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Water Performance Indicators and Benchmarks for Dairy Production Systems †

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† OECD disclaimer: The opinions expressed and arguments employed in this publication are the sole responsibility of the authors and do not necessarily reflect those of the OECD or of the governments of its member countries.

Abstract: The aim of the study is to discern benchmarks for the indicators L water cow^{-1} day^{-1} and L water kg milk^{-1} day^{-1} per type of production system and season. A total of 876 commercial dairy farms underwent comprehensive water consumption monitoring from January 2021 to December 2022. The monitored water consumptions were animal drinking water and water usage for cleaning. Confined systems exhibited the highest average for animal drinking and cleaning, 87.5 L water cow^{-1} day^{-1} and 84.4 L water cow^{-1} day^{-1}, respectively. Semi-confined systems presented the lowest average for animal drinking, 54.4 L water cow^{-1} day^{-1}. Pasture systems showed the lowest average for cleaning, 45.2 L water cow^{-1} day^{-1}. The benchmarks proposed in this study can serve as the first references for animal drinking and milking parlor washing consumption for production systems in tropical conditions.

Keywords: confined; drinking; pasture; semi-confined; washing parlor

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Citation: Palhares, J.C.P.; Matarim, D.L.; de Sousa, R.V.; Martello, L.S. Water Performance Indicators and Benchmarks for Dairy Production Systems. *Water* **2024**, *16*, 330. https://doi.org/10.3390/w16020330

Academic Editor: Didier Orange

Received: 6 December 2023
Revised: 5 January 2024
Accepted: 10 January 2024
Published: 19 January 2024

1. Introduction

The water crisis stands out as one of the ten most significant risks facing humanity in the coming years, as identified by the World Economic Forum [1]. Projections from the Organization for Economic Co-operation and Development [2] and the Food and Agriculture Organization [3] suggest that between 40% and 66% of the world's population will experience water-stressed conditions by 2025.

In the agricultural sector, the livestock industry is a substantial consumer, utilizing 20% of the total water allocation [3]. From a global perspective, the dairy sector accounts for 18.1% of the overall consumptive water usage [4]. Shine et al. [5] emphasize that the production of milk and dairy products on a global scale must be conducted with careful consideration of water consumption.

As the fifth-largest milk producer globally [6], Brazil saw its livestock production accounting for 11.6% of the total water consumption in 2019 [7]. The Brazilian National Water Agency [7] has projected a risk of economic losses in livestock production amounting to 44.57 billion Brazilian Real by 2035 due to water availability constraints.

Water usage emerges as arguably the most critical resource challenge confronting dairy production, both currently and in the future [8]. The assessment of water resources in animal husbandry by Yu et al. [9] facilitates an enhanced understanding of the dynamics between water supply and demand. Bica et al. [10] assert that water, often the most economical nutrient in various production systems, tends to be consistently undervalued in its allocation to cattle. Shine et al. [11] highlight a significant gap in research, indicating a lack of substantial work to date on attributing the overall direct water utilization (including drinking, parlor activities, and miscellaneous purposes) on dairy farms. Palhares and Pezzopane [12] underscore one of the primary challenges in milk production, which is the limited awareness concerning the management of freshwater resources.

Accurately measuring the water requirements for various procedures on a dairy farm is crucial. Ajiero and Campbell [13] highlight that while water is essential for the majority of dairy farm processes, factors such as rising water costs, stricter regulatory regimes, and the high energy expenses associated with water pumping and processing underscore the growing importance of optimizing water use on dairy farms.

Spencer et al. [14] emphasize the need to understand water requirements for livestock, proposing a well-structured survey as a valuable tool for creating benchmarking indicators related to water use in dairy systems. Farooq and Shahid [15], along with Al-Bahouh et al. [16], stress the importance of quantifying on-farm water use and comprehending water usage patterns in different production setups. This understanding can identify management practices for efficient water use.

Establishing benchmarks for on-farm dairy water use could incentivize farms to surpass these standards, fostering the adoption of best water practices. Ajiero and Campbell [13] suggest that benchmarks can enhance water performance at a relatively low cost. Ultimately, benchmarking aims to improve performance through comparisons and the adoption of established best practices. Palhares et al. [17] argue that a detailed understanding of livestock water use and efficiency can promote the internalization of water management within the sector. Marston et al. [18] highlight the appeal of the benchmarking approach, which is not prescriptive in terms of practices or technologies, offering flexibility in reducing water consumption.

In order to appraise the water management practices of dairy farms, this study conducts an assessment of water efficiency indicators, with specific focus on production systems and utilization during the wet and dry seasons. The primary objective is to discern benchmarks that can serve as informative metrics for the development of programs and policies geared towards optimizing water efficiency in dairy farming. Additionally, this study aims to address the existing research gap by specifically examining water utilization on dairy farms in tropical regions, exemplified by the case study of Brazil.

2. Materials and Methods

In early 2020, Embrapa Pecuaria Sudeste initiated the Water Management in Dairy Farms program in Brazil, in collaboration with the private sector. The initial phase of the project involved the invitation of dairy farmers to install water meters to quantify various processes involved in two types of water consumption on their farms.

With the consent of each participating farmer, a total of 876 commercial dairy farms underwent comprehensive water consumption monitoring from January 2021 to December 2022. The monitoring utilized continuous flow analog water meters, specifically installed to measure two distinct water consumptions: animal drinking and water usage for cleaning purposes (including milking parlors, waiting corrals, milking rooms, and milk tanks). This included 314 farms for the former and 562 for the latter. As highlighted by Usva et al. [19], drinking water for dairy cattle and washing water in farming operations constitute pivotal factors contributing to total consumptive water use.

The farms were categorized based on their production system into pasture-based, semi-confined, and confined systems. Monthly data were systematically recorded through an online platform, with farmers personally reading each installed meter and inputting the relevant data into the system. The information gathered encompassed water consumption per water meter, the average number of milking cows, and milk yield.

2.1. Water Use Indicators and Benchmarks

Metric benchmarks involve the evaluation of quantitative (numeric) information related to an activity, originating from the need to gauge the performance indicators associated with human activities. According to Alegre et al. [20], performance indicators constitute measures assessing the efficiency and effectiveness of data elements collected from the field, which can be merged into processing rules to delineate performance.

This study focuses on two performance indicators: liters of water per lactating cow (L water cow^{-1} day^{-1}) and liters of water per liter of milk (L water kg milk^{-1} day^{-1}). The utilization of normalized data, expressed per unit of product, is deemed the most effective approach for evaluating the volumetric use of freshwater resources.

Kingdom [21] underscores the importance of noting that while metric benchmarking is very useful for analyzing quantitative data, it comes with significant challenges. Cabrera Jr. et al. [22] elaborate on these challenges, which include the difficulty with identifying comparable systems or suitable performance indicators in the units of collected data. It should be acknowledged that these challenges were successfully addressed in this study, as the performance indicators were measured in comparable dairy systems using the same units and time parameters. This approach adopts the perspective that the same dairy system operating within identical contexts, recognizing variables such as climate, animal management, and the quality of workers, will influence differences in water usage.

2.2. Data Analysis

The database comprised 1863 records of producers from four states in Brazil (Sao Paulo, Minas Gerais, Goias, Parana), covering the years 2021 and 2022. The Knowledge Discovery in Databases (KDD) process [23] was implemented, encompassing the extraction of data from spreadsheets generated by the online system and subsequent data preprocessing. These steps aim to assess data quality by identifying missing or inconsistent data and preparing the data for subsequent data mining processes, which involve the application of supervised and unsupervised learning algorithms to extract information and generate classifier or predictor models. The nine criteria outlined in Table 1 were established for preprocessing, resulting in the exclusion of potential outliers.

Table 1. Boundary conditions for outlier exclusion.

Criteria	Boundary Condition
I	Records with missing (blank) information
II	Farm information with fewer than 10 lactating cows
III	Water consumption records measured at meter reading intervals exceeding 90 days
IV	Water consumption information below 10 L per animal per day
V	Observations from farms with daily milk production less than 200 L
VI	Annotations of water consumption per cow per day less than 1 L
VII	Values of the indicator L water kg milk^{-1} day^{-1} less than 1
VIII	Annotations of milk production per cow per day less than 10 L
IX	Farm information with fewer than four water meter readings

The filtered data underwent analysis using descriptive statistics, incorporating parameters such as mean, median, standard deviation, coefficient of variation, as well as minimum and maximum values. Our statistical analyses were stratified based on water use category, season, and production system. Descriptive analyses were conducted for all variables. The statistical procedures were executed using SAS 9.4 (SAS Institute Inc., Cary, NC, USA).

In the final step following the KDD process, the data underwent transformation. Information regarding the collection month was aggregated into seasons, classifying data collected from October to March as the Wet Season and data from April to September as the Dry Season. Additionally, quartiles (Q1, Q2, Q3 and Q4) were established for the two calculated indicators to set benchmarks during the transformation. Target benchmarks for each water consumption were determined based on water performance indicators achieved by those surpassing the median, utilizing the median as the base indicator (quartiles). Farms with performance indicators above the median were categorized as 'poor', those falling between the median and the 25th percentile limits were labeled ‘regular’, while those below the 25th percentile limits were classified as ‘excellent’.

3. Results and Discussion

The utilization of descriptive data in this study is crucial for assessing water consumption, providing a more detailed representation of the results. In the environmental field, where small numerical differences can have significant implications, descriptive analysis stands out as a more sensitive approach to capture important nuances. Concerning water resource conservation, a numerical discrepancy can have practical and environmental relevance.

3.1. Productive Farm Data Aspects

Tables S1 and S2 (Supplementary Material) present descriptive analyses of productive aspects categorized by the type of consumption, production system, and season. Considering both types of consumption (Tables S1 and S2), the confined system exhibited the highest averages of lactating cows per farm for both seasons, while the pasture system showed the lowest averages. Regarding animal drinking consumption, the confined system’s wet season average was 21.5% higher than in the semi-confined system and 64% higher than in the pasture system. The confined dry season average was 2.1% and 80.9% higher than the semi-confined and pasture systems, respectively.

Regarding cleaning consumption, irrespective of the production system, the dry season exhibited higher averages of lactating cows compared to the wet season. However, for animal drinking consumption, this trend was only observed in semi-confined and confined systems. The higher average number of cows during the wet season for animal drinking consumption in the pasture system may result from the increased utilization of pasture as feed, given its limited availability during the dry season.

According to the Brazilian Institute of Geography and Statistics [24], the average daily cow milk yield in Brazil is reported to be 7.0 kg. Tables S3 and S4 (Supplementary Material) present descriptive statistical variables for kg milk cow day^{-1}, categorized by season and production system, for each type of consumption.

The confined system exhibited the highest daily averages of cow milk yield in the dry season, with values of 24.4 kg milk cow^{-1} day^{-1} for animal drinking and 22.8 kg milk cow^{-1} day^{-1} for cleaning consumption. In the semi-confined system, the daily cow milk yield was nearly identical for both seasons in animal drinking consumption (15.6 kg milk cow^{-1} day^{-1}, wet; 15.7 kg milk cow^{-1} day^{-1}, dry), and 0.3 kg milk cow^{-1} day^{-1} lower in the dry season than the wet season for cleaning consumption. The pasture system demonstrated daily cow milk yields of 18.2 kg milk cow^{-1} day^{-1} in the wet season and 17.5 kg milk cow^{-1} day^{-1} in the dry season for animal drinking consumption. For cleaning consumption, these averages were 13.8 kg milk cow^{-1} day^{-1} in the wet season and 14.2 kg milk cow^{-1} day^{-1} in the dry season.

As production systems become more intensified, higher levels of productive efficiency (kg milk cow^{-1} day^{-1}) are anticipated. This increased efficiency resulting from intensification is attributed to various productive aspects, including improved nutritional management, enhanced sanitary control, better welfare conditions, and greater training of the workforce. The relationship between intensification and productive efficiency is evident for cleaning consumption, where the averages for the confined system surpass those of the other two systems and are higher for the semi-confined system, than for pasture (Table S4). However, animal drinking consumption shows higher averages in pasture than in the semi-confined system (Table S3). To understand this discrepancy, further investigation into the specific productive aspects of each farm within the pasture and semi-confined groups would be necessary.

High dispersions are expected in studies involving data from commercial farms, as these represent diverse environmental conditions, production management practices, and workforce qualities. The indicators of milk production and the number of lactating cows can still be influenced by the dry and rainy seasons.

3.2. Water Consumption—Animal Drinking

There are significant variations in the water intake of dairy cattle across different production systems and milk yield levels, with limited research supporting current water use estimates. Singh et al. [25] highlight that water intake in dairy cattle may be influenced by factors such as breeds, age, properties of feeds, water qualities, and quantities, as well as management practices associated with watering animals. Due to the impact of these factors, more research on a country-wide basis is warranted to recommend water supply practices for dairy animals.

Table 2 shows descriptive statistical variables for the indicator L water cow^{-1} day^{-1}. The confined system showed the highest averages for the indicator L water cow^{-1} day^{-1}, with values of 87.5 L in the wet season and 80.6 L in the dry season. The lowest averages were observed in the semi-confined system, with 58.4 L and 59.1 L cow^{-1} day^{-1} in the wet and dry seasons, respectively. The pasture system presented intermediate averages, with 67.8 L and 65.9 L water cow^{-1} day^{-1} in the wet and dry seasons, respectively. Animal drinking water consumption values found in the literature align with the values obtained in this study, for example 70.3 L water animal^{-1} day^{-1} [26], 81.5 L water animal^{-1} day^{-1} [27], 77.2 L water animal^{-1} day^{-1} [28], and 78.4 L water animal^{-1} day^{-1} [29]. Al-Bahouh et al. [16] calculated the drinking water consumption for lactating cows in a confined system as 94 L water animal^{-1} day^{-1} while Kraub et al. [30] reported that cows consumed 54.4 L cow^{-1} on average for a milk yield of 25.4 kg cow^{-1} day^{-1}. Palhares et al. [17] evaluated the influence of crude protein content on the drinking water consumption of cows on pasture. Animals with a higher percentage of crude protein in the ration had higher daily water consumption (83.3 L animal^{-1} day^{-1}) than those with a lower percentage (80.4 L animal^{-1} day^{-1}).

Table 2. Descriptive statistical variables for L water cow^{-1} day^{-1}, per season and production system, for the animal drinking consumption.

Water Consumption—Pasture System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	27	67.8	63.8	27.5	40.6	119.8	24.3
Dry season	33	65.9	66.2	26.2	39.7	107.7	23.3
Water Consumption—Semi-Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	56	58.4	50.3	26.9	46.0	119.4	21.4
Dry season	76	59.1	49.9	29.2	49.5	119.8	15.8
Water Consumption—Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	54	87.5	87.9	16.9	19.4	116.2	37.9
Dry season	68	80.7	80.9	16.6	20.6	114.1	26.9

Notes: n—number of records; SD—standard deviation; CV—coefficient of variation; Max.—Maximum; Min.—Minimum.

The coefficient of variation values were lower for the confined system (19.4% and 20.6% for the wet and dry seasons, respectively) and higher for the other two systems (Table 2).

Variations in drinking water requirements are inevitable as they are influenced by various productive and environmental aspects. Studies indicate that the daily drinking water intake of cows depends on productive factors (milk yield, live weight, dry matter content of the feed, dry matter intake, sodium intake, days in milk, etc.) as well as climatic factors (rainfall, temperature, wind speed, etc.) [31–33].

The indicator water consumption per lactating cow per day showed a direct and increasing relationship with the indicator milk yield per cow per day. The confined system demonstrated the highest daily cow milk yield for both seasons, followed by the pasture and semi-confined systems. Observing the maximum values of the indicator L water cow^{-1} day^{-1} for the three production systems (Table 2), the highest maximum values for both seasons were noted in the semi-confined system.

A relationship is also expected between water consumption and the seasons, as climatic variables such as temperature influence the animals' daily water intake. According to Novelli et al. [34], under high temperatures, cattle exhibit increased water intake as a strategy to reduce heat and regulate body temperature. Given that the wet season typically has higher average temperatures, it is anticipated that animals, particularly in the pasture and semi-confined systems, would demonstrate the highest water consumption due to increased exposure to climate variations. This observation was true for the pasture and confined systems, where the dry season average was lower than that of the wet season. However, this behavior was not observed in the semi-confined system, where the season averages showed the opposite pattern.

A direct relationship was identified between the number of lactating cows, milk yield, and animal drinking water consumption. The confined system, which exhibited the highest daily animal water consumption, also had higher numbers of lactating cows and higher milk yields. Therefore, in the process of intensifying milk production, it is crucial to consider that animals will likely have a higher daily water consumption. Prior to intensifying the production system, critical questions should be addressed, such as whether the farm possesses adequate water resources to support intensification and whether greater daily water consumption poses a threat to both the farm and the water security of the river basin.

Productive intensification may be associated with increased efficiency in terms of the indicator L water kg milk^{-1} day^{-1}. The results of this study indicated that this relationship depends on the water indicator used in the analysis. When assessing water consumption per cow per day (Table 2), it can be seen that the confinement system showed higher water expenditure for both seasons. However, when evaluating the usage through water efficiency, i.e., water consumption per kilogram of milk (Table 3), the confined system during the wet season demonstrated a similar performance to the pasture system (3.8 L water kg milk^{-1} day^{-1} for both) and a better performance than the semi-confined system (3.9 L water kg milk^{-1} day^{-1}). During the dry season, the confined system showed better efficiency compared to the other systems, while the semi-confined system showed lower efficiency (4.1 L water kg milk^{-1} day^{-1}) compared to the pasture system (3.9 L water kg milk^{-1} day^{-1}).

3.3. Water Consumption—Washing Milking Parlor

The confined system showed the highest averages for washing the milking parlor in both seasons, with values of 70.3 and 84.4 L water cow^{-1} day^{-1} for the wet and dry seasons, respectively. In the wet season, the pasture system showed a lower average compared to the semi-confined system, but this trend was reversed in the dry season (Table 4). Manazza [35] emphasized that the milk productivity gains in large-scale systems (meaning 24 kg milk cow^{-1} day^{-1}) did not offset the higher volume of water used in the milking parlor routine, resulting in the highest relative values of water per liter of milk (exceeding 5 L water kg milk^{-1} day^{-1}).

The standard deviation and coefficient of variation values for this indicator are exceptionally high across all production systems and seasons, resulting in minimum values of 10.5 L water cow^{-1} day^{-1} (semi-confined in the dry season) and maximum values reaching 531 L water cow^{-1} day^{-1} for the same system and season. Published studies also confirm this considerable variability.

Table 3. Descriptive statistical variables for L water kg milk^{-1} day^{-1}, per season and production system, for animal drinking consumption.

Water Consumption—Pasture System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	27	3.8	3.2	1.7	43.6	6.9	1.5
Dry season	33	3.9	3.8	1.9	47.9	7.6	1.2
Water Consumption—Semi-Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	56	3.9	3.8	2.0	50.8	8.9	1.2
Dry season	76	4.1	3.2	2.6	63.6	10.8	1.1
Water Consumption—Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	54	3.8	3.8	0.9	25.5	6.2	2.0
Dry season	68	3.5	3.4	0.9	28.8	6.7	1.3

Notes: n—number of records; SD—standard deviation; CV—coefficient of variation; Max.—Maximum; Min.—Minimum.

Table 4. Descriptive statistical variables for L water cow^{-1} day^{-1}, per season and production system, for cleaning consumption.

Water Consumption—Pasture System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	55	45.2	25.8	40.1	88.8	198.1	11.2
Dry season	66	61.6	38.7	59.0	95.9	212.4	10.8
Water Consumption—Semi-Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	167	50.3	33.5	41.1	81.8	319.7	12.9
Dry season	182	56.4	33.8	60.0	106.4	531.3	10.5
Water Consumption—Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	42	70.3	35.3	76.1	108.2	273.4	19.8
Dry season	50	84.4	47.1	78.8	93.4	254.3	18.6

Notes: n—number of records; SD—standard deviation; CV—coefficient of variation; Max.—Maximum; Min.—Minimum.

Thomson et al. [36] assumed wash water for lactating dairy cows to be 25 L water cow^{-1} day^{-1}. Bray et al. [37] indicated that cleaning the milking parlor could represent a consumption of 23 L day^{-1} but could reach up to 114 L day^{-1} in certain dairies. Kraub et al. [30] reported the use of 33.8 L water cow^{-1} day^{-1} for cleaning, when applying high-pressure cleaners and hoses with large diameters. A Canadian study found that 246 L cow^{-1} water was used daily for on-farm activities at dairy farms on average [16]. The estimated wash water generated was 58.0 L cow^{-1} day^{-1} [38]. Gordeev et al. [39] reported an average consumption of 15.6 L cow^{-1} day^{-1} for cleaning a milking parlor with high-pressure washers. Le Riche et al. [40] observed 22.9 L cow^{-1} day^{-1} for floor washing with a hose. Gutierrez et al. [41] documented a consumption range of 55–60 L cow^{-1} day^{-1} in an experimental farm, and monitoring the same use in five commercial farms showed a variation from 22–76 L cow^{-1} day^{-1}. Farooq and Shahid [15] monitored water consumption at Pakistani commercial dairy farms, with values ranging from 500–924 L water cow^{-1} day^{-1}.

The variability in washing the milking parlor is not standardized between different dairy farms and is influenced by various factors such as the architecture of the milking parlor and waiting corral, type of milking machine, waiting time for animals, floor conditions, floor scraping practices before washing, use of pressurized water, washing systems (hose or flushing), and labor training for this management. Therefore, the high variability of the indicator can be considered intrinsic to this type of management. Harner et al. [42] and Janni et al. [43] reported water use on 14 dairy farms in Minnesota ranging from 8.6–35.3 L cow^{-1} d^{-1}, with variations from 140–400% due to factors such as animal performance and weather conditions.

The significant variability in washing parlor consumption does not necessarily imply water inefficiency on farms for this management. For example, if the median for the confined system in the dry season is 47.1 L water cow^{-1} day^{-1}, a farm using 254.3 L water cow^{-1} day^{-1} has the opportunity to significantly reduce water usage, even considering its specific production characteristics. There is potential for substantial water savings on farms, depending on the water intensities of the processes applied. Based on the results, it can be inferred that farms with poor performance have greater potential for water savings.

The possibility that the high variability observed for the indicator in the current study may be linked to declarative inconsistencies in the types of consumption recorded by the water meter cannot be disregarded.

For all production systems, the means and medians in the dry season were higher than those in the wet season. Al-Bahouh et al. [44] observed that water used in washing the milking parlor in confined dairy farms was 58.9 L cow^{-1} day^{-1}, ranging from 57.5 in the summer to 60.9 in the winter.

The use of water to wash the milking parlor is a type of consumption that is greatly influenced by the workforce. If the operator is not educated and trained to carry out this management, there is a tendency to use more water than necessary. The importance of the human factor and daily management is emphasized by Jennerich et al. [45] as the variables with the greatest impact on water consumption on dairy farms. The authors concluded that proposing indicators to monitor them can lead to better water practices and improved water efficiency.

The indicator averages for washing parlor use are similar to those of animal drinking (Tables 3 and 5). The highest and lowest averages were found for the pasture system, with 3.3 L water kg milk^{-1} day^{-1} in the wet season and 4.5 L water kg milk^{-1} day^{-1} in the dry season. The semi-confined system exhibited 3.5 L water kg milk^{-1} day^{-1} in the wet season and 4.0 L water kg milk^{-1} day^{-1} in the dry season. Similar to the indicator L water cow^{-1} day^{-1}, the coefficient of variation was also high for all production systems and seasons, indicating the inherent variability in this type of consumption.

Table 5. Descriptive statistical variables for L water kg milk^{-1} day^{-1}, per season and production system, for cleaning consumption.

Water Consumption—Pasture System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	55	3.3	2.3	2.9	89.1	15.2	1.0
Dry season	66	4.5	2.6	4.5	99.1	18.3	1.0
Water Consumption—Semi-Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	167	3.5	2.3	3.4	97.9	28.5	1.0
Dry season	182	4.0	2.3	5.5	135.8	51.5	1.0
Water Consumption—Confined System							
Season	n	Average	Median	SD	CV (%)	Max.	Min.
Wet season	42	4.1	1.8	5.2	126.9	21.8	1.1
Dry season	50	3.9	1.9	4.1	101.2	13.3	1.0

Notes: n—number of records; SD—standard deviation; CV—coefficient of variation; Max.—Maximum; Min.—Minimum.

Miglierina et al. [46] reported that the volume of water consumed per kilogram of milk produced was 1.9. Holter and Urban [26] suggested a level of 2.0 L drinking water per kg of milk, while Krauß et al. [30] reported 0.9 L water kg^{-1} of milk. When comparing the values from these studies with our average values, it is clear that our values are almost double those cited. However, if we compare them with our median values, these are very similar to the values mentioned.

3.4. Benchmarking Water Consumption—Quartile-Based Approach

Table 6 presents benchmark values per quartile for the indicator L water cow^{-1} day^{-1}. The confined system exhibited the highest benchmarks for animal drinking consumption in both seasons and quartiles, with 90.9 L water cow^{-1} day^{-1} in the dry season and 98.7 L water cow^{-1} day^{-1} in the wet season. The pasture system showed intermediate values, ranging from 40.8 L water cow^{-1} day^{-1} (dry season first quartile) to 87.7 L water cow^{-1} day^{-1} (wet season third quartile). The semi-confined system had the lowest values, ranging from 37.2 L water cow^{-1} day^{-1} (wet season first quartile) to 77.9 L water cow^{-1} day^{-1} (dry season third quartile).

Table 6. Benchmark values per quartiles to the indicator L water cow^{-1} day^{-1}, per water consumption, season, and production system.

Animal Drinking Consumption				
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Wet Season	Q1	48.9	37.2	79.5
	Q2	63.8	50.3	87.9
	Q3	87.7	76.0	98.7
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Dry Season	Q1	40.8	39.6	72.2
	Q2	66.2	49.9	80.9
	Q3	86.4	77.9	90.9
Cleaning Consumption				
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Wet Season	Q1	17.7	25.4	23.6
	Q2	25.8	33.5	35.3
	Q3	53.5	60.1	63.8
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Dry Season	Q1	20.6	22.9	32.1
	Q2	38.7	33.8	47.1
	Q3	61.9	67.0	94.2

The gains in water efficiency between the third and first quartiles for pasture, semi-confined, and confined systems in the wet season were 44%, 51%, and 19.4%, respectively. In the dry season, these gains were 52.7%, 49%, and 20.5%, respectively. It is clear that the most significant efficiency gains between what we classify as excellent and poor conditions occur in the pasture and semi-confined systems, with the smallest gains seen in the confined system. This is attributed to the fact that animals in the confined system are less exposed to climatic variations, and there is greater control over dry matter intake, both of which are determining factors in an animal's daily water consumption. Consequently, a lower interquartile distance between the first and third quartiles was expected for the confined system.

Considering the average number of lactating cows per day in the pasture, semi-confined, and confined systems of 46, 70, and 80, respectively, and applying the values of the first quartile for the wet season, the total daily consumption would be 2.25 m^3 day, 2.60 m^3 day, and 6.36 m^3 day, respectively. For the third quartile, consumption would be

4.0 m^3 day, 5.32 m^3 day, and 7.90 m^3 day, respectively. Therefore, the gain in water efficiency between the first and third quartile would represent daily water savings of 1.75 m^3 day, 2.72 m^3 day, and 1.54 m^3 day for pasture, semi-confined, and confined systems, respectively.

It is known that animals have a daily demand for water, which is primarily regulated by climatic variables and the composition of their diet. Climatic variables can be managed by providing shade to the animals (pasture and semi-confined systems), installing cooling systems in the sheds and milking parlors, and selecting more adapted genetics. In the composition of their diet, the correct balance must be taken into account, respecting the daily requirements of the herd. Therefore, even for animal drinking consumption, which has physiological specificities of the animal, it is possible to promote efficiency gains.

Benchmark values per quartile for the indicator L water cow^{-1} day^{-1} for cleaning consumption are show in Table 6. The dry season exhibited the highest values for the indicator in all quartiles. A minimum value of 20.6 L water cow^{-1} day^{-1} was observed in the first quartile for the pasture system, while the maximum value was 94.2 L water cow^{-1} day^{-1} in the third quartile for the confined system. In the wet season, the minimum and maximum values were 17.7 L water cow^{-1} day^{-1} (pasture system, first quartile) and 63.8 L water cow^{-1} day^{-1} (confined system, third quartile), respectively.

As mentioned earlier, this type of water use is influenced by the quality of the workforce, as observed from the interquartile distance between the values of the third and first quartiles in all production systems. For example, in the confined system in the wet season, it is possible to have an excellent water consumption condition, which means a consumption of 23.6 L water cow^{-1} day^{-1}. If the condition is poor, this will mean 40.2 L more water used per animal per day, or 1.7 times the consumption for the excellent condition. In the case of the semi-confined system in the dry season, the excellent benchmark represented a daily consumption of 22.9 L water cow^{-1} day^{-1}, while this was 67.0 L water cow^{-1} day^{-1} in the poor condition, resulting in water savings of 44.1 L water cow^{-1} day^{-1} between the first and third quartile, almost double the value of the excellent benchmark.

The benchmark values for washing the milking parlor demonstrate the potential for achieving significant gains in water efficiency through structural and management changes. Continuous training of the workforce is essential, and promoting learning from experiences is encouraged.

Table 7 shows benchmark values per quartile for the indicator L water kg $milk^{-1}$ day^{-1}, representing animal drinking consumption. In the wet season, the third quartile value was consistent for both pasture and semi-confined systems, at a level of 5.4 L water kg $milk^{-1}$ day^{-1}, while it was lower in the confined system, with a result of 4.4 L water kg $milk^{-1}$ day^{-1}. The lowest value in the first quartile was observed in the semi-confined system, at 2.2 L water kg $milk^{-1}$ day^{-1}. In the dry season, the confined system also presented the lowest value for the third quartile, with 4.1 L water kg $milk^{-1}$ day^{-1}, but the lowest value for the first quartile was observed in the pasture system, with a result of 2.1 L water kg $milk^{-1}$ day^{-1}.

Paul and Clark [47] recommend an additional water intake of five to seven liters, beyond maintenance needs, for each kilogram of milk produced. In our study, the maximum value observed was 5.4 L water kg $milk^{-1}$ day^{-1}. The variation between studies can be attributed to differences in productive and environmental aspects.

Table 7 also presents benchmark values per quartile for the indicator L water kg $milk^{-1}$ day^{-1}, specifically for cleaning consumption. The highest values for this indicator were observed in the semi-confined system in the third quartile for both seasons, with values of 4.1 L water kg $milk^{-1}$ day^{-1} in the wet season and 4.8 L water kg $milk^{-1}$ day^{-1} in the dry season. The lowest value was 1.3 L water kg $milk^{-1}$ day^{-1} for pasture in the wet season and confined in both the wet and dry seasons.

Table 7. Benchmark values for quartiles of the L water kg milk^{-1} day^{-1}, per water consumption, season, and production system.

Animal Drinking Consumption				
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Wet Season	Q1	2.7	2.2	3.3
	Q2	3.2	3.8	3.8
	Q3	5.4	5.4	4.4
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Dry Season	Q1	2.1	2.5	2.8
	Q2	3.8	3.2	3.4
	Q3	5.4	4.9	4.1
Cleaning Consumption				
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Wet Season	Q1	1.3	1.6	1.3
	Q2	2.3	2.3	1.8
	Q3	3.9	4.1	2.5
Season	Quartile	Pasture System	Semi-Confined System	Confined System
Dry Season	Q1	1.4	1.5	1.3
	Q2	2.6	2.3	1.9
	Q3	4.3	4.8	3.5

Higham et al. [38] conducted a study monitoring and analyzing 35 pasture-based dairy farms in New Zealand, calculating a parlor water usage value of 3.9 L water kg milk^{-1} day^{-1}. Our study found a similar value for the 25% classified as poor in the wet season and a slightly higher value (4.3 L water kg milk^{-1} day^{-1}) in the dry season. However, our results demonstrate that it is possible to produce the same volume of milk in kilograms in the pasture system while consuming only 1.3 L of water per day^{-1}. Therefore, this serves as the efficiency indicator to be achieved.

Introducing structural changes to milking parlors and implementing management practices in the 25% classified as poor could elevate them to the values of the 25% classified as excellent. This would result in savings of 2.6, 2.5, and 1.2 L water kg milk^{-1} day^{-1} for the pasture, semi-confined, and confined systems, respectively, in the wet season. In dry conditions, these savings would amount to 2.9, 3.3, and 2.2 L water kg milk^{-1} day^{-1} for the pasture, semi-confined, and confined systems, respectively.

4. Conclusions

This paper assessed water use efficiency indicators, namely L water lactating cow^{-1} day^{-1} and L water kg milk^{-1} day^{-1}, and identified benchmarks based on different types of production dairy systems and water uses (specifically, animal drinking and milking parlor cleaning). The evaluation included 876 Brazilian dairy farms, categorized as pasture-based, semi-confined, and confined systems.

The benchmarks showed a wide range between the quartiles, mainly for the pasture and semi-confined systems. These ranges are the result of productive (animal breeding, milking architecture, type of diet, etc.), environmental (climatic characteristics) and social (labor training) aspects. As these aspects have a greater control pattern in the confined system, the distance between the quartiles is smaller.

The benchmarks proposed in this study can serve as the first references for animal drinking, milking, and washing consumption for production systems in tropical conditions.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/w16020330/s1, Table S1: Descriptive statistical variables for the number of lactating cows per season and production system, monitored for the animal drinking consumption; Table S2: Descriptive statistical variables for the number of lactating cows per season and production system, monitored for cleaning consumption; Table S3: Descriptive statistical variables for kg milk cow day^{-1}, per season and production system, monitored for the animal drinking consumption; Table S4: Descriptive statistical variables for kg milk cow day^{-1}, per season and production system, monitored for cleaning consumption.

Author Contributions: Conceptualization, J.C.P.P.; Methodology, J.C.P.P.; Resources: J.C.P.P.; Software, L.S.M., D.L.M. and R.V.d.S.; Supervision, J.C.P.P., L.S.M. and R.V.d.S.; Validation, J.C.P.P., L.S.M., D.L.M. and R.V.d.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was developed in the context of the project "Water management of dairy through the use of water responsible tools and practices and in the face of the impacts of climate change" (number, 409361/2022-4), founded by National Council for Scientific and Technological Development (CNPq).

Data Availability Statement: Data are contained within the article and Supplementary Materials.

Acknowledgments: The authors thank the company Nestle S.A. for its partnership in the study, and the technicians from Nestle S.A. who assisted in collecting water consumption data on farms. This work was presented at the workshop "Assessment of Water Use in Livestock Production Systems and Supply Chains", which took place in Potsdam, Germany on 14–16 December 2022. The Workshop was sponsored by the OECD Co-operative Research Programme: Sustainable Agricultural and Food Systems, whose financial support made it possible for some of the invited speakers to participate in the Workshop.

Conflicts of Interest: Author Julio Cesar Pascale Palhares was employed by the company Brazilian Agricultural Research Corporation. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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