Water footprint of a dairy production system in Costa Rica

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Abstract: Water management optimization is imperative in a sustainable productive system, and the production of dairy is no exception. However, in Costa Rica there is little information regarding the quantity of water consumed during milk production. This study generated the first water footprint assessment of a productive system of milk in the country on a monthly basis using the Water Footprint Network methodology. The water footprint was calculated in terms of volume of water required to produce one kg of fat- and protein-corrected milk (FCPM) and is comprised of three components: the water requirement of crops due to evapotranspiration (green water), consumed water incorporated in the production of milk (blue water) and the water required to dilute pollutants found in the wastewater of the dairy production system (grey water). Samples of wastewater were obtained from the third sedimentation tank of the dairy production system so the concentration of phosphates and total nitrogen could be determined and used in the grey water component. This temporal approach allowed the identification of both high- and low-water consumption months of the dairy farm. The total monthly water footprint ranged from 902.14 to 1226.75 L/kg FCPM for phosphates, whereas the range for total nitrogen oscillated between 903.95 and 1219.86 L/kg FCPM. The months with higher water footprint values were January, February, and December for both cases. The data and analyses presented herein are extremely important in Costa Rica to have a broader sense of water consumption in milk production regions across the country.

Keywords: dairy production, environmental sustainability, optimization, water footprint, water use optimization.

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1 Introduction

The management of natural resources is a key aspect of sustainable development. In such context, water plays a key role in productive systems ranging from industrial to agricultural ones. However, the availability of this natural resource is currently a concern around the world; especially when considering that more than two billion people live in countries with strong water scarcity and about four billion people deal with water shortages at least once a month (WWAP, 2019).

Parallel to the latter, water quality is a top priority in both development and environmental agendas worldwide (Giri, 2021). Human activity has affected this natural resource over the years, and ecosystems have received direct impacts from diverse pollutants present in wastewaters (Akpor, 2011). This is a critical

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point in terms of managing water for sustaining life on the planet, considering that 74% of wastewater generated in anthropogenic productive systems is discharged in superficial water streams (WWAP, 2017).

To achieve a better understanding of water consumption in productive systems and to study the potential effect of anthropogenic activities on the environment, a calculation of water footprint was developed. This estimator has the potential of indicating both the direct and indirect usage as well as consumption of fresh water for the creation of a product, and consists of three components: green, blue, and grey water footprints (Hoekstra et al., 2011). The first one corresponds to precipitation that does not run off on the soil but is stored in the form of crops. The blue water footprint contemplates the consumed water that is incorporated in the product, whereas the grey water component is the theorical volume of water required to dilute the pollutants present in the system's effluent so that their concentration complies with national quality water standards (SABMiller Plc and World Wildlife Foundation, 2009).

Several studies around the world have used the water footprint approach in the agricultural sector for crops, animal products and processed products. These studies were conducted to reduce the impact of anthropogenic practices on water resource. In crops, for example, researchers have determined the usage of water to produce wheat (around 1050 L kg^{-1}) in the Shandong Province of China (Zhai et al., 2019) and for apple orchards in the Western Cape Province of South Africa, which required an average of 212.1 L kg^{-1} (Gush et al., 2019). For the animal industry, water consumption of poultry, pork, and beef at different production systems (grazing, mixed and industrial) has been calculated in countries such as Brazil, China, Netherlands, and the United States. In these countries, the water footprint ranged for poultry between 1250 L kg^{-1} and 6300 L kg^{-1}, for pork between 3750 L kg^{-1} and 12500 L kg^{-1}; meanwhile, beef ranged for 3750 L kg^{-1} to 23750 L kg^{-1} (Gerbens-Leenes et al., 2013). For processed products, the water usage of wine was determined in New Zealand for the Marlborough and Gisborne regions, where reported values indicated that 742.5 L and 667.1 L were necessary to produce a 750 mL bottle of wine at the winery gate respectively (Herath et al., 2013), meanwhile, vegetable soups have been analyzed in the south-easter Spain in which 580.5 L were required to produce 1 L of a chilled vegetable soup known as gazpacho (Rivas Ibáñez et al., 2017).

In Costa Rica, around 42% of total water consumption (excluding water for hydroelectric generation) corresponds to agricultural activity (Comité Técnico Interinstitucional para las Estadísticas del Agua, 2023). As such, it is relevant to quantify water consumption at different levels and types of productive systems, especially given the orientation of the country toward becoming completely environmentally sustainable and that the country declared water to be a basic, essential inalienable right (Gobierno del Bicentenario, 2020). In efforts to determine the consumption of water in the agricultural activity in the country, several annual water footprints for crops have been calculated, including banana, coffee, and rice at values of 176.25 L kg^{-1}, 2056.61 L kg^{-1}, 2096.27 L kg^{-1} (waterlogged rice) and 2785.96 L kg^{-1} (rainfed rice) respectively (Centro de Recursos Hídricos para Centroamérica y el Caribe, 2013); however, no information is available for dairy production systems, because most of the focus has been on the mitigation of the effects of climate change, such as the Nationally Appropriate Mitigation Actions (NAMA) for the livestock sector, which promotes the reduction of the greenhouse gases (GHGs) in this sector (Ministerio de Agricultura y Ganadería de Costa Rica, 2015).

In Costa Rica, there is a lack of scientific information on water consumption in dairy production systems. Moreover, monthly calculations for any productive system are non-existent, as far as we know, despite their high potential of integration with other temporal variables affecting production and the importance of understanding temporal fluctuations of water consumption on a yearly basis. Therefore, the aim of the present study was to calculate the monthly and annual water footprint of a dairy production system in Costa Rica in terms of green, blue, and grey components.

2 Materials and methods

This research was conducted at the dairy farm module of the Alfredo Volio Mata Experiment Station (EEAVM, abbreviation in Spanish) of the University of Costa Rica during 2021. The station is located on the Ochomogo region (9°54’42.11” N and 83°57’19.12” O) of Cartago province, Costa Rica at 1558 meters above sea level (m.a.s.l.) with soil categorized as Andisol (Centro de Investigaciones Agronómicas, 2020), due to good natural drainage and fertility because of its volcanic origin (Instituto Nacional de Innovación y Transferencia en Tecnología Agropecuaria, 2015). The main vegetation found in the EEAVM corresponds to pastures dedicated to dairy production. Per the collected weather data, of 2021 the average temperature was 17.3°C, with a minimum of 12.2°C and a maximum of 23.1°C, the average relative humidity was 88.7% and presented an accumulated precipitation of 1810 mm distributed through May and November (rainy season).

The study contemplated two phases including the determination of the boundaries associated with the system under study and the calculation of the water footprint in three subcomponents (green, blue, and grey). The boundaries of the system were determined through field visits to the EEAVM, and the calculation of the water footprint followed the Water Footprint Network approach developed by Hoekstra et al. (2011).

For the calculation of the water footprint, the functional unit used was one kilogram of fat- and protein-corrected milk (FCPM). This unit is directly linked to milk quality as it creates comparable values across different kinds of breeds and feed regimes (International Dairy Federation, 2017) by including the percentage of fat and protein in the final calculation. Figures for protein and fat content were obtained from acceptance reports provided by the Cooperativa de Productores de Leche R.L. (better known locally as the Dos Pinos company). FCPM was calculated as follows, where kg_m is milk production:

$$FCPM\ [kg] = kg_m * [(0.1226 * \%fat) + (0.0776 * \%protein) + 0.2534] \quad (1)$$

2.1 Determination of the boundaries associated with the system under study

The boundaries of the dairy production system considered in this study consisted of three sections referred to as (i) field, (ii) dairy production module, and (iii) wastewater management (Figure 1). The first section considered the areas dedicated to forage production and cattle grazing paddocks, as well as the irrigation systems used during the dry season. The predominant forage crops in the station are African star grass-based pasture (*Cynodon nlemfuensis*), forage black sorghum or Columbus grass (*Sorghum almum*) and King grass (*Pennisetum purpureum* var. Taiwan). During the rainy season, part of the harvested pasture was ensiled for posterior use during the dry season.

The dairy production module was divided into four sub sections. These were a) the feeding area where most of the cattle hydrate and feed is provided; b) the waiting area, where cattle wait before and after milk is drawn; c) the milking parlor, used twice a day (6:00 am and 3:00 pm); and d) the milk storage area. The wastewater generated in the first three sections is redirected to the wastewater management system.

The wastewater treatment system consisted of three sedimentation tanks. The first two tanks stored the solids from the wastewater, while the third one was used to store the residual water later used for fertilizing the grazing areas.

For this study, the input of the system corresponds to consumptive water (irrigation, water intake of the cattle, water content of feed, content of water in milk and water used in the milking parlor and milk storage area). Meanwhile, the outputs consider the volume of water associated with the evapotranspiration of the crops and all water that was used for cleaning and is directed to the waste management system. It’s important to clarify that the amount of liquid in milk is not considered an output of the system since this approach was developed at a farm level (field, diary production module and wastewater management system), therefore the exit of milk from the dairy production system to other types of production systems was not considered.

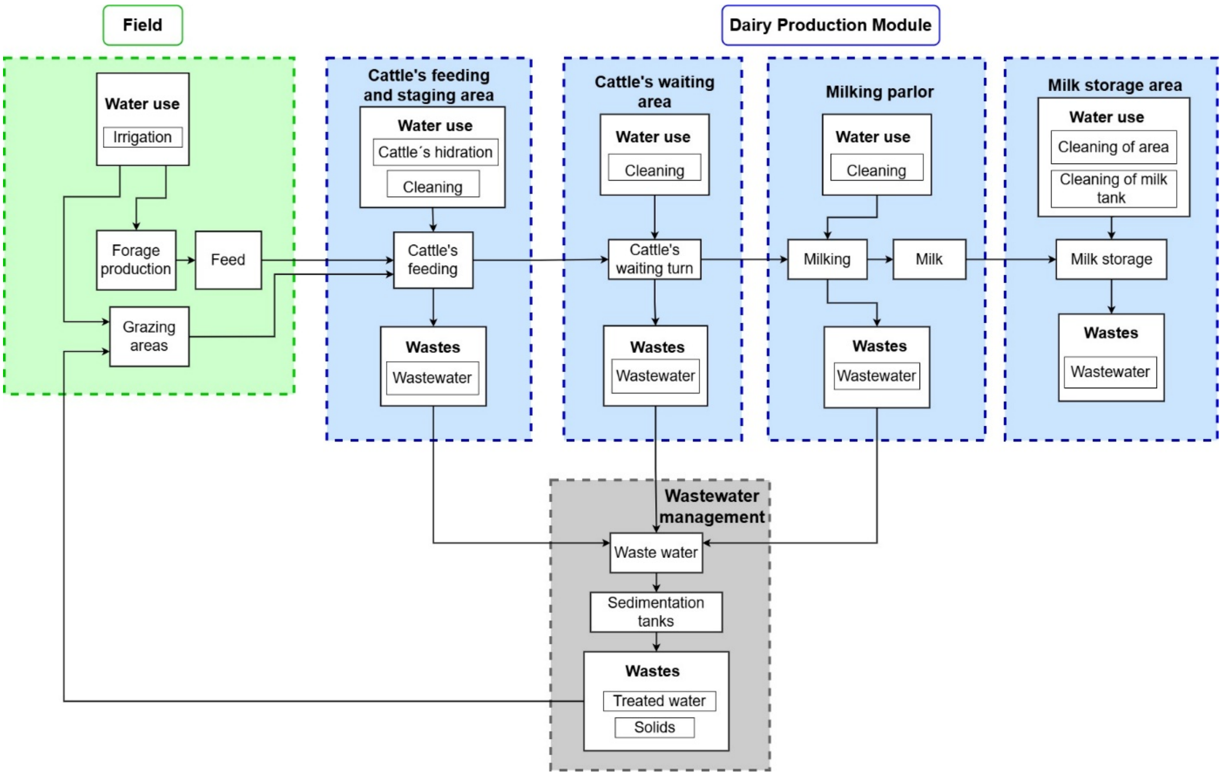


Figure 1 Boundaries of the dairy system studied in the EEAVM during 2021

2.2 Water footprint calculation

The estimation of the water footprint associated with the studied dairy production followed the methodology published by Hoekstra et al. (2011). For this part, the green, blue, and grey water footprint components were determined monthly using primary data corresponding to water consumption, effluent nutrient load, feed, and milk production of the farm. The first variable was determined using data from a series of water meters that complied with ISO 4064 (four of 2 inch, two of ½ inch and one of ¾ inch diameters, respectively) that were installed on site. The rest of the data were recorded via field visits, book recording and non-structured interviews with workers associated with the dairy module of the EEAVM.

For the calculation of the green water footprint (WF_{green}) component, climatic data from a weather station located in situ was used. The Hargreaves equation (Hargreaves and Samani, 1985) was used to generate radiation data. The Penman-Monteith equation (Allen, 1998) was used to calculate the reference evapotranspiration (ETo), while the evapotranspiration of crops (ETc) was determined by multiplying ETo by the crop coefficient (Kc). The crops considered for this calculation were the two most used in the diet of cattle (African star grass-based pasture and forage black sorghum). For pastures, due to the rotative grazing behavior of the cattle in the field, an average Kc of 0.95 was used (Allen, 1998); and for sorghum, its different growth stages were considered. In this manner, the Kc used in the latter case ranged from 0.3 – 1.2 (Allen, 1998; Piccinni et al., 2009), from late March until mid-December.

WF_{green} was determined using the following equation.

$$WF_{green}\left[\frac{m^3}{month}\right]=\sum_{i=1}^{n}ET_c \qquad (2)$$

The blue water footprint (WF_{blue}) component (Equation 3), considered the water of (i) the liquid used for hydration of cattle [W_{animal}], from calves to lactating cows, (ii) the irrigation of pastures [W_{irr}], (iii) the hydric content of feed given to the cattle [W_{feed}], (iv) the amount of liquid in milk [W_{milk}] and (v) the milking parlor and milk storage area use [W_{sto}]. Since water troughs were filled automatically with a buoy system, a water meter was installed in the main pipeline connecting them to the drinking water system.

To calculate the water volume associated with the irrigation system, the flow value of the commercial sprinklers used in the EEAVM was used (0.648 m^3 $hour^{-1}$) (Fortuntek Industrial Co. Ltd, 2010) along with the average number of active sprinklers and an operating time of twelve hours per day. To determine the volume of water associated with animal feed, a sample obtained weekly. For each sample, water content was determined using the oven methodology of drying the samples at 65℃. Such value was multiplied by the total weight of feed given to the livestock. To determine the quantity of water in the milk (around 87% per kg of product), the percentage of total solids provided by the Cooperativa de Productores de Leche R.L., was used. This company receives the milk from EEAVM and returns a quality report upon acceptance of the product.

To keep track of water consumption in the milking parlor and milk storage area, a water meter was installed in the main pipeline of the dairy production module. The total volume of this section was corrected by subtracting the water used in the toilets by keeping track of bathroom use in a logbook.

$$WF_{blue}[m^3/month] = W_{animal} + W_{irr} + W_{feed} + W_{milk} + W_{sto} \quad (3)$$

For the grey water footprint (WF_{grey}) component, the volumes of the effluents considered were the water used for cleaning and disinfecting both milking parlors and waiting/exiting areas. These volumes were measured using a water meter. Samples of wastewater were obtained from the third sedimentation tank every month, upon which, the samples were transported in coolers to a commercial laboratory to determine total nitrogen and phosphate.

These pollutants were selected for being the main components of the dairy production systems that in excess can generate a negative impact on the quality of the receiving bodies and therefore on aquatic ecosystems (Elizondo-Salazar, 2005, 2006). For each contaminant the grey water footprint was determined with Equation (4).

$$WF_{grey}\left[\frac{m^3}{month}\right] = \frac{Effluent\ volume*[C_{effluent} - C_{water\ intake}]}{[C_{max} - C_{water\ body}]} \quad (4)$$

Where，

$C_{effluent}$ is the concentration of the pollutants in the effluent (mg L^{-1})；

$C_{water\ intake}$ is the concentration of the pollutant in the main water intake (mg L^{-1})，the Chiquito river in this case；

C_{max} is the maximum concentration of the contaminant according to national quality water standards (mg L^{-1})；

$C_{water\ body}$ is the natural concentration in a receiving body (mg L^{-1}).

In the present study the latter was taken as zero since the effluent is used for the fertilization of pastures and does not arrive at a water body. Each calculated water footprint was divided by the rate of milk production [kg $month^{-1}$] to leave the values in units of m^3 kg^{-1}.

Additionally, an evaluation of differences in water footprint among dry and rainy seasons as carried out. The normality of the data was evaluated using the Shapiro-Wilk test upon which either a, T-Student or Mann-Whitney test was selected for parametric and non-parametric cases, respectively. For this analysis an alpha value of 0.05 was used as a threshold for the rejection of the null hypothesis of no differences.

3 Results and discussion

The EEAVM dairy production module across 2021 was characterized by having several lactating cows that ranged from 35 to 50 per month (Table 1). The highest milk production was observed in March with a total of 23448 kg FPCM while the lowest production was in December with 15337 kg FPCM.

Effluents generated by the dairy production module, the concentration of phosphates and total nitrogen fluctuated during the year. These variations were likely attributed to nutritional differences in the type of feed given to the animals during the dry and rainy season. For instance, during the dry season most of the feed consisted of sorghum silage.

Table 1 Farm production and water treatment characteristics

Parameters	Lactating Period (month)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Production and performance characteristics												
Average number of lactating cows	36	35	41	44	46	45	44	45	49	50	47	42
Average daily DMI per cow (kg)	10.3	10.0	12.2	9.7	8.7	5.4	4.7	3.3	6.3	8.1	7.5	9.9
Monthly milk production (kg FPCM)	17 304	16 279	23 448	19 620	21 234	19 489	21 155	20 629	20 327	17 621	16 051	15 337
Milk protein (%)	3.6	3.5	3.4	3.2	3.1	3.2	3.3	3.4	3.4	3.4	3.4	3.4
Milk fat (%)	4.4	4.6	4.6	4.5	4.3	4.2	4.2	4.3	4.4	4.5	4.5	4.4
Milk water (%)	86.7	86.6	86.6	87.0	87.3	87.3	87.4	87.2	87.0	87.0	87.0	87.0
Wastewater properties												
Phosphates of water intake point (mg L^{-1})	0.98	0.44	0.50	0.44	1.58	2.49	1.19	0.44	1.57	1.72	1.99	1.58
Phosphates from dairy production module effluent (mg L^{-1})	140	142	5	36.8	57.4	61.8	42.6	36.9	59.2	55.7	48.4	76.4
Total Nitrogen of water intake point (mg L^{-1})	1.0	1.3	1.0	5.0	2.18	2.0	1.0	2.0	3.0	5.0	2.0	19.0
Total Nitrogen of dairy production module effluent (mg L^{-1})	130	176	142	152	121	124	197	131	400	133	108	146

Note: Dry Matter Intake (DMI), Fat and Protein Corrected Milk (FPCM)

Water consumption for cleaning the feeding, waiting, and milking areas of the dairy production module accounted for, on average, 56% of total water necessary for milk production in the farm (considering breeding, milking parlor and milk storage areas as well as cleaning and animal hydration water). The use of water during the studied year increased during the rainy season, with August being the month in which more water was used for cleaning purposes.

It is important to highlight that the volume of water used for cleaning depended on variables such as the number of cows and the personnel in charge of the activity. For instance, in the first case, the manure volume was higher in situations with more animals, whereas in the second case, due to the rotation of personnel, the strategies and timing of sub activities varied depending on the crew in charge.

Monthly water footprint of the system considering phosphates as the pollutant for the grey component is shown in Figure 2. The calculated values were all positioned within the range between 902.14 and 1226.75 L/kg FCPM.

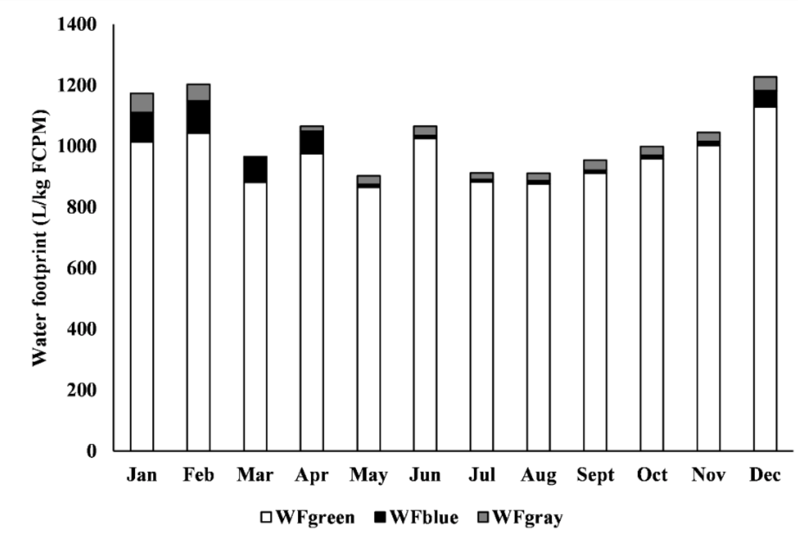


Figure 2 Water footprint considering phosphates across 2021 year

Similarly, when total nitrogen was considered as the pollutant for the grey component, the values ranged between 903.95 and 1219.86 L/kg FCPM (Figure 3). As expected, in both cases, the highest observed values corresponded to months within the dry season, when more external water was required by both crops and animals.

Considering the above, when performing the T-Student test, it was found that for both cases (phosphates and total nitrogen), there were significant differences between the water footprint of the dry and rainy season ($p<0.05$). The difference was mainly due to the impact of the blue component, since when the three components were analyzed statistically separately, the only one that showed significant differences was the WF_{blue}, which is mainly due to the use of irrigation during the dry season.

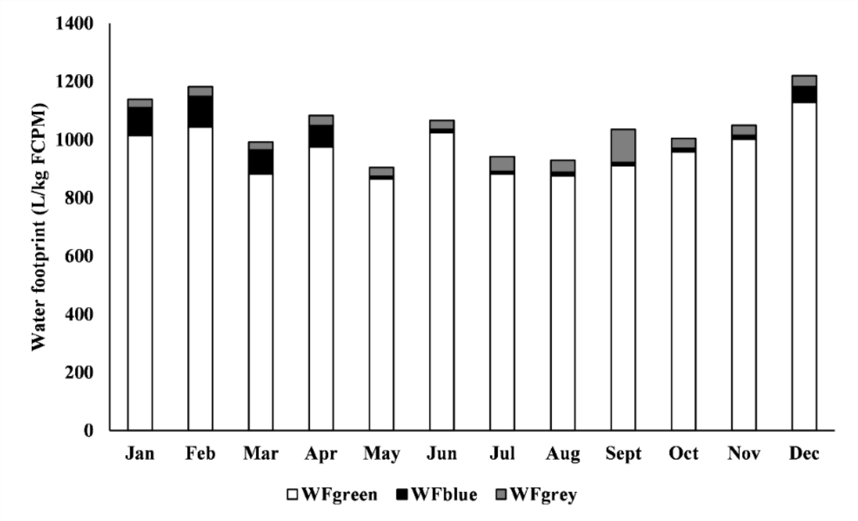


Figure 3 Water footprint considering total nitrogen across 2021 year

The WF_{green} was the highest of all the three. It ranged between 864.64 and 1127.42 L/kg FCPM. The months with the highest values were those during the dry season ones, when crops evapotranspire more due to higher temperatures and radiation. From a percentual perspective of the overall water footprint, values in the dry season oscillated between 86.4% and 91.9% when considering phosphates; and between 88.2% and 92.4% when total nitrogen was considered in the grey component. Meanwhile, for the rainy season, the green water footprint ranged between 95.5% and 96.7% when considering phosphates in the grey component, and between 88.0% and 96.1% when total nitrogen was included in the calculation.

The WF_{green} results obtained in this study are consistent with those reported in previous water footprint studies on agricultural crops in Costa Rica, where the green component was also the highest of the three. This was the case which from an average percentual perspective (year 2008 to 2011) for banana represented 96.7%, for coffee a 78.1%, and rainfed rice with 97% of the overall water footprint. The only case in which this pattern did not occur was for rice in waterlogged condition, because 73.1% belonged to the WF_{blue}, due to high water consumption because of the irrigation systems, meanwhile 23.3% was from the WF_{green} (Centro de Recursos Hídricos para Centroamérica y el Caribe, 2013).

Overall, the WF_{blue} obtained was the lowest of all three components, except during the dry season when its range oscillated between 4 and 105.72 L/kg FPCM (for equivalent relative frequency ranges between 4.4% and 8.8% contemplating phosphates and between 4.4% and 8.9% considering total nitrogen in the grey component). The monthly values associated with the rainy period ranged between 8.52 and 13.09 L/kg FCPM (for relative frequencies between 0.9% and 1.2% including phosphates and between 0.9% and 1.2% with total nitrogen). Such differences are due to the use of water for irrigation in selected grazing areas. Therefore, irrigation of pastures has such a high impact on the WF_{blue}. On average, for the dry season it was 87.2%

greater than on the rainy season. Percentagewise, during the rainy season the most important component of this water footprint is the volume of liquid used for hydrating animals which showed an average of 60.8% contrasting strikingly with an average value of only 8.8% for the dry season.

A higher water intake during the rainy season can be attributed to the number of cows but also to the effect of climatic factors such as air temperature and relative humidity. During the rainy season, the air temperature ranged between 16.94°C and 17.88°C and relative humidity between 89.59% and 93.62%; meanwhile, during the dry season, air temperature ranged from 16.35°C and 17.59°C and relative humidity between 80.71% and 89.05%. During the rainy season both parameters had the higher values, which coincidently are two of the factors that influence thermal perception (Yang et al., 2024), which therefore can be impacting the need of the cattle to drink more water in this season Also, both air temperature and relative humidity are parameters used in conjunction to determine temperature-humidity index (Cesca et al., 2021; National Research Council, 2001), which can be an important parameter to be considered as well to understand the impact of climate factors on the heat discomfort in dairy cows and its relationship with high water intake (Waltner et al., 2023) as well with milk yield and milk composition (Das et al., 2016; Lee et al., 2023; Moore et al., 2024).

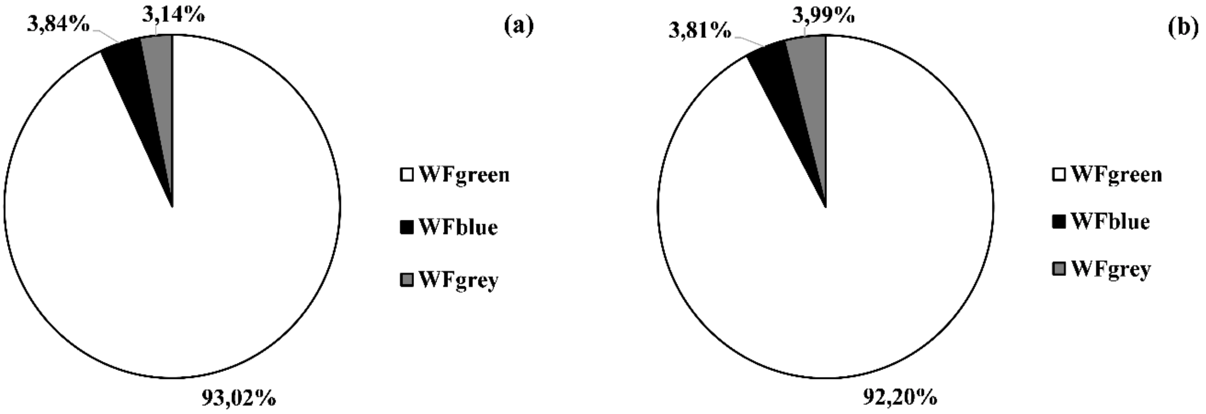
To comply with Costa Rican quality guidelines for water bodies, it is important to maintain a specific concentration of pollutants. In case of phosphates, it is 25 mg L^{-1}, whereas, for total nitrogen is 50 mg L^{-1} (Ministerio de Ambiente y Energía, 2006). In this regard, to potentially dilute the concentration of the pollutants in the wastewater of the studied system (WF_{grey} for phosphates), monthly volumes of water of approximately 610 m^3 and 540 m^3 are necessary for the dry and rainy periods, respectively. The values calculated considering total nitrogen were, on average, 593 m^3 and 947 m^3 for the dry and rainy periods as well. For the monthly production of milk, the WF_{grey} calculated with phosphates averaged 36.339 and 27.933 L/kg FPCM during the dry and rainy season; whereas the values calculated with total nitrogen were 32.646 and 48.022 L/kg FCPM for those same periods.

Even though during the rainy season more water is consumed for cleaning, and the same overall volumes are used for both grey components, differences are related to concentrations in residual water. Phosphates showed higher concentrations in the dry season and total nitrogen showed the highest value during the rainy period. In this manner, the contribution of both grey water components to the total water footprint ranged between 0.2% and 5.4% for phosphates and between 2.6% and 11.0% for total nitrogen. The highest value obtained for grey water footprint was total nitrogen in September, due to the presence of manure in the water of the third sedimentation tank.

Both dry and rainy seasons are important to consider for the administration of the water resource, and according to the obtained results, water footprint is affected by each one of them. For the dry season, the average total water footprint obtained was 1126.33 and 1122.64 L/Kg FPCM for phosphates and total nitrogen respectively; meanwhile, for the rainy season, the water footprint was lower, with values of 969.41 and 989.50 L/kg FPCM, respectively. These results show the same pattern that was obtained in the study done in the La Villa River basin in Panama, where water footprint from dairy farms with different technological levels was studied during dry and rainy season, being the latter with the lowest values. For the dry season the values ranged from 951.31 to 1082.96 L L^{-1} of milk; meanwhile, for rainy season, the values ranged from 692.93 to 1021.39 L L^{-1} of milk (Muñoz-Quintero, 2014).

Another aspect to which the difference in water intake between dry and rainy seasons might be attributed as well is the feeding composition given to the animals. During the dry season most of the feed consisted of forage sorghum silage and grains with minerals; meanwhile, during the rainy season, it consisted of fresh harvested grass and forage sorghum mixed with grains and minerals. Also, the ration differed between months during the period of study, potentially impacting on water intake; however, considering the data recollected in this herein study and the lack of other studies that contemplate this aspect, it is considered that further studies should be carried out to fully comprehend the relationship between feed composition and cattle water intake, and its impact on the water footprint.

Analyzing the overall water footprint in the studied productive system during 2021, the calculated values were 1025.08 and 1034.14 L/kg FCPM for phosphates and total nitrogen, respectively (see Figure 4 for percentual contributions). These results were similar to the value determined by Mekonnen and Hoekstra (2010), of about 1020 L of water required. Studies from Brazil have presented similar values, such the case of a conventional and organic milk production systems of dairy cattle, where for nitrates 962 and 808 L/kg ECM were obtained respectively, and for phosphorus, the conventional system generated 1422 L/kg per energy corrected milk (ECM); meanwhile, for the organic system was 1510 L/kg ECM. In both cases, WF_{green} was the main component of the overall water footprint. Its contribution represented 62.2% and 46.5% for conventional and the organic system considering phosphorus as the pollutant, and 91.9% and 87% respectively in case of nitrates (Palhares and Pezzopane, 2015).



(a) phosphates (b) total nitrogen for 2021

Figure 4 Composition of the total water footprint

Based on the results obtained and the characteristics of the dairy production module in this study, the most notable ways for reducing water consumption and therefore the overall water footprint at farm level are a) improving the irrigation system, which contemplates addressing the leaks in the hoses, and b) using shovels more frequently or other similar tools for collecting most manure instead of using water (Paniagua-Madrigal, 2006). The water used for cleaning the areas of the studied dairy production module herein was obtained from the Chiquito river; however, a way to reduce its extraction from this water body and help the sustainability of the environment, is the use of rainwater (Fundecooperación para el Desarrollo Sostenible and Fondo Multilateral de Inversiones, 2020). This alternative water resource can also be used for the hydration of the cattle, helping in the reduction of costs associated to the drinking water provided by the Costa Rican Institute of Aqueducts and Sewers (AYA, abbreviation in Spanish).

Finally, this study has shown that the water footprint is a valuable tool for analyzing water consumption at the farm level, and when determined on a monthly basis, it allows the identification of periods of high-water consumption, which can inform irrigation scheduling and water-saving strategies. However, it is necessary to mention some limitations, this includes: i) since the results are based on a single year of observation, temporal variations across multiple years could influence the water footprint values; ii) for the calculation of the water footprint we need precise climatic and production data, which may not be readily available for all farms; and iii) the green water footprint component requires the knowledge for the calculation of evapotranspiration and the processing of climatic data, which can be a technical limitation for the majority of dairy producer in Costa Rica. Additionally, it is important to note the necessity to know how to manipulate and process these climatic databases to obtain the required information, since most of the time it is provided in a raw and unprocessed form. Also, usually, climatic data has an associated cost, which can be obtained by purchasing it from institutions such as the National Meteorological Institute (IMN, abbreviation in Spanish). In best case scenario, if there is already a weather station installed on site, an agreement could be reached with its owner to provide the data.

4 Conclusions

The present study calculated the first water footprint for a productive system of milk in Costa Rica, a starting point for determining the consumption of water in this type of systems around the country and the Central American region.

The highest observed values of the monthly water footprint of 1226.75 L/kg FCPM (considering phosphates) and 1219.87 L/kg FCPM (considering total nitrogen) corresponded to the dry season (December through April) due to the higher water consumption associated with irrigation of fields.

The calculation of water footprints on a monthly basis is necessary for finer analyses of temporal variability, as it allows the identification of those months when the intensity of resource usage peaks high or low. A yearly value, the most common metric calculated in similar studies, does not allow the identification of temporal patterns within calendar years.

Further studies that contemplate the feed composition given to the cattle and their water intake need to be carried out to understand their relationship and how they impact the water footprint.

Studies that contemplate climate factors in conjunction with variables such as temperature-humidity indexes need to be carried out as well along with water footprint analysis, to have a broader understanding of the factors that influence water intake of dairy cattle through the year, and therefore its impact on the WF_{blue}.

The implementation of actions such as using a shovel or a similar tool to collect most manure is recommended to reduce water consumption. The current use of hoses for cleaning both solid and liquid waste in both the waiting/staging area as well as in the milking parlor has an impact increasing the water footprint of the productive system.

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