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ASSESSMENT OF BLUE WATER FOOTPRINT IN DAIRY FARMING IN THE NORTHERN REGION OF PARANÁ, BRAZIL

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Verônica Cristina Heringuer Garbelini[a], Ana Paula Kuller Zanoni[a], Aline Romano Cunha[a], Lucas Nascimento Castanho Saibani[b], Rafael Fagnani[a,b]*

Anhanguera Unopar University, Londrina – PR, Brazil[a]
State University of Londrina– UEL, Londrina – PR, Brazil[b]
****E-mail: rafaelfagnani@hotmail.com***

ABSTRACT

This study investigates the blue water footprint of milk production in the northern region of Paraná, Brazil, focusing on water consumption in dairy cattle farms. Despite Brazil's significant position in global milk production, the country lacks robust initiatives addressing water footprint concerns within its dairy sector. Thirteen dairy farms were assessed to determine water consumption patterns, revealing an average water footprint of 45.48 (L kg-1 ECM of milk year-1), encompassing direct water use for animal drinking and washing dairy machinery. Notably, the proportion of water allocated for services, predominantly milking and cleaning, contributed significantly to water wastage, representing 68% of the total water footprint. Correlation analyses showcased a negative relationship between milk productivity and water footprint values, highlighting the potential for increased productivity to reduce water consumption. Additionally, no significant difference was found in water footprint values between manual and mechanical milking methods, emphasizing the adaptability of smaller-scale farming approaches in aligning with water sustainability principles. Considering the importance of water availability in contextualizing water footprints, this study underscores the need for broader dissemination of the water footprint concept within the dairy sector in Brazil. Implementing strategies to enhance productivity and reduce water consumption, along with fostering awareness and water reuse practices, emerges as crucial steps towards sustainable water management in dairy farming systems.

Keywords: Milk production; Water consumption; Sustainable.

INTRODUCTION

Globally, there is a growing concern over the sustainable use of natural resources to produce food and feed. The effects of climate change and the rising demand for agri-food products brought on by urbanization, economic growth, and population expansion are putting pressure on freshwater resources (BĂNĂDUC *et al.*, 2023). The dairy sector should align with the global trend of prioritizing measures to minimize the water footprint in milk production. Adapting sustainable practices, the dairy sector can contribute significantly to mitigating the environmental impact of its operations and fostering a more sustainable future for milk production worldwide (SHAMSUDDOHA *et al.*, 2023).

Brazil boasts a robust dairy industry characterized by diverse production systems and a vast array of cattle breeds, positioning it as one of the world's leading milk producers (LEITE *et al*., 2023). The sector accommodates both small-scale family-owned dairy farms, where traditional methods persist, and large-scale commercial operations characterized by innovative techniques and mechanization. The country's commitment to enhancing milk quality, increasing productivity, and meeting international standards has fortified its position as a major player in the global dairy market. However, the concern for the water footprint in Brazilian dairy production and industrialization is incipient (FEIL *et al.*, 2020).

Within the scope of Brazilian dairy production, recent endeavors have primarily concentrated on achieving carbon neutrality within the industry. A significant milestone was marked in 2021 with the introduction of the country's inaugural brand marketing carbon-neutral milk (GRANATO *et al.*, 2022). However, concerning the water footprint aspect, current initiatives are predominantly confined to research institutes, lacking visible integration into the industry's product labeling. The focus remains largely skewed towards carbon footprint reduction, highlighting a nascent stage in incorporating and visibly communicating efforts to address water footprint concerns within Brazil's dairy sector.

The most comprehensive and noteworthy analyses about water footprint in dairy production in Brazil are conducted by the Brazilian Agricultural Research Corporation (EMBRAPA). Their publications consistently underscore a critical conclusion: the scarcity of reliable estimates regarding water consumption per kilogram of milk produced in Brazil (PALHARES; PEZZOPANE, 2015). Authors repeatedly emphasize the necessity of disseminating such crucial information to both society and water resource managers. This dissemination aims to foster a less confrontational perception of the production chain while highlighting its commitment to enhancing water efficiency through various practices and programs, despite its inherently water-intensive nature.

The water footprint as defined by Hoekstra *et al*. (2011) is a thorough indication of the appropriation of freshwater resources that goes beyond conventionally limiting metrics of water withdrawal. The total amount of fresh water used to make a product is known as the "water footprint." Water consumption and pollution at every stage of the production process are taken into account when estimating it. The water footprint approach facilitates water management and generates knowledge. An animal product's water footprint is made up of two parts: the direct water footprint associated with the drinking and service water consumed, and the indirect water footprint of the feed. Increasing the sustainability of food requires an understanding of how animals use water in various management systems (GOMEZ-ZAVAGLIA *et al.*, 2020).

In its computation, three essential water components can be monitored according with Afreen *et al.* (2024): the term "green Watter footprint" describes the amount of water used that comes from "green" water resources, such as soil-stored rainfall. The use of blue water resources (net abstraction from surface and groundwater) is referred to as the "blue Watter footprint." The grey water footprint is a measure of water pollution and is defined as the amount of freshwater needed to absorb a load of pollutants given natural background concentrations and current ambient water quality standards.

The objective of this study was to determine the blue water footprint of milk production in Brazilian dairy cattle farms located in the northern region of Paraná, and to identify the elements and procedures that consume the greatest amount of water. The study focused on exploring relationships and disparities in blue water footprint across different milking methods, soil types, and selected farm characteristics, aiming to understand potential influences on water consumption within the dairy farming context.

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MATERIAL AND METHODS

Sampling and attributes of dairy farms

The present study underwent evaluation and approval by the Ethics Committee for Research involving Human Subjects at Unopar, holding the CAAE (Certificate of Presentation for Ethical Appreciation) number 40230620.1.0000.0108.

The sample universe comprised dairy farms registered in a dairy plant in Arapongas, Paraná, Brazil. A convenience sampling method was employed, inviting property owners through telephone contacts. In total, out of 252 properties contacted, only 16 agreed to participate in the survey. In-person visits to these farms were made to fill out a questionnaire about their zootechnical features, such as the sources and applications of freshwater (rivers, groundwater) to produce fodder, crop cultivation, cleaning of milking parlors and annexes, animal hydration, waste management, and other water-related activities. Following this, three properties were removed from the study because there was not enough information available. This left 13 dairy farms, all whose features are listed in Table 1.

Table 1. Characteristics of 13 dairy cattle farms assigned to water use monitoring during the years 2020/2021.

Dairy Farms	Farm area (ha)	Irrigated area (ha)	Soil type	Water source	Annual rainfall (mm)	Number of lactating cows	Milk productivity (L per cow)	Milking system
1	0.5	0.0	S	AW	1559	12	9	MM
2	2.4	0.0	C	AW/R	1829	12	15	MM
3	4.8	0.0	C	AW	1616	10	7	MM
4	6.0	0.0	C	D	1829	35	16	BMC
5	6.0	0.5	C	S	1616	80	20	PMS
6	6.0	0.0	C/S	AW/PW	1829	16	16	BMC
7	6.1	0.0	C	AW/PW	1559	9	14	MM
8	6.1	0.0	C	AW	1730	12	22	MM
9	7.3	0.0	C	AW/PW	1730	12	8	MM
10	7.7	0.0	C/S	AW/R	1616	10	7	MM
11	12.1	0.0	C	AW/R	1616	12	18	MM
12	14.5	0.0	S	AW	1559	23	20	BMC
13	48.4	0.0	S	AW	1829	42	23	PMS

C: clayey; S: sandy; PMS: Pipeline milking system; BMC: Bucket milking machine; MM: Manual milking; AW: Artesian well; S: Spring; R: River, PW: Pit water, D: Dam.

The farm areas range from 0.5 to 48.4 hectares, with only one farm having an irrigated area of 0.5 hectares. Soil types vary between sandy (S) and clayey (C), and the farms utilize different water sources including artesian wells (AW), springs (S), rivers (R), pit water (PW), and dams (D). Annual rainfall on these farms ranges from 1559 to 1829 mm. The number of lactating cows per farm varies from 9 to 80, with milk productivity per cow ranging from 7 to 23 liters. Milking systems also differ across the farms, including manual milking (MM), bucket

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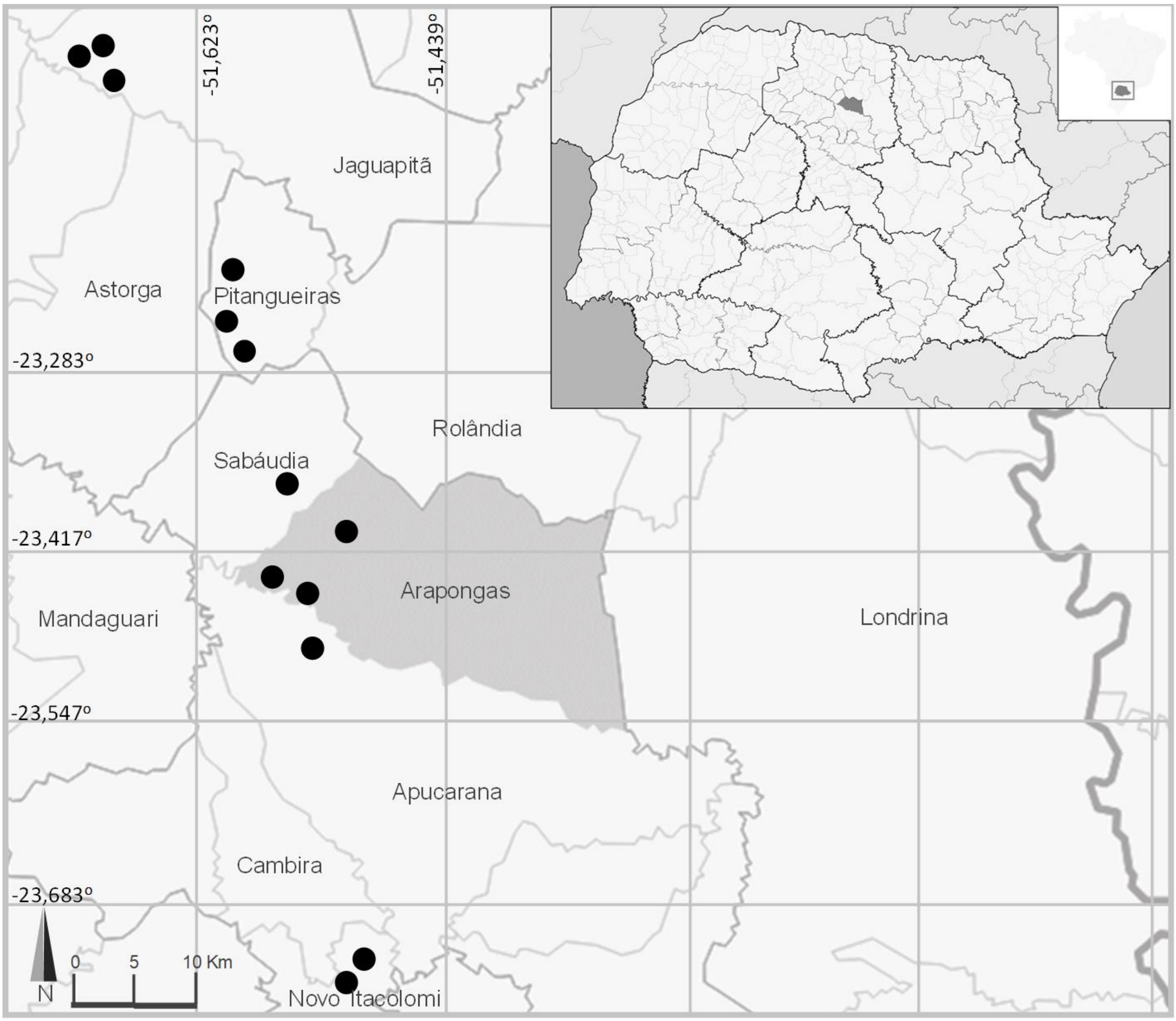
milking machines (BMC), and pipeline milking systems (PMS).

The geolocation of the dairy farms included in this study is shown in Figure 1, with 3 farms in the municipality of Jaguapitã, 3 in Pitangueiras, 3 in Arapongas, 1 in Sabáudia, 2 in Novo Itacolomi, and 1 in Apucarana. Geographically, all municipalities have a humid subtropical climate (Cfa) according to the Köppen classification.

Figure 1. Geographic distribution of the 13 dairy farms assigned to water use monitoring during the years 2020/2021 from the northwestern region of the State of Paraná (Brazil).



For the years 2020 and 2021, monthly values of the climate parameters were taken from the Agritempo database (AGRITEMPO, 2019).

Water footprint calculation

In this study the blue water calculation comprises the sum of direct water use (animal drinking and water for

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washing dairy machinery). The equation for blue water is expressed as:

$$BW = (Wan.drink) + (Wwash.\ mach) \quad (1)$$

Where BW is blue water (m3 year−1); Wan.drink is consumption of (drinking) water by animals (m3 year-1); Wwash.mach is the amount of water for washing dairy equipment and installations of milking.

According to the National Academies of Sciences, Engineering, and Medicine (2021), the drinking water intake of lactating cows was calculated from the milk production (kg/day), dry matter intake (kg/day), sodium intake (kg/day), and the minimum ambient temperature. Calves, heifers and dry cows drinking water intake values were 3.1 kg/day (calves) and 45 kg/day (dry cows and heifers). The amount of water used for cleaning at dairy farms was estimated by Guerra et al. (2011) to be 25 L $m^{2\ -1}$.

The functional unit was 1 kg of energy corrected milk (ECM) at the farm gate. It represents the energy content of milk produced, adjusted to include 3.2 percent protein and 3.5 percent fat. Milk production was measured along the lactation period and recorded monthly per cow.

Statistical analysis

The assessment of blue water footprint variation among dairy farms with manual and mechanical milking methods was conducted using the Mann-Whitney test. Additionally, the comparison among different soil types (clayey, sandy, or mixed) was executed utilizing the Kruskal-Wallis test.

Evaluation of the blue water footprint's correlation with irrigation presence and water source types was not subjected to statistical analysis due to limited data variability (only one entry for irrigated property, pond, and spring).

Correlations between the blue water footprint and productivity, property area, and animal count were analyzed using Spearman's correlation coefficient.

All statistical analyses were performed using Statistica 10.0 software, maintaining a significance level of 5% (StatSoft, Inc. 2008).

RESULTS AND DISCUSSION

Our response rate of 6% signifies a limited interest and awareness among milk producers regarding the environmental water context. Efforts need to be directed toward fostering a water-conscious culture and dispelling the misconception that water is an abundant input in Brazil. Exploring strategies to enhance participation is imperative, considering the low response rate. Future research endeavors should delve into potential reasons behind this diminished engagement, thereby paving the way for a deeper understanding of factors influencing response rates and facilitating improvements in data collection methodologies (WHITE et al., 2019).

Water footprints values are presented in Figure 2. The average water footprint among the 13 dairy farms under study was calculated at 45.48 (L kg-1 ECM of milk year-1), ranging from 32.77 to 117.77. Blue water consumption was 14.8 (± 8.6) L per kg raw milk for drinking water and 30.7 (± 18.0) L per kg raw milk for washing water. Cows had an average yearly intake of 2260 m3 of drinking water, while an average of 4802 m3 per year was used for washing and milking purposes. The proportion of drinking and washing water use averaged 32% ± 3% and 68% ± 3% respectively of the total blue water footprint. This approximate ratio of 1 to 3 between drinking water and servicing water (mainly devoted to milking, cleaning) and was also identified in the study conducted by Ibidhi and Salem (2020).

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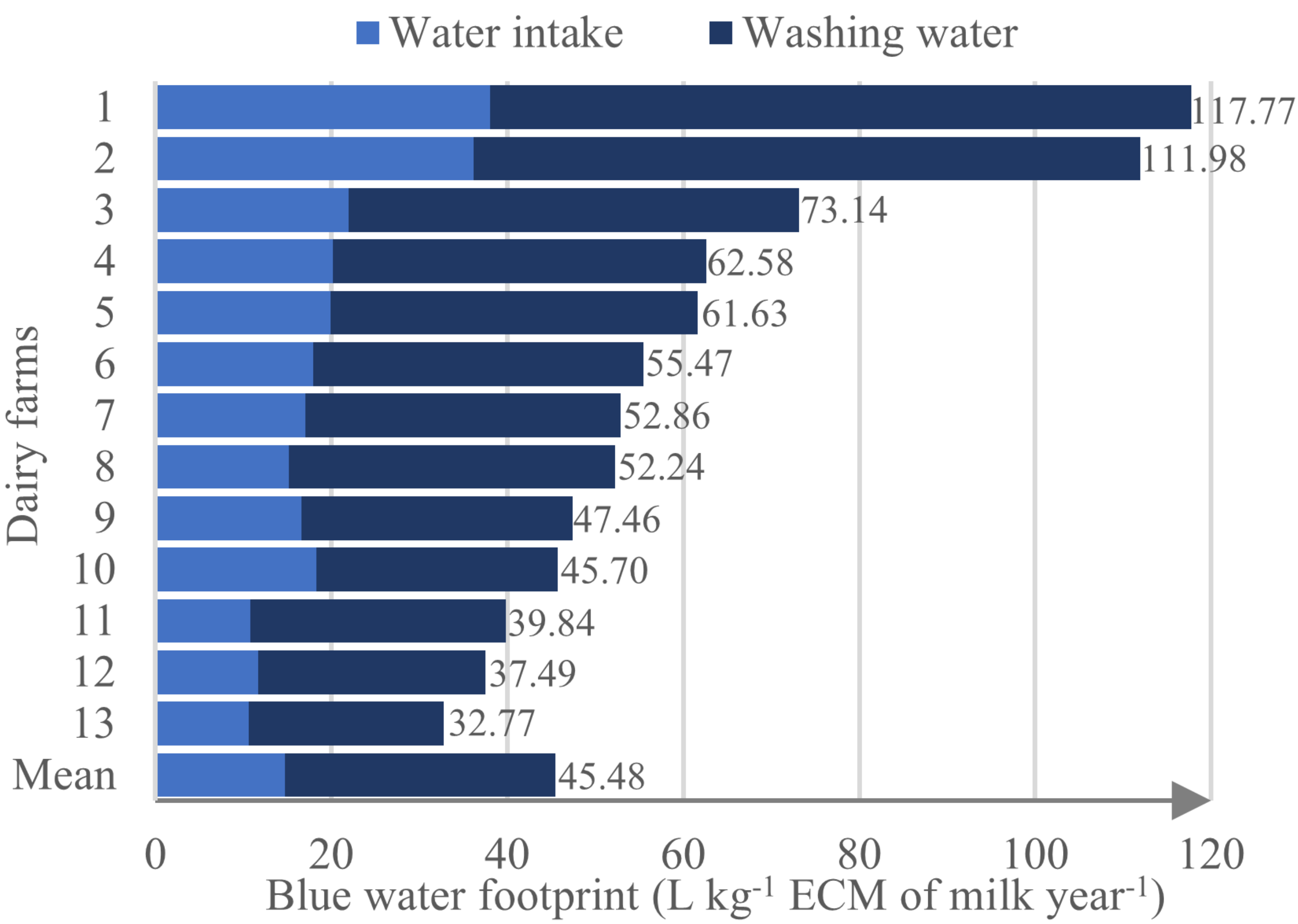
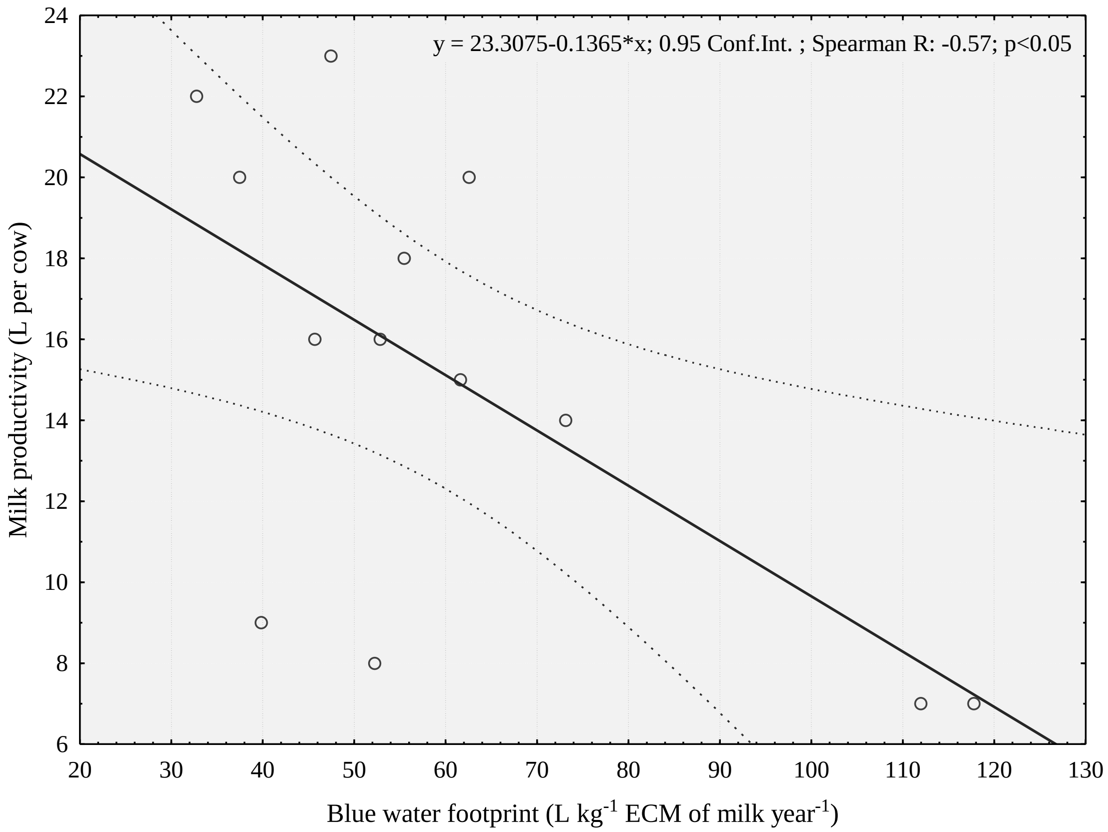
Figure 2. Blue water footprint categorized by water intake of lactating cows and water for washing dairy equipment of 13 dairy farms located in northern Paraná State, Brazil during the years 2020/2021.



Based on our study, the water allocated for services significantly contributes to water wastage, representing an average of 68% of the total water footprint of milk. This result emphasizes the value of mitigation strategies, especially reusing cleaning-in-place (CIP) water. Typically, alkaline detergents used to clean milk pipes consist primarily of hydroxide, predominantly sodium or potassium, often supplemented with sequestering and surface-active agents. In the dairy farms that comprised our study, we noticed that these alkaline cleaning solutions were single use. Conversely, in dairy plants, these solutions undergo recycling for reuse, depending on processing practices and equipment soiling levels. Consequently, this recycling method, involving basic procedures like sedimentation and centrifugation, could similarly be implemented on dairy farms. Repurposing these alkaline solutions from dairy farms for alternative uses is also a viable option. Merin *et al*. (2002) assessed the effectiveness of recycled caustic solutions (NaOH) from dairy plants and observed notable efficiency, improved cleanliness, and significantly accelerated cleaning rates when removing fouling from ultrafiltration membranes.

The dairy farms situated within the upper quartile (highest water footprint values), were notably associated with lower productivity. In fact, Spearman's correlation analysis revealed a significant negative correlation ($p<0.05$) between productivity and blue water footprint values (Figure 2). This finding elucidates that higher levels of productivity on these farms were consistently linked to reduced blue water footprint, emphasizing a potential inverse relationship between productivity and water consumption within the context of these dairy farming operations.

Figure 3. Spearman correlation between the blue water footprint and productivity of 13 dairy farms located in northern Paraná State, Brazil during the years 2020/2021.



In addition to milk productivity, Palhares and Pezzopane (2015) emphasize an optimal threshold, asserting that 81% of cows ideally should be lactating. Enhancing this metric could yield positive implications for footprint values as it aligns with higher milk production without substantial alterations in the consumption of water. Another significant metric highlighted is the proportion of heads comprising cows, standing at 65% overall.

Regarding the number of lactating dairy cows and the farm's area, no significant correlation (p>0.05) was observed with the blue water footprint. The Spearman rank correlation was -0.17 for area and -0.44 form lactating cows. These variables, despite being considered in the study, demonstrated no discernible association with the blue water footprint, indicating that other factors, such as productivity per cow, might predominantly influence or contribute to this particular aspect of water usage within the context of the study.

Dairy farms employing manual milking methods exhibited comparable water footprints when compared with those utilizing mechanical milking systems (p>0.05) (Table 2). This lack of statistically significant difference in water footprint values between manual and mechanical milking practices suggests a similar water consumption pattern across these distinct milking methods within the sampled properties.

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Table 2. Average and standard deviation (SD) of blue water footprint categorized by milking type during the years 2020/2021 across 13 dairy farms located in northern Paraná State, Brazil.

Blue Water Footprint (L kg^{-1} ECM of milk year^{-1})		
	Average ± SD	Min-Max
Pipeline milking or bucket milking machine (n=5)	42.22a ± 9.28	37.49 – 62.58
Manual milking (n=8)	68.10a ± 31.44	32.77 – 117.77

a, b: equal values within the same column did not differ according to the Mann-Whitney test (p>0.05).

In the observed context, the adoption of technology did not correlate with an elevation in the water footprint value. This suggests that even producers with limited technological advancements, particularly within small-scale family farming, can effectively produce milk within the framework of water sustainability. These findings underscore that extensive technological implementation is not necessarily pivotal for operating in a water-sustainable manner within dairy production, allowing room for small-scale and less technologically advanced farming approaches to align with principles of water sustainability.

Although studies specifically measuring the water impact of manual milking are lacking, there exists a common perception that increased technological interventions result in higher water expenditure for equipment cleaning. Manual milking often occurs in pasture settings without a dedicated milking parlor, consequently eliminating water usage associated with washing pipelines. However, manual milking requires the manual sanitation of buckets, cans, and utensils, factors we believe contribute to balancing water expenditures when comparing manual and mechanical milking methods. This dynamic underscore the need for a nuanced assessment of water usage across different milking practices, where the absence of specific infrastructural requirements in manual milking systems might offset some of the expected higher water usage associated with technological advancements in mechanized milking.

Another point to consider is that, although a crucial criterion for sustainable development, the water footprint can hardly be compared across different regions without considering water availability. Palhares and Pezzopane (2015) stated that depending on water availability, a product with a smaller water footprint could be more harmful to the environment than one with a larger water footprint. In that case, some dairy farms have less of an impact on water consumption and footprint because there was more ground and superficial water available. Water availability is influenced by catchment features, climate, agricultural practices, effective water use, and legal and regulatory frameworks.

As example, Murphy *et al*. (2017) found that green water inputs dominate over blue water inputs due to the rainfed grass-based system of farming in Ireland, estimating that the production of 1 kg of Irish milk required 690 L of water per kg FPCM, of which only 1% was blue water. However, at the same regional level, Mekonnen and Hoekstra (2010) estimated that the production of 1 kg required 670 L of water, of which about 6% was blue water. The difference can be explained by differences in data collection.

It is important to note that the outcomes of the previously discussed studies are affected by methodological variations, which may impact their direct comparability. In this sense, Higham, Singh and Horne (2024) stated that water availability and usage levels can differ within catchments in a region, and these variations can be obscured when using regional or national water scarcity factors to quantify water scarcity footprint indices for local milk production.

CONCLUSION

In conclusion, it is evident that in Brazil, the water footprint concept requires broader dissemination within the dairy sector, coupled with heightened awareness among dairy industries to prioritize its implementation in dairy farms. Furthermore, employing zootechnical strategies to enhance productivity, implementing techniques to curtail consumption, and adopting water reuse practices for cleaning purposes can significantly impact the reduction of water footprints on dairy properties. Improving these indices could lead to more efficient resource utilization within dairy farming systems, warranting further attention for sustainable practices and water footprint management.

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