AJ ACADEMIC JOURNALS
expand your knowledge

African Journal of Agricultural Research

Full Length Research Paper

Modeling the water balance of a ruminant production system in the semi-arid region

Samuel Rocha Maranhão[1]*, Rodrigo Gregório da Silva[2], Gherman Garcia Leal de Araújo[3] and Magno José Duarte Cândido[1]

[1]Departamento de Zootecnia, Centro de Ciências Agrárias, Universidade Federal do Ceará, Av. Mister Hull, 2977, Bl. 808, Pici, 60440-554, Fortaleza, Ceará, Brasil.
[2]Instituto Federal do Ceará - Campus Limoeiro do Norte, Rua Estevão Remígio, 1145, 62930-000, Limoeiro do Norte, Ceará, Brasil.
[3]Centro de Pesquisa Agropecuária do Trópico Semiárido, Empresa Brasileira de Pesquisa Agropecuária, BR-428, km 152, Zona Rural, 56302-970, Petrolina, Pernambuco, Brasil.

In the Brazilian semi-arid region, most cattle properties that use small dams as a source of water are unaware of the water balance of this system, which makes it difficult to plan and use this resource rationally. In this context, the objective was to demonstrate the impact of water consumption from a ruminant production system in a small reservoir. The water use model was developed using the Vensim PLE™ software for a hypothetical farm located in Petrolina, Pernambuco State, Brazil. The reservoir capacity and evaporation, infiltration and runoff rates were estimated from the literature and rainfall was estimated using the probability density function in the @RISK© software. The use of irrigation, water consumption of the family and farm, and water consumption by goats, sheep and cattle were estimated from the literature. In the horizon of 30 years, in only five of these the maximum capacity of the reservoir was reached. In the most demanding water scenarios, years are observed in which the reservoir dries up completely, making animal production unfeasible. Using the proposed model, it was possible to estimate, using real indicators, combinations to find the best way to use water, depending on the type of herd and the use of irrigation.

Key words: Animal production system, small reservoir, stochastic simulation, systems dynamics.

INTRODUCTION

Water is undoubtedly the element that is related to all the "steps" of humanity, from the primitive need for watering to the current agricultural and industrial development. Civilizations had their development on the margins of bodies of water, like the records of the Sumerian peoples (approximately 4000 BC) who had instructions on irrigating crops, and the Egyptians who had technologies to control the water level upstream and downstream of the Nile river (El-Rawy et al., 2020).

In contrast to the coverage of 70% of the Earth's

*Corresponding author. E-mail: samuel_zootec@hotmail.com. Tel: +55 85 996652721.

surface by water, only 3% is fresh, 29% of which is accessible, distributed as follows: 18% is groundwater, 7% is in rivers and lakes and about 4% is in the form of water vapor. Of the volume of accessible water, 8% goes to human consumption and 70% is used in agriculture (Erthal and Berticilli, 2018; Nikolaevich et al., 2020), with a large part directed to the production of grains and fodder for animal feeding (Opio et al., 2011). The above-mentioned amount of water that is destined for agriculture is necessary, but it is still difficult for society to understand that food production requires water.

In arid and semi-arid areas of the planet, which comprise approximately 17.7% of the planet (Rotenberg and Yakir, 2010), rainfed agriculture and livestock farming depend only on rainfall. Thus, agricultural activity in this case behaves like natural vegetation and does not cause a significant effect on the volume of accessible water that could be destined for human consumption, for example. Water can be present in different compartments within the system, such as soil, vegetation and the animal itself, especially at the farm level, where such compartmentation becomes unique.

Through the stochastic and dynamic modeling of systems it is possible to draw a diagram of the water flow in the farm, allowing glimpsing the best way to manage this resource, determining the amount of future water to be needed in a given period of time. In this context, the present study is characterized as an attempt to improve water management and understand its ways within livestock production systems. Therefore, the objective was to develop a water flow model in livestock production, associated with the possibilities of carrying out simulations, that is, creating scenarios to assist in decision making.

MATERIALS AND METHODS

The model addresses System Dynamics as a way of understanding the elements involved in water dynamics in a livestock production system located in the Brazilian semi-arid region. As a support tool for the construction of the model, Vensim PLE™ software (Ventana Systems Inc., 2010) was chosen, as it has an accessible interface and has graphic elements that clearly show the system events in simulation.

Model creation

The production system model chosen for the study comprises a hypothetical rural property located in Petrolina (Latitude 09° 23 'S and Longitude 40° 30' W), Pernambuco State, Brazil. The region's climate is classified as Bshw (Köppen, 1936) with low average annual rainfall (435 mm), high rates of potential evapotranspiration (1,521 mm) and significant water deficit throughout the year (Jatobá et al., 2017).

At first, it is important to identify the first variable that will be the center of the modeling process, with the other variables interconnected to create a logical structure. It is also important to highlight that the understanding of the system under study goes beyond the perception of the processes involved, it encompasses all actions over time and their return actions. The first variable in the

simulation model will be the water reservoir (Figure 1), which was chosen for being a key part in the storage of the main water input in the system (rainfall) in the vast majority of properties. In addition, small ponds are common in the Brazilian semi-arid region, due to the low cost of construction, easy access to the small farm, in addition to being the main source of use of rainwater by intermittent water courses (Assunção and Livingstone, 1993; Campos, 1997).

In order to estimate precipitation, a history of precipitation calculation was made annually for the municipality of Petrolina, Pernambuco State, Brazil (Figure 2), for later determination of the probability density function of the variable in the @RISK© software. In the Weibull function, the one that best describes the precipitation behavior for Petrolina, Pernambuco State, Brazil, was found. Taking into account the almost random nature of the rains in the Brazilian semi-arid region (Andrade et al., 2006), the RANDOM *Weibull* function was used in the Vensim PLE™ software to improve the predictive capacity of the model (Figure 2).

The volume of the reservoir, that is, the maximum storage capacity of the reservoir, given in m³, is estimated by the equation of Molle and Cadier (1992), where the volume of the reservoir (m³) is given by the ratio of its height (m) multiplied by the surface of the water mirror (m²), over an average shape of the reservoir (2.70). In the impossibility of measuring the lowering of the reservoir, that is, obtaining information on evaporation and infiltration rates, approximate calculations can be adopted. For smaller reservoirs (depth less than 5 m), a loss of 10 to 12 mm day^{-1} in the dry period can be considered, whereas for reservoirs with a water mirror greater than 10 ha, losses can reach from 07 to 09 mm day^{-1} (Molle and Cadier, 1992). In this study, we adopted an average evaporation and infiltration rate of 40% (Araújo and Piedra, 2009; Leão et al., 2013; Oliveira, 2017).

For the runoff, which concerns the drainage grid of the land to collect water from the reservoir, a hypothetical rate of 30% of the volume of the formation multiplied to the reservoir capacity is used. The maximum capacity of the reservoir is 6481 m³, considering a depth of 2.5 m and a water mirror of 7000 m² Equation by Molle and Cadier (1992).

So far, we have built the logic of the water component of the model using precipitation, the reservoir and its main losses of water (evaporation, infiltration) when without human or animal use.

With regard to natural pasture, the inventory of water use must consider the water balance of all inputs and outputs, including the green water ingested by the animals during grazing. For this purpose, we will approach the consumption of water from natural pasture only in a conceptual way in the model, but making a slight estimate of the consumption of water present in natural forage by the forage consumption by the animal.

As an example of pasture cultivated under irrigated management, the cactus pear (*Opuntia stricta*) was chosen. The application of a 7.5 mm irrigation depth every 14 days by the drip system (Pereira et al., 2015) during the period of seven months, considering the period of drought in the region, was adopted (Lopes et al., 2017). In the rainy season, water consumption was treated in a conceptual way. The model has three main outputs for water, evaporation and infiltration, as already shown, spillway and uses. The spillway has the function of letting excess water out of the system. In this example, when the reservoir capacity is complete, the excess water, via precipitation, follows downstream through the spillway. As for the uses, these can be for human use, different uses, use for irrigation and animal use.

Water for human use is also part of the production system and consists of calculating the minimum amount of water to satisfy a person's basic needs. The "water for human use" was estimated at 200 m³ year^{-1} for five people, taking into account the minimum demand of 110 L per person day^{-1} suggested by the UN. As for "water for different uses", half of the water volume (100 m³) used in the variable "water for human use" was adopted. Water for various uses, on the other hand, includes all the water used on the farm for
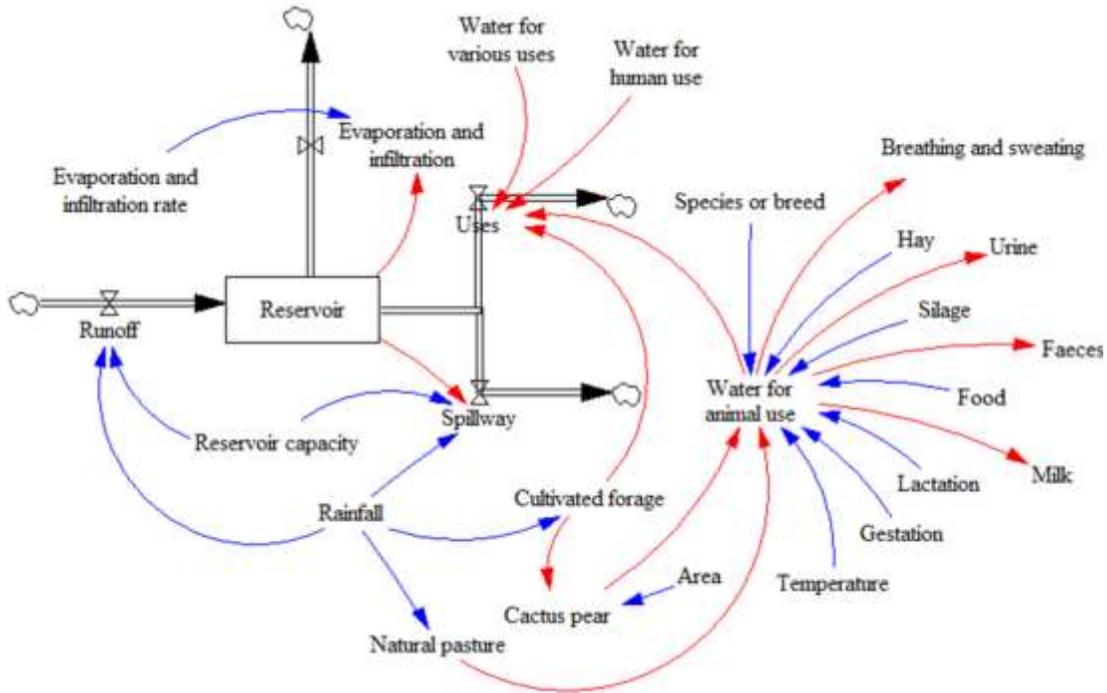
Figure 1. Diagram of the water flow of a hypothetical livestock production system in a semi-arid environment. The blue and red arrows represent inputs and outputs of the system water, respectively. Source: Elaborated by the author.
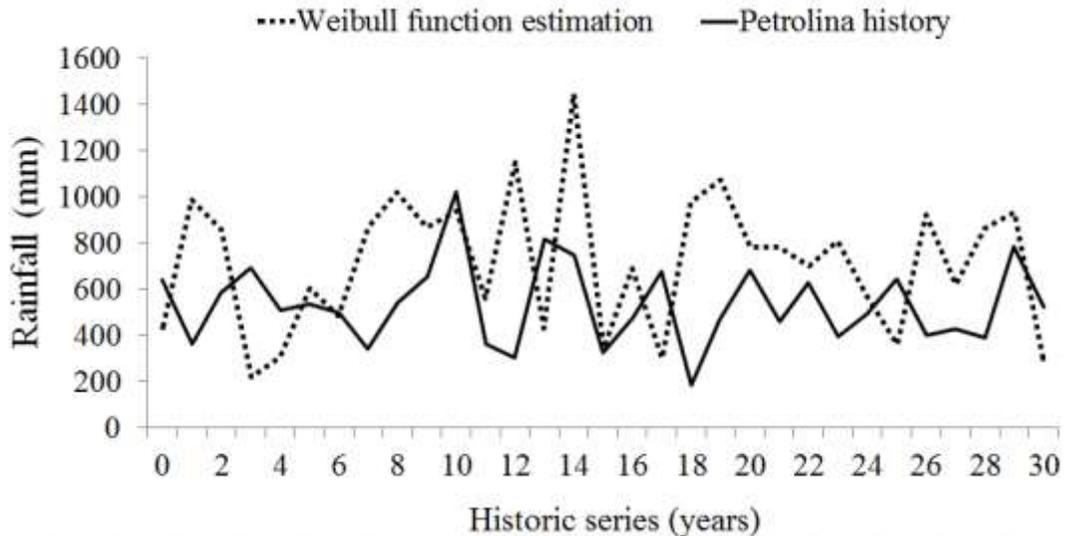

Figure 2. Petrolina precipitation history (1989-2019) and precipitation estimated by the Weibull function (mm year^{-1}).

uses such as cleaning utensils, washing facilities, etc.

The animal component of the system is represented as a sub-model, with its own flows and inflows. In the animal sub-model, to facilitate the understanding and arrangement of the equations, the calculation of water use will be related to the water consumption verified in the literature for sheep (3.42 L day^{-1}) and goats (2.31 L day^{-1}) without a defined breed standard, in a state of maintenance (Alves et al., 2007) and in the gestational phase, where an additional 126% in water consumption was added for each species (Brito et al., 2007; NRC, 2007). The data above correspond to the animals bred in the Brazilian semi-arid region.

In the case of livestock, due to the lack of information on water

consumption in the Brazilian semi-arid region, the water demand for this species was recommended in relation to the consumption of dry matter and air temperature in dry regions (Pallas, 1986), considering in this work animals in a state of maintenance and lactation. According to Pallas (1986), for animals raised at temperatures above 27°C, water consumption is estimated at 5.5 L of water per kg of DM ingested. Thus, for cattle in a state of maintenance (AU = 450 kg BW) consuming 3% of the live weight in DM, the daily water intake was estimated at approximately 75 L day^{-1}. For pregnant animals, this value is suggested to be 1.5 times the water consumption of an animal in a state of maintenance (approximately 112 L day^{-1}) and for lactating animals 0.86 L of water is added per liter of milk produced. In this study, an estimated production of 5 L cow^{-1} day^{-1} for animals was adopted with the Caatinga vegetation as the main source of food (Zoccal and Dusi, 2013).

As water inputs in the animal we have: the water of water, water contained in the food and metabolic water; as output/losses, we have: water lost in breathing and perspiration, urine, feces and milk (lactating animal) (Khelil-Arfa et al., 2012). Some factors directly influence water intake, such as species and breed (Ribeiro, 2006; Alves et al., 2007), food management (Neiva et al., 2004; Ribeiro, 2006), physiological state (Brito et al., 2007; NRC, 2007), terrain slope, water distribution, temperature (Cândido et al., 2004; Pompeu et al., 2009), among others.

The main causes of water in the sub-model, the animals will be treated in a conceptual way and highlighted in the flowchart by means of red arrows (Figure 1). It is important to emphasize again that the simulations in this work are theoretical and illustrative; they do not accurately represent the components of the production system, such as other categories of animals and more intrinsic water pathways. However, it lists the main characteristics of water consumption of a small farm located in the Brazilian Semi-arid region.

Scenarios of water consumption by goats, sheep and cattle

In these topic different simulations of production systems involving goats, sheep and cattle are presented. At first, the hypothetical farm has an undetermined area of natural pasture, a pasture area cultivated with cactus pear (01 ha) and a reservoir with a capacity of 6,481 m³ of water. The herd will be 300 goats or 300 adult sheep, depending on the simulation. The number of animals in the sheep and goat herd is based on personal communication with small producers located in the Brazilian semi-arid domains, who claim to have sufficient breeding stock for a minimum income to justify their breeding. The idealized scenarios for water consumption by goats and sheep were:

Scenario 1: herd of 300 sheep;
Scenario 2: herd of 300 goats;
Scenario 3: herd of 300 sheep + irrigation of the cactus;
Scenario 4: herd of 300 goats + irrigation of the cactus;
Scenario 5: herd of 300 sheep in gestation + irrigation of the cactus;
Scenario 6: herd of 300 goats in gestation + irrigation of the cactus.

In relation to cattle, the simulations start from three different family-based milk production systems, where: (1) milk production is intended for family consumption and small commercialization with a herd of 10 cows, 4 of which are in lactation; (2) production system for marketing the herd with a herd of 20 cows, 11 of which are in lactation and (3) production system for marketing the milk with herd of 50 cows, 34 of which are in lactation (Zoccal et al., 2008). The idealized scenarios for water consumption by cattle were:

Scenario 7: herd of 6 cows in maintenance + 4 in lactation;
Scenario 8: herd of 6 cows in maintenance + 4 in lactation +

irrigation of the cactus;
Scenario 9: herd of 9 cows in maintenance + 11 in lactation;
Scenario 10: herd of 9 cows in maintenance + 11 in lactation + irrigation of the cactus;
Scenario 11: herd of 16 cows in maintenance + 34 in lactation;
Scenario 12: herd of 16 cows in maintenance + 34 in lactation + irrigation of the cactus.

RESULTS AND DISCUSSION

Simulation I - Estimation of the maximum reservoir volume

In this first stage, it is necessary to establish the maximum volume of the small reservoir, so that the recharge, evaporation, infiltration and release events can be simulated. In a scenario of 30 years, for a reservoir with a maximum capacity of 6481 m³ (maximum depth of 2.5 m and a water mirror of 7000 m²), there were only five moments when the precipitated volume exceeded the capacity of the reservoir despite the high reservoir recharge rate (runoff) (Figure 3). The high water loss in the system is due to high rates of evaporation and infiltration commonly seen in small reservoirs (Molle and Cadier, 1992; Santos et al., 2009). This first analysis is important to assess the capacity of the reservoirs and determine the minimum volume for supplying the farm, taking into account the natural water losses in the system.

Simulation II - Water consumption in different goat and sheep production scenarios in a semi-arid environment

The higher water demand of sheep compared to goats increased the water consumption of the reservoir by approximately 18% (123 m³) in scenarios 1 and 2 (Figure 4), an amount sufficient to supply a family of five for 223 days according to the UN (110 L per person day^{-1}). In scenarios 03 and 04, where the cultivation of cactus pear is practiced, irrigation increased water consumption considerably (Figure 4), causing a water deficit in the reservoir. The water consumption of cactus pear during the dry period (seven months) would be equivalent to 1050 m³. In scenario 04, there is a water deficit in the years 01 and 07, totaling a volume of -578 m³. For scenario 03, the water deficit was greater (1406 m³), covering a greater number of years (years 01, 07, 08 and 09) (Figure 5).

In the last two scenarios, now for pregnant animals (Scenarios 05 and 06), water consumption was more significant (Figure 4). The number of years in which the reservoir goes into deficit has increased and, consequently, the volume to be demanded to meet the farm's needs increased by 6345 and 3856 m³, respectively (Figure 5).

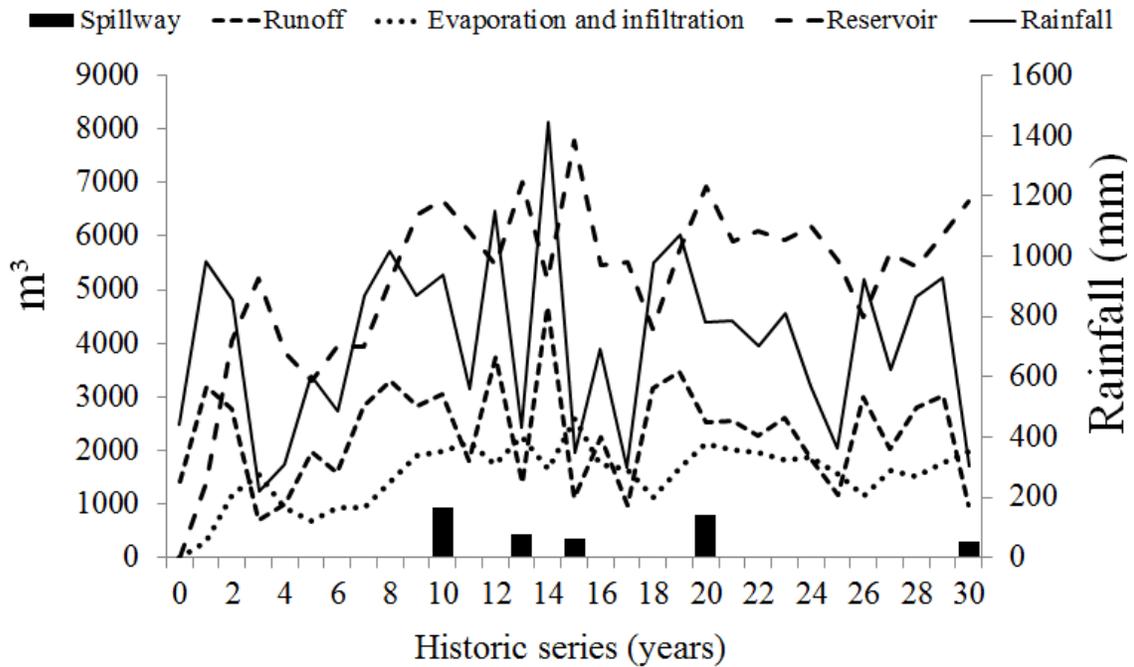In the years when the reservoir dries up completely due

Figure 3. Reservoir recharge rates (m³), runoff (m³), evaporation (m³), infiltration (m³), spillway (m³) and rainfall (mm) estimated for a hypothetical watershed in the Petrolina, Pernambuco State, Brazil.
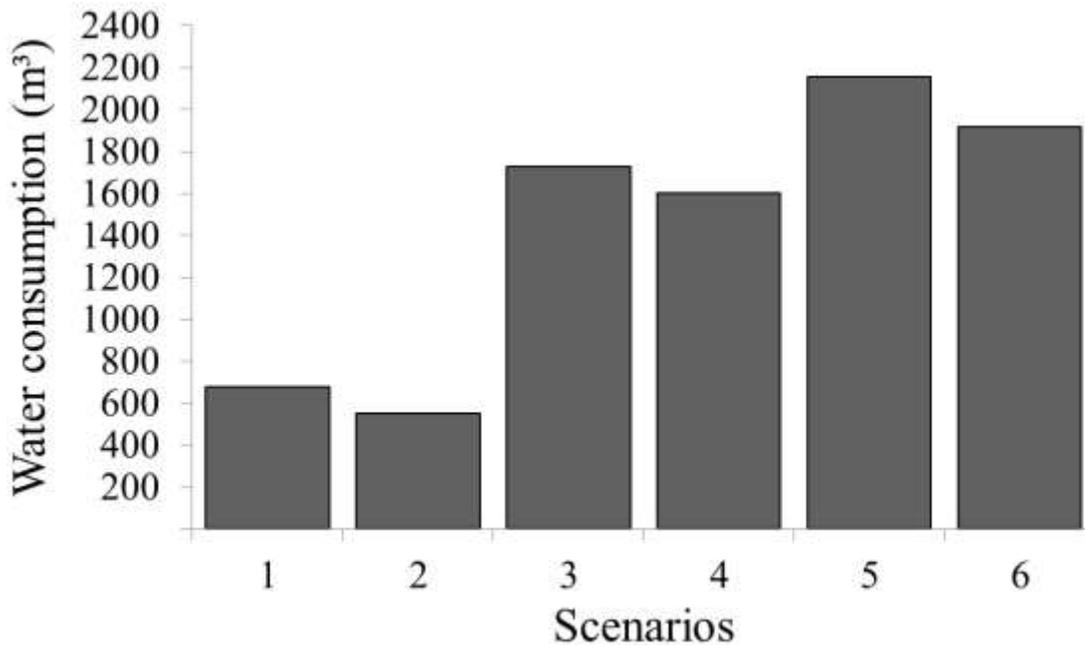

Figure 4. Water consumption scenarios by six different goat and sheep production systems in Petrolina, Pernambuco State, Brazil.

to not only natural losses, but also the intense use of the farm, it is up to the producer or technician to scale the production system to that volume of water available, the vast majority unknown to the actors. Once the water demand of the farm is known, it is possible to manage the use of this resource. In the two scenarios previously mentioned, the cactus pear irrigation practice would be compromised, unless the producer obtains water from
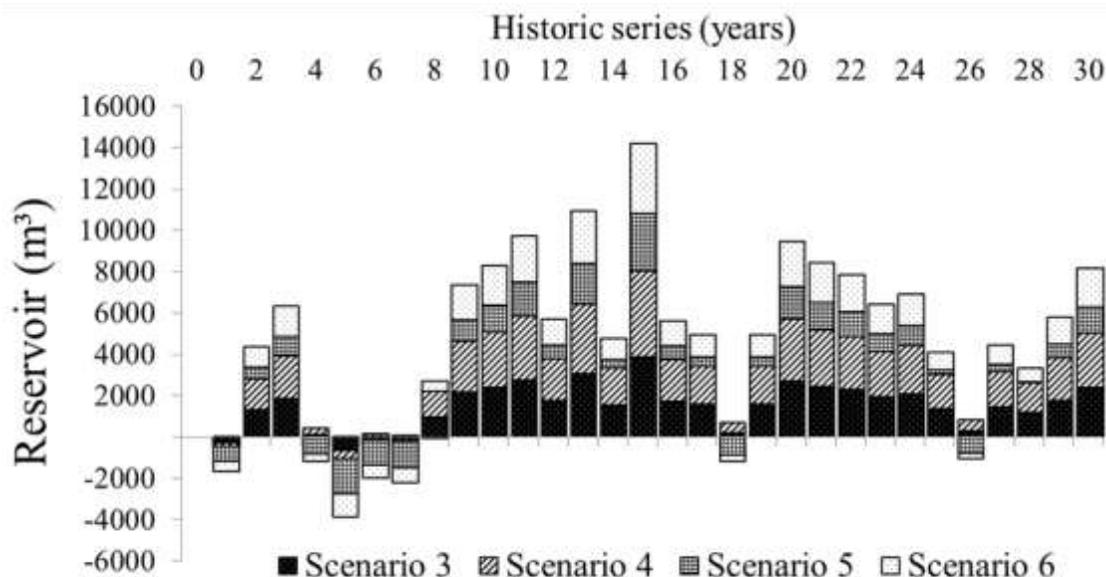
Figure 5. Simulations of reservoir water use by four different goat and sheep production systems in Petrolina, Pernambuco State, Brazil.

external sources for the consumption of the farm.

Irrigation, contained in the item "cultivated pasture", was included to assess the impact of one of the most economical irrigation systems (drip) and which has been widely used in the cultivation of cactus pear (Araújo et al., 2019; Santos et al., 2020). In scenarios 05 and 06, the small reservoir does not allow the use of irrigation in a continuous way. The decrease in water consumption by the farm, such as reducing the number of animals, would not have a significant effect on the water consumption of the farm, not justifying the reduction of the herd.

For the condition of a small reservoir, the cactus pear was chosen in a planned manner, since this crop requires little water (Pereira et al., 2017) and the suppression of irrigation would not cause any significant damage, as it is a plant tolerant to long periods of drought, having high efficiency in the use of water (Lédo et al., 2019; Souza et al., 2019). Cactus pear irrigation could be carried out in a complementary manner (Santos et al., 2020) to increase the biomass production of the farm, taking into account particular conditions, such as the sale of cladodes and/or providing greater food security for the animals. Thus, irrigation would be performed in a controlled manner by monitoring the reservoir's water supply, and its interruption would be carried out in those years when the reservoir did not receive sufficient recharge. Therefore, the need to work water on the farm as a sole unit is clear, listing the potential of the farm according to the availability of water, obviously, and how the use of that water will be depending on the soil and on the objectives of the producer. However, it is not so simple to identify where the water moves inside the farm without a systemic view, contemplating the inputs and outputs to

better manage this important resource.

Simulation III - Water consumption in different cattle production scenarios in a semi-arid environment

Notably, cactus pear irrigation had the greatest impact on water consumption in the different scenarios proposed (Figure 6). The greatest amplitude in the water volume is verified between scenarios 07 and 08, this response being expected due to the low water consumption of the small number of animals (10 cows). In scenarios 07 and 09, with herds of 04 and 11 cows producing 20 and 55 L day^{-1}, respectively, the water consumption by the farm as a whole did not cause total depletion of the dam for a hypothetical horizon of 30 years.

Considering water consumption, the volume of milk produced in scenarios 07 and 09 (Figure 6) and the average price paid to the producer for the liter of fresh milk (R$ 3.00 in Petrolina) in the informal market, a common condition of commercialization of milk practiced by the small farmer in the Northeast region (Reis Filho and Silva, 2013), the estimates point to a regular condition of water supply by the small weir that would allow an economic activity with gross revenue of R$ 1,800.00 and R$ 4,950.00 per month, respectively, for the sale of the milk produced. Although the estimates presented here do not consider the costs involving the entire production system and consider the use of an extensive system in the Caatinga vegetation, these inferences are important, since approximately 56% of dairy farms have a herd between 10 and 99 animals (Reis Filho and Silva, 2013).
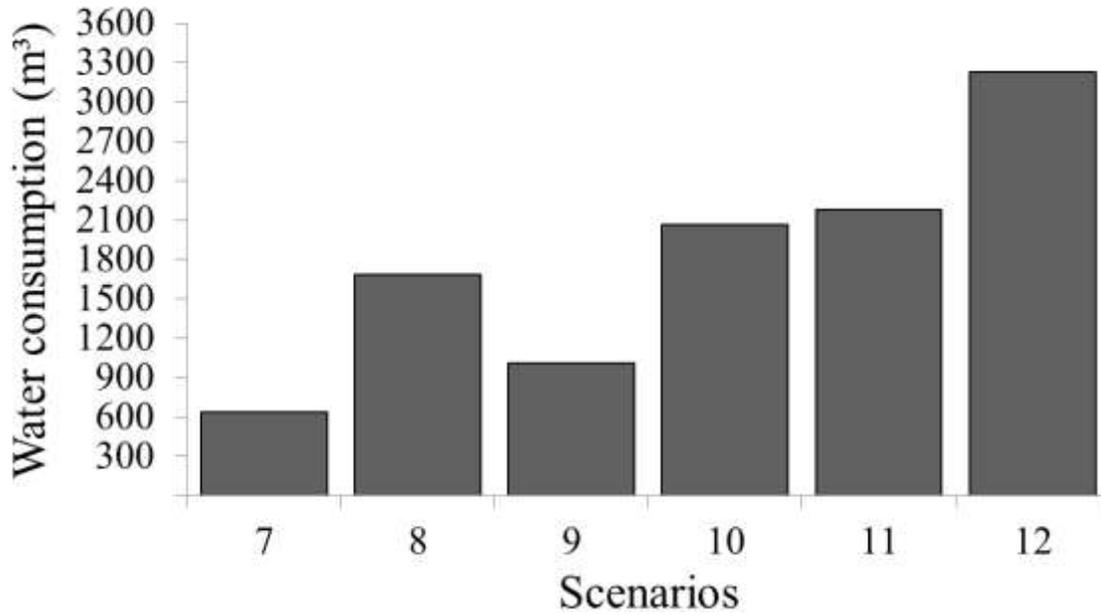
Figure 6. Scenarios and water consumption by six different cattle production systems in Petrolina, Pernambuco State, Brazil.
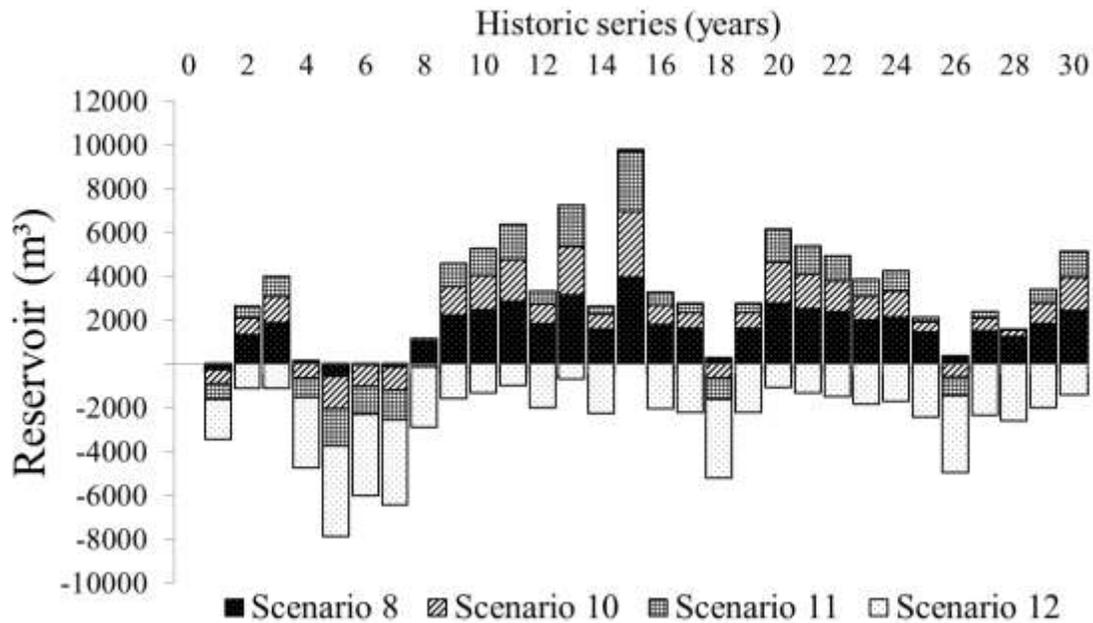

Figure 7. Simulations of reservoir water use by four different cattle production systems in Petrolina, Pernambuco State, Brazil.

In scenario 11, the first case is observed where the consumption of water by the herd without the use of irrigation dries the reservoir, being compared to scenario 10, where the irrigation of the cactus pear projects a consumption of 1050 m³ of water (Figure 7). Starting from a completely dry reservoir in year zero of the simulation, the water demand in scenarios 10 and 11 would be compromised in the first seven years, where the rainfall volume, simulated based on Petrolina's history, would not be able to meet the herd's demand and accumulate water in the small reservoir.

The small reservoir exemplified in this study is a

representation of the small reservoir in the Brazilian Semiarid region, mostly shallow and with a large mirror of water, which facilitates evaporation losses (Molle, 1994). The natural losses of water through evaporation and infiltration correspond to approximately 40% of the volume of the small reservoir (Araújo and Piedra, 2009; Leão et al., 2013; Oliveira, 2017). In these scenarios, they would correspond to a loss of approximately 6000 m³ in the first seven years, equivalent to the maximum capacity of the reservoir in question. These losses cannot be avoided, but this potentially lost volume can be used for irrigation when there is no need for water by other components of the farm. In this case, part of the water would be "retained" in the plant tissues of strategic plants, such as cactus pear, in which approximately 90% of the total fresh biomass is made up of water, being, therefore, an important water and forage reserve for herds.

In scenario 12, with the exception of the year 15, in which the simulated precipitation was greater than 1400 mm during the rainy season, the water demand of the herd together with irrigation of the cactus pear would be impractical (Figure 7). The rainfall estimate, using the probability density function of the rain behavior in Petrolina to generate a time series, instead of average data from the measured series, brings a more effective perspective of the reality of the water supply in view of the uncertainty of precipitation in the semi-arid region. In addition to simulating the years of low rainfall, it also estimates those years in which the volume of rainfall is higher than the historical average. Taking for example scenario 12, if the average volume of rainfall that occurred in the last 30 years in Petrolina (476 mm) is used, instead of the simulation of rain by the Weibull function, calculated in Vensim PLE™ software [minimum (0), maximum (1e+012), Weibull shape S "alpha" (2.6453) Weibull shift (0) Weibull scale "mean" (476) and seed (0)], in any 30-year scenario, the water deficit would be -3998 ± 546 mm, with a deficit greater than -4000 mm as of the seventh year of this trial.

In short, this work sought to explore practical indicators through modeling with the intention of helping technicians and farmers to understand and optimize the use of water in terms of productivity in the small farm located in the Brazilian semi-arid region. Once the model is in operation, it is possible to carry out numerous simulations and combinations to find the best way to use water, depending on the size of the herd, the reservoir and the use or not of irrigation.

Due to the ease of changing the variables, the producer or technician will be able to use modeling to create scenarios that assist in decision making. Through simulation, the logic of the farm can take its course, often disrupted, when in many cases the purchase of animals comes first and then the producer thinks about what they will feed on and drink.

The simulations portrayed in this study reflect a little of the reality faced by smallholders who have the small reservoir as the only source of water for herds, crops and the family. The purchase of water is routine and brings high costs to agricultural activities, in most cases of pure subsistence. The correct size of the reservoirs, the renewal of the bed (removal of sediments) and conservation of the riparian forest in the streams present in the watershed are actions that must be emphasized to enhance the use of water in the small reservoir, improving the lives of those who produce in the Brazilian semi-arid region.

Conclusion

In a scenario of 30 years, the natural rates of evaporation and infiltration of the small reservoir are the biggest cause of water losses in the system. As cactus pear irrigation is considered in the system and the animals' water demand increases, there are years when the reservoir dries up completely.

In this example, it was possible to devise, using real data, combinations to find the best way to use water, depending on the type of herd and the use of irrigation. In the opposite situation, it can help in the calculation of the construction of a new reservoir, according to the demand of the intended herd.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEGMENTS

REFERENCES

Alves JM, Araújo GGL, Porto ER, Castro JMC, Souza LC (2007). Feno de erva-sal (*Atriplex nummularia* Lindl.) e palma-forrageira (*Opuntia ficus* Mill.) em dietas para caprinos e ovinos. Revista Brasileira de Saúde e Produção Animal 9:43-52. doi:10.15528/412.

Andrade AD, Souza ED, Silva DD, Silva IF, Lima JRS (2006). Produção animal no bioma caatinga: Paradigmas dos' Pulsos-Reservas'. Revista Brasileira de Zootecnia 35(1):138-155.

Araújo JC, Piedra JIG (2009). Comparative hydrology: analysis of a semiarid and a humid tropical watershed. Hydrological Processes 23(8):1169-1178. https://doi.org/10.1002/hyp.7232.

Araújo JS, Pereira DD, Lira EC, Félix ES, Souza JTA, Lima WB (2019). Palma Forrageira: plantio e manejo. Campina Grande: INSA 60 p.

Assunção LM, Livigston I (1993). Desenvolvimento inadequado: construção de açudes e secas do Nordeste. Revista Brasileira de Economia 47(3):425-448.

Brito TS, Viana MH, Figueiredo FOM, Cavalcanti LFL, Couto JRL, Macedo Júnior GL, Ferreira MIC, Borges I, Benavides YI, Campos WE (2007). Consumo de água e sal mineral de ovelhas da raça Santa Inês gestantes submetidas a dois manejos nutricionais. In: Congresso Brasileiro de Zootecnia, 17; Congresso Internacional de

Zootecnia, 4.; Reunião Nacional de Ensino de Zootecnia, 13., Londrina. Proceedings., Londrina: Universidade Estadual de Londrina, 1 CD-ROM.

Campos JNB (1997). Vulnerabilidades hidrológicas do semi-árido às secas Planejamento e Políticas Públicas 16:261-298.

Cândido MJD, Benevides YI, Farias SF, Silva RG, Peixoto MJA, Aquino DC, Bozzi R, Neiva JNM (2004). Comportamento de ovinos em pastagem irrigada sob lotação rotativa com três períodos de descanso. In: Reunião Anual da Sociedade Brasileira de Zootecnia, 41., Campo Grande. Proceedings., Campo Grande: Embrapa Gado de Corte, 1 CD-ROM.

El-Rawy M, Abdalla F, El Alty M (2020). Water resources in Egypt. In: Hamimi Z, El-Barkooky A, Martínez Frías J, Fritz H, Abd El-Rahman Y. The geology of Egypt, regional geology reviews. Springer Nature pp. 153-189. doi: 10.1007/978-3-030-15265-9_2.

Erthal ES, Berticilli R (2018). Sustentabilidade: Agricultura irrigada e seus impactos ambientais. Ciência and Tecnologia 2(1):64-74.

Jatobá L, Silva AF, Galvíncio JD (2017). A dinâmica climática do Semiárido em Petrolina-PE. Embrapa Semiárido-Artigo em periódico indexado (ALICE). doi:10.5935/1984-2295.20170006.

Khelil-Arfa H, Boudon A, Maxin G, Faverdin P (2012). Prediction of water intake and excretion flows in Holstein dairy cows under thermoneutral conditions. Animal 6(10):1662-1676. doi:10.1017/S175173111200047X.

Köppen W (1936). Das Geographische System der Klimate, Vol. 1., Part C. In: Köppen W, Geiger R. Handbuch der Klimatologie. Gebruder Borntraeger, Berlin pp. 1-44.

Leão R, Soares AA, Teixeira ADS, Silva DDD (2013). Estimation of evaporation in the Banabuiú dam, in the state of Ceará, Brazil, by different combined methods, derived from the Penman equation. Engenharia Agrícola 33(1):129-144. doi:10.1590/S0100-9162013000100014.

Lédo AA, Donato SL, Aspiazú I, Silva JAD, Donato PE, Carvalho AJD (2019). Produtividade e eficiência do uso da água da palma forrageira sob arranjos, espaçamentos e adubações. Revista Brasileira de Engenharia Agrícola e Ambiental 23:413-418. https://doi.org/10.1590/1807-1929/agriambi.v23n6p413-418.

Lopes I, Guimarães MJM, Melo JMM, Ramos CMC (2017). Balanço hídrico em função de regimes pluviométricos na região de Petrolina-Pe. IRRIGA 22(3):443-457. doi:10.15809/IRRIGA.2017V22N3P443-457.

Molle F (1994). Geometria dos pequenos açudes. SUDENE-DPG/PRN/HME, RECIFE 139 p.

Molle F, Cadier E (1992). Manual do pequeno açude. RECIFE. SUDENE/ORSTOM, SUDENE/TAPI 523 p.

Neiva JNM, Teixeira M, Turco SHN, Oliveira SMP, Moura AAAN (2004). Efeito do estresse climático sobre os parâmetros produtivos e fisiológicos de ovinos Santa Inês mantidos em confinamento na região litorânea do Nordeste do Brasil. Revista Brasileira de Zootecnia 33(3):668-678. https://doi.org/10.1590/S1516-35982004000300015.

Nikolaevich MA, Vladimirovna ME, Azretovich HK, Damirovich GA (2020). Global and national food security issues in the context of land and water resources. Caspian Journal of Environmental Sciences 18(5):467-472.

National Research Council (NRC) (2007). Nutrient requirements of small ruminants: sheep, goats, cervids, and new world camelids. Washington, DC. 384 p.

Oliveira RRVM (2017). Perda de água por evaporação em um pequeno reservatório do semiárido. Trabalho de Conclusão de Curso. Universidade Federal do Rio Grande do Norte - UFRN, Rio Grande do Norte 16 p.

Opio C, Gerber P, Steinfeld H (2011). Livestock and the environment: addressing the consequences of livestock sector growth. Advances in Animal and Veterinary Sciences 2(3):601-607. doi:10.1017/S204047001100286X.

Pallas P (1986). Water for animals. Land and Water Development Division. FAO (Food and Agriculture Organization of the United Nations), Rome, Italy 82 p.

Pereira PC, Silva TGF, Zolnier S, Silva SMS, Silva MJ (2017). Water balance in soil cultivated with forage cactus clones under irrigation. Revista Caatinga 30:776-785. https://doi.org/10.1590/1983-21252017v30n326rc.

Pereira PDC, Silva TGFD, Zolnier S, Morais JEFD, Santos DCD (2015). Morfogênese da palma forrageira irrigada por gotejamento. Revista Caatinga 28(3):184-195. http://dx.doi.org/10.1590/1983-21252015v28n321rc.

Pompeu RCFF, Rogério MCP, Cândido MJD, Neiva JNM, Guerra JLL, Gonçalves JS (2009). Comportamento de ovinos em capim-tanzânia sob lotação rotativa com quatro níveis de suplementação com concentrado. Revista Brasileira de Zootecnia 38(2):374-383. https://doi.org/10.1590/S1516-35982009000200022.

Reis Filho RJC, Silva RG (2013). Cenários para o leite e derivados na Região Nordeste em 2020. Recife: SEBRAE 154 p.

Ribeiro VL (2006). Comportamento ingestivo de caprinos Moxotó e Canindé, submetidos à alimentação à vontade e restrita. Dissertação de mestrado. Universidade Federal Rural de Pernambuco – UFRPE, Recife 40 p.

Rotenberg E, Yakir D (2010). Contribution of Semi-Arid forests to the climate system. Science 327(5964):451-454. doi: 10.1126/science.1179998.

Santos FA, Silans AMBP, Porto RQ, Almeida CN (2009). Estimativa e análise do volume dos pequenos açudes através de imagem de satélite e levantamento de campo na bacia hidrográfica do Açude Sumé. In. XVIII Simpósio Brasileiro de Recursos Hídricos 14 p.

Santos MR, Donato SLR, Cotrim JRPR (2020). Irrigação na palma forrageira. Revista Agrotecnologia 11(1):75-86.

Souza JA, Ribeiro JER, Ramos JPF, Sousa WH, Araújo JS, Lima GFC, Dias JA (2019). Rendimento quântico e eficiência de uso da água de genótipos de palma forrageira no Semiárido brasileiro. Archivos de Zootecnia 68(262):268-273. doi:10.21071/az.v68i262.4146.

Ventana Systems Inc (2010). Vensim PLE. Avaiable at: http://www.vensim.com.

Zoccal R, Dusi GA (2013). Modelo ideal para produção de leite no Brasil. Animal Business Brazil 9:34-37.

Zoccal R, Martins PC, Carneiro AV, Reis Filho RJC, Nogueira JNA (2008). Competitividade da cadeia produtiva do leite no Ceará: produção primária. Juiz de Fora: Embrapa Gado de leite 384 p.