broilers) on the day range (l/day)

2.1. Model and numerical approximation of the storage in the RWH system

The definition of the sizing of the tank was according to the developed model, which allows estimating the tank volume through a continuous daily water balance of supply and demand throughout the poultry cycle production. The developed model of the RWH system selects an optimum volume to store the required water for a poultry production cycle, for which an increase in capacity did not represent significant gains in water collection.

We have used a model of input-output in a tank where the input values are determined by the rainwater data, the hypothetical size of the tank (setting a max volume value - Vmax), the roof area, and the Cf constant. The output is determined by the consumption of birds under some considerations. If the water in the tank is under the requirement of consumption of the day (1.8 (liters/bird)*day feed) the output is set to zero and the output is just open if the tank is at least filled in the 10% of the total tank. According to Table 2 on day 4 of the cycle, an animal eats approximately 0.022kg of food so for 18000 of broiler chickens produced in a cycle per poultry house, we have a consumption of 1.8*0.022*18,000 = 712.8 liters of water. Figure 2, represents the daily water consumption in the poultry house accordingly to Table 2, where 3 days were added to reflect the days when the building is under maintenance and are setting the conditions for a new poultry production cycle. Finally we assume that the tank is empty in every start of the year(V(0)=0) (Equation 1).

$$dV/dt = \mathrm{input}(t, Vmax, roof, Cf) - \mathrm{output}(t, Vmax, food(t), V) \tag{1}$$

Afterwars the constant values were set so that there was no dependence of the time(t), or volume(V), roof area (roof), constant of roof (Cf), maximum capacity in the tank (Vmax), and the data of food consumed per day (food(t)). The data provided in food and rain could be understood as a piece constant function, then the model is reduced to an ordinary equation of the form (Equation 2):

$$dy / dt = f(t,y) \tag{2}$$

With this model we use a third-order strong stability preserving Runge-Kutta (SSPRK3) to advance in time as described below (equation 3 to 6).

$$k_1=f(t_n,y_n) \tag{3}$$

$$k_2=f(t_n+\Delta t,y_n+t(1/2k_1)) \tag{4}$$

$$k_3=f(t_n+1/2\Delta t,y_n+t(1/4k_1+1/4k_2)) \tag{5}$$

$$y_n+_1=y_n+\Delta t(1/6k_1+1/6k_2+2/3k_3) \tag{6}$$

More details about the strong stability properties and this methods are discussed on [27].

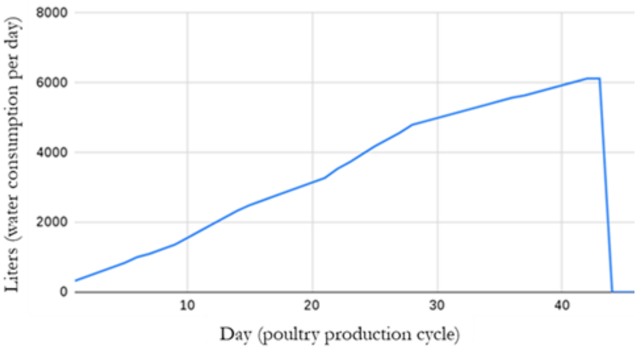


Figure 2. Consumption for each day according to Table 2.

3. Results and discussion

We first made a first approximation assuming an infinite tank without feed the birds to measure the potential of RWH system by the roof along each year, having some interesting results just to show. Figure 3 presents some examples of the results of the rainwater harvest in 2010. Figure 4 shows the rainwater harvest in 2016. Furthermore, in 2016, the precipitations were under the effects of El Niño Southern Oscillation (ENSO), but we can see that even in this dry season, La Mesa de Los Santos region is not heavly impacted by this phenomenal. The results have shown that the RWH system has a potential of more than 10,000 liters of water, enough to feed more of six poultry production cycles of 18,000 of Broiler Chicken.

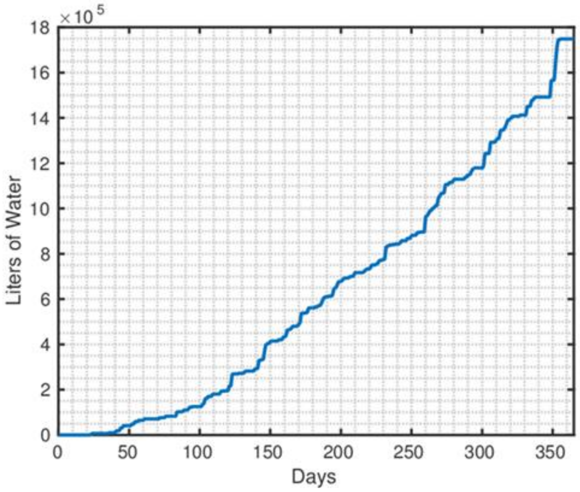


Figure 3. Rainwater harvested by the roof along the year 2010.

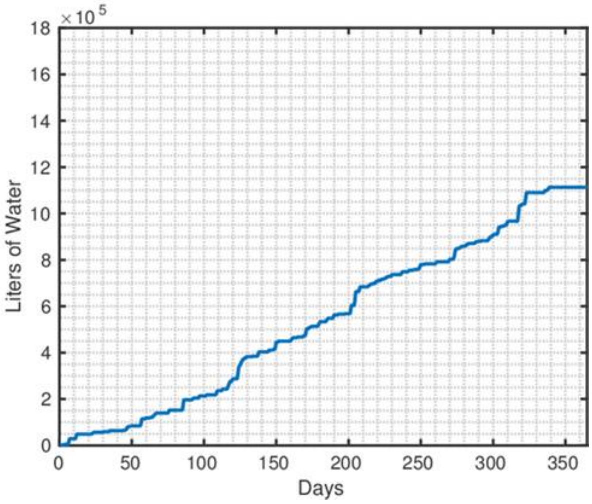


Figure 4. Rainwater harvested by the roof along the year 2016.

Under the assumption of an infinite tank, were obtained the following results that summarize the minimum, maximum, average and standard deviation measured in the potential to feed the poultry cycles just with the rainwater harvested in periods of 90 days. A poultry cycle requires 149,914.8 liters of water in 90 days, and it is possible to feed a maximum of 2 cycles of Broiler Chicken. Figure 5 presents this results and represents that it is possible to have a sustainable source of water base on the RHW system because at least, on average most of the cases have enough water for more than two cycles just with the rain-water harvest in 90 days.

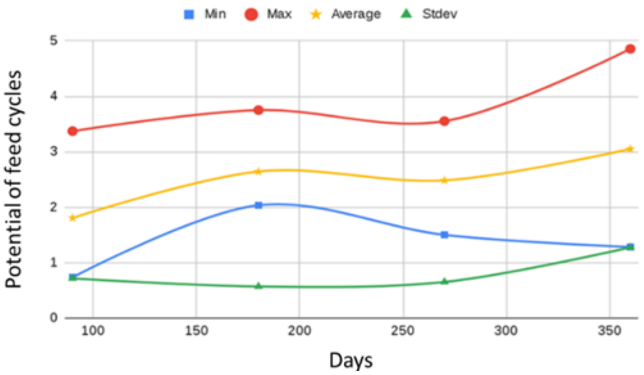


Figure 5. Minimum, Maximum, Average and standard deviation of cycles feed on 2010 to 2018 based on Rainwater harvest in periods of 90 days.

3.1. Optimizing the Water Tank

The simulations were based on data and the setting of different amounts in the available capacity for the water tank and decrease the number of days without water. It is important to highlight that the RWH system counts as a day without water when the water tank is filled below the 10%, or when the water in the tank is less than the required to feeding the broiler chickens for that day. Figure 6 presents the results of simulations showing the relations between the number of days without water along the years from 2010 to 2018, and the capacity available in the tank (liters). After this analysis we can recommend a tank with a capacity of around 100 cubic meters (100,000 liters) because around this capacity of tanks is reached the minimum, and we can also see that bigger value does not increase the number of days without water significantly, and it could make a higher inversion for farmers without significant improve.

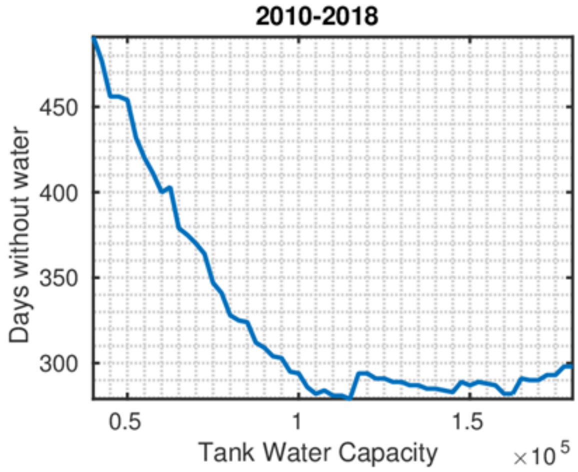


Figure 6. Days without water from 2010 to 2018 and the capacity in the water tank measured in liters.

4. Conclusions

We have developed a numerical code based on SSPRK3 that uses the rainwater information and estimates the optimum capacity of the projected tank of the RWH system. Thus, representing the reduction in the dependency of external sources of water (i.e. underground and in tanker trucks).

To better estimate the values obtained in this work, data collection should be carried out on more poultry houses during several production cycles, and rainwater seasons to account for changes in the water management practices and the bird water consumption. Moreover, it is important to highlight the importance of performing the precipitation measurements directly on-farm. The methodology used in this research allows improving the outputs considering the measurements directly in the field for a long period of time.

This work could influence positively the farmers, entrepreneurs, and policymakers, to include new alternatives that improve the economy of the region and introduce a sustainable way of water management for the poultry industry in the region of La Mesa de Los Santos.

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