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Blue and gray water footprint of some Hungarian milking parlors

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ABSTRACT

Unpredictable weather conditions urge us to find sustainable water management solutions. This research gives examples for dairy farmers on how to assess water use, calculate water footprint (WF), and find water-saving opportunities. Three large-scale Hungarian dairy farms were selected to assess water use and WF based on characteristics that answer to this research's hypothesis: there is a correlation between milking technology and WF. The WF of feeding was excluded from this research. In a farm using a parallel milking system ($Farm_{pl}$), the amount of service water, and thus the footprint of blue water, was the highest, more than twice at the polygon ($Farm_{poly}$) or robotic ($Farm_{rob}$) milking parlor service water. The milking robot was less advantageous in water use than polygon milking. The gray water footprint was the most unfavorable for $Farm_{rob}$. If blue, green, and gray WFs are clarified within a farm, it will be easier to investigate the water uses of dairy farms and assess the ratio of each water category. These data can serve as the basis for dairy farmers dealing with Holstein Friesian cattle for assessment of their water management. The novelty of this research is that no study has investigated the relationship between milking technology and WF.

Key words: dairy cattle, sustainable, water footprint, water use

HIGHLIGHT

- Novelty of this research is that no study has investigated the relationship between milking technology and WF comparing the traditional and robotic milking systems in Hungary.

1. INTRODUCTION

Sustainable use of natural resources for agri-food systems has come into the focus of research lately (McLaughlin & Kinzelbach 2015). In terms of water consumption, two main components of agriculture are crop production, where the demand for irrigation water is primarily significant, and livestock production, where irrigation water used for fodder production is present in addition to drinking water consumption. Agriculture represents 69% of global water use (FAO 2016). Water-related issues are getting serious in water scarcity areas due to overexploitation of freshwater resources. Mitigation strategies should assess social, ecological, and economic contexts, which are basic pillars of sustainability (Borsato *et al.* 2018). Water scarcity is made more severe by temperature increases and by a reduction in precipitation. Extreme climate events such as drought or storms affect water availability and the capacity of water supply services from ecosystems to society. Current water sources should be preserved for future generations at least in the same condition as they were inherited from ancestors. Reasonable water use, reuse, recycling, and desalination are the most promising water stress solutions (Peters 2019). Increasing water demand, progressive application of resource-efficient technologies, and rising acceptance of purified water are the driving forces in the current situation, which is that one-fifth of the population live in water-scarce areas. According to WWF (World Wide Fund for Nature 2010), habitat destruction, species extinction, and agricultural market prices could become more serious by the increment in the water footprint (WF) of water-scarce areas.

1.1. WF a comprehensive tool for assessing water use

Quantity of WF refers to the water amount that is required for long-term sustainability of population considering given standard of living (Hoekstra & Chapagain 2007). However, when WF is assessed in agriculture, factors such as extreme climatic conditions (drought, flood), soil characteristics, and agricultural potential all can result in different WF levels (Kumar & Singh 2005). The WF concept, which is a quantitative and qualitative indicator, was introduced by Hoekstra & Hung (2002). It is quantitative since it calculates the volume of water consumption to produce goods or services during their total supply chains, and it is qualitative since it assesses the amount of water required to assimilate pollutants based on the water quality standard in an ecosystem (Chapagain & Hoekstra 2004). WF analyzes the possible reduction of wasting water caused by production and consumption activities (Borsato *et al.* 2018). However, it also means a qualitative load according to the local water resource availability (Galli *et al.* 2012; Pfister & Bayer 2014). The WF of an individual, community, or business is the total volume of freshwater that is used to produce the goods and services consumed by the individual or community or produced by the business. Blue WF can be defined as blue water consumption from surface and groundwater resources through the total supply chain of a product. Consumption refers to water loss from ground waterbodies in a catchment area by evaporation, returning to another catchment area, or incorporation into a product. The green WF is the part of rainwater that undergoes evapotranspiration by crops and feeds the animals. The gray WF considers the freshwater volume required to assimilate a certain pollutant load that meets water quality standards of the region or country. The concept of gray WF expresses pollution volume, and thus can be compared with the volume of water consumption (Hoekstra & Chapagain 2007). Gray WF is interesting, if polluted water can be reused after different kinds of wastewater treatments. If treated water reaches the quality standards of irrigation water, it will decrease the negative impact of the system on the environment. Therefore, the production could be more sustainable environmentally. If this treated gray water can substitute for blue water for irrigation, the production might be more sustainable in an economic way as well. For being able to develop strategies for sustainable water use, green, blue, and gray WF elements of the WF indicator should be analyzed in more detail (Vanham & Bidoglio 2013).

1.2. WF of the animal sector

'*The global water footprint of animal production amounts to 2,422 billion m^3/year (87% green, 6% blue, 7% gray). One-third of this total is related to beef cattle, and another 19% is related to dairy cattle*' (Mekonnen & Hoekstra 2010). 98% of the WF of animals refers to feed. Drinking, service, and mixing water account for the remaining 2%. Relationships between livestock production and water use have come into focus to understand the distribution and demands for fresh water in livestock production (Ridoutt & Pfister 2010). Production of animal-sourced food in a resource-efficient way is one of the biggest challenges in future food sustainability (Steinfeld *et al.* 2013; Aiking 2014). Global water use for livestock production is 2.422 billion m^3/year (Hoekstra 2012).

1.3. WF of dairy cattle

Dairy farming is highly water-intensive, although water use efficiency varies by region and animal species (Singh *et al.* 2004). Dairy cattle's WF accounts for 19% (460 million m^3/year) of the global animal WF (Mekonnen & Hoekstra 2010). The biggest part of animal WF (98%) is related to feed production. The remaining part consists of drinking and service water for washing and cooling (Hoekstra 2012). The proper amount of drinking water is required for dairy cattle for sustaining animal health, milk production, and comfort (LeJeune *et al.* 2001). 83% of the total water requirement of dairy cattle consists of drinking water. Temperature determines how dairy cows behave (Meyer *et al.* 2004; Car *et al.* 2008), revealed that the comfort range of dairy cattle is between −5 and 21 °C. Besides environmental factors, milking technology, management, and milk yield also have an impact on water use. Equipment and management influence the technical water use of a dairy farm. However, it has to be taken into account that there is no single water requirement for a species or an individual. These hotspots might be useful for farmers and experts in this field to make their production more cost efficient related to water use. According to the study of Gough *et al.* (2010) from Michigan, in areas where water availability is low there is competition for water between different types of users; thus making water use of dairies more efficient is crucial for the future. Our work aimed to find the reasons for the difference in water use and water footprints of the studied dairy farms, with special regard to the applied milking technologies, i.e. the hypothesis of this work: there is a correlation between milking technology and WF. The outcomes of this research contribute to defining national strategies to improve water efficiency of Hungarian milk production. The WF of Hungarian dairy farms applying farm-specific data is incomplete.

2. METHODS

2.1. Farm site and milking characteristics

Three large-scale dairy farms (300–500 Holstein Friesian dairy cows) were selected based on the characteristics on which the hypothesis of this research focused on. These were located in the southeast part of Hungary. The annual average temperature is 9–10 °C, annual average precipitation is 500 mm. Three large-scale Hungarian dairy farms were selected to assess water use and WF based on characteristics of this research's hypothesis: there is a correlation between milking technology and WF. The WF of feeding was excluded from this research. The milking technology was different: 2×12 parallel in $Farm_{pl}$, 4×8 polygon in $Farm_{poly}$, and robotic in $Farm_{rob}$. In the parallel milking system, cows stand parallel to each other, so workers can reach the udder at the rear end. The milking process starts when all cows are in their stalls, i.e one flock is 24 cows in one milking tour, and they are all released from the parlor at the same time. In the polygon milking parlor, the milking machines are positioned in the middle – the 'spine' of the fish – between two aisles with room for the cows. The cows come into the parlor, and line up between each 'fish bone', creating two rows of cows. The herd is 32 cows. In the case of robotic milking, when a cow enters the pen, an ID tag is scanned that tells the system when the cow was last milked, how the udder is shaped, and the rate at which each teat dispenses milk. Robotic arms simultaneously sanitize and stimulate the teats, prompting the cow to let down milk. The monitoring period included data collection from August 2018 and August 2019. Herd information was collected from farm management software (RISKA), and farm records provided by farm managers and employees. Taking into account the feeding technology of investigated farms, total mixed rations (TMR) were fed on $Farm_{pl}$ and $Farm_{poly}$, containing all ingredients mixed and delivered to the cow for proper milk production and reproductive health. A partially mixed ration (PMR) containing all the forage and some of the concentrate was offered in the feed bunk in the case of $Farm_{rob}$. An additional amount of concentrate was fed through the robotic milking system during milking which amount varied according to the cow's stage of lactation. The main farm site characteristics of the investigated farms can be seen in Table 1.

Table 1 | Farm site characteristics of $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$

	$Farm_{pl}$	$Farm_{poly}$	$Farm_{rob}$
The average number of lactating cows	218	534	522
The average number of milkings per day	436	1,602	1,461
Feeding	TMR	TMR	PMR
Average body weight of cows	597	588	573
Daily milk production (L)	5,552	19,507	18,755
Daily milk production/cow (L/cow)	25.47	36.53	35.93

2.2. Water use of dairy farms

A bluewater source was ensured through piped water on $Farm_{pl}$, supplied from water station of a nearby village. On $Farm_{poly}$, a water tower pulled water from a 365 m depth driven well. On $Farm_{rob}$, water was supplied from a 300 m depth driven well. Drinking water, water used in the milking parlor (washing udders, washing platform, and milking equipment), and milk tank washing were all assessed on investigated farms. On $Farm_{pl}$ and $Farm_{poly}$, automatic inside and manual outside washing of milking equipment, and platform were applied too. During the time of milking, after one row of cows was milked, manure and urine were washed away from the platform. After all cows were milked, the walls and surface of the platform, and milking equipment were carefully washed off manually by a water hose. On $Farm_{pl}$ and $Farm_{poly}$, daily milking was always followed by milking machine washes. There were three stages in the daily internal washing of the milking equipment. The first warm water wash was performed for five minutes, the second stage was the main wash with hot water; with acidic detergent once a week, and with alkaline detergent on the other days of the week, and in the third stage the cold-water wash took place. At pre-milking teat preparation, a teat wash spray gun was applied on $Farm_{pl}$. This involved washing teats by hand with water and drying teats with a paper towel, just before the machine was attached. On $Farm_{poly}$, teat-preparation applied paper soaked with disinfection detergent, therefore it was made without water. On $Farm_{rob}$, a robotic milking system applied an automatic program for washing pre-treatment cups and the liner by brief and thorough steam-cleaning after each milking. Automatic inside washing of the whole system happened 4 times a day and an additional manual outside global washing of the robotic system occurred 3 times a day. Additional contamination from the outside part of the robot was cleaned manually 8 times a day. Teat preparation was carried out by water on $Farm_{rob}$. The pre-treatment, extensive steam cleaning, and udder spray system ensure the best possible udder health (SAC 2021).

Blue water was used in the milk house for milk tank washing on all farms. Wastewater was collected into water pits, which finally flowed into one pool on all farms. The main data about water use of investigated farms can be seen in Table 2.

Table 2 | Water use on $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$

	$Farm_{pl}$	$Farm_{poly}$	$Farm_{rob}$
Water source	piped	driven well	driven well
Washing of milking equipment.	automatic	automatic	automatic
Platform washing	manual	manual	manual
Pre-milking teat preparation method	water hose wash	teat sanitizer paper	teat cleaner cup
Type of milking system	2×12 parallel system milking parlor	4×8 polygon parlor with herringbone stands	automatic robotic milking system

2.3. Calculation of drinking water consumption

Stock size data and data of lactating cows during the observation period on $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$ were taken from the farm monitoring system of each farm. The average number of lactating cows was 218 on $Farm_{pl}$, 534 on $Farm_{poly}$, and 522 on $Farm_{rob}$. Drinking water consumption of lactating cows (DWC; liter/day) was calculated using the equation of Meyer *et al.* (2004):

$$DWC = -26.12 + 1.516(t_{average}) + 1.29(m_{milk\ prod}) + 0.058(m_{bodyweight}) + 0.46m_{Na} \quad (1)$$

where $t_{average}$ is the average temperature value, $m_{milkprod}$ is the daily quantity derived from daily milking (kg/day), $m_{bodyweight}$ is the bodyweight of animals (kg), and m_{Na} is the quantity of daily sodium intake (g/day).

To determine the bluewater quantity used for the production of 1 liter of milk, the daily milk amount was corrected to a unified 4% fat and 3.3% protein, as suggested by FAO (2021). It is a means of evaluating milk production records of different dairy animals and breeds on a common energy basis.

$$\mathrm{FPCM} = milk\ amount\left(\frac{kg}{day}\right)\cdot(0.337 + (0.116\cdot fat\%) + (0.06\cdot protein\%)) \quad (2)$$

2.4. Determination of service water use

Daily service water use included water use consisting of washing of milking equipment, platform washing, udder preparation, and washing milk tanks in the milk house. Water use for inner washing of milking equipment was determined based on the product description of milking equipment on each farm. Exact data were given on how many water is used per each washing for the inner cleaning of milking equipment. For assessing outside washing of milking equipment and platform washing, average daily water use was determined by a water meter and own measurement considering how much m^3 water was used by workers during and after each milking. Milk tank washing water use was determined based on how much water was used daily by the automatic system for milk tank cleaning.

2.5. Blue WF calculation

Mekonnen & Hoekstra (2012) calculated the total WF of dairy farms based on the equation

$$WF_{(a,c,s)} = WF_{feed\ (a,c,s)} + WF_{drink\ (a,c,s)} + WF_{serv\ (a,c,s)} \quad (3)$$

where $WF_{(a,c,s)}$ relates to the water footprint of an animal for animal category (a), in country (c), and in production systems (s) considering feed, drinking water, and service-water consumption, respectively. WF_{drink} means the WF of animal drinking, WF_{serv} relates to service WF refers to technical water use. The WF of an animal and its three components were expressed in terms of m^3/y/animal. However, the WF of feed was not included in this research because the average amount and composition of the feed was the same at farms, only feed dosage differed. In our research, only the bluewater used during milking was taken into consideration, apart from the water used in the lavatories and the cooling water of cows that is used against heat stress during summertime.

2.6. Gray WF calculation

In the case of point sources of water pollution, when chemicals are directly released into a surface water body in the form of wastewater disposal, the load can be estimated by measuring the effluent flow, and the concentration of a chemical in the effluent (Hoekstra 2011).

$$WF_{process,\,grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl \cdot c_{effl} - Abstr \cdot c_{act}}{c_{max} - c_{nat}} \tag{4}$$

where $WF_{process,gray}$ is the gray WF of a process, it shows the pollutant load (mass/time), c_{max} is the maximum acceptable concentration of pollutant (mass/volume), c_{nat} is the natural concentration in the receiving water body (mass/volume), Effl is the effluent volume (volume/time), c_{effl} is the concentration of the pollutant in the effluent (mass/volume), Abstr is the water volume of the abstraction (volume/time) and c_{act} is the actual concentration of the intake water (mass/volume). The water volume of the abstraction and actual concentration of the intake water were excluded from the calculation as wastewater streams through a closed sewage system so no evaporation occurs. Therefore, gray WF was calculated by the following equation:

$$WF_{grey} = \frac{L}{c_{max} - c_{nat}} = \frac{Effl \cdot c_{effl}}{c_{max} - c_{nat}} \tag{5}$$

Chemical oxygen demand (COD) tests were taken from wastewater pits from each farm to determine the concentration of the pollutant in the effluent. COD was analyzed in test tubes with an ET 108 digester and a PC CheckIt photometer (Lovibond, Germany). The digestion was done at 150 °C for 2 hours, as the measurement protocol requires. The official limit value for discharge into the public sewer is 1,000 mg/L COD based on Hungarian wastewater management standards. The natural pollutant concentration in the receiving water body was 4 mg/L as that was the average pollutant concentration of tap water in Hungary. Gray water footprint (WF_{gray}) was calculated based on COD as a pollutant characteristic (Eq.6).

$$WFgrey = \frac{\text{daily load of gray water } \frac{l}{day} \times COD\ of\ local\ samples \frac{mg}{l}}{\text{max acceptable concentration of pollutant} - \text{natural concentration in the receiving water body } \frac{\text{mass}}{\text{volume}}} \tag{6}$$

3. RESULTS AND DISCUSSION

To determine the blue and gray WFs of the milking parlors, we summed the water consumption of the dairy cows as well as the so-called service water demand, and the pollution value of each contamination point, expressed in COD.

3.1. Drinking water consumption

To calculate drinking water demand, the Equation (1) was used. For comparability, the amount of daily drinking water per cow is given, and the amount of drinking water per liter of produced milk, and per litre of FPCM milk was also calculated. The results of calculation i.e. the average daily water consumption (L/cow), average daily milk production (L/cow), specific daily water consumption (SWC) in (L_{water}/L_{milk}), and normalized daily water demand (NWD) in ($L_{water}/L_{FPCMmilk}$) are shown in Table 3.

Table 3 | Average daily water consumption, average daily milk production, fat and protein content, fat and protein corrected milk, and specific daily water consumption

	Average daily water consumption (L/cow)	Average daily milk production (L/cow)	FPCM (L/cow)	Specific daily water consumption (L_{water}/L_{milk}) SWC	Normalized daily water demand (L_{water}/L_{FPCM}) NWD
$Farm_{pl}$	87.8	25.47	24.54	3.45	3.61
$Farm_{poly}$	103.4	36.53	33.80	2.83	3.09
$Farm_{rob}$	97.1	35.93	35.71	2.70	2.78

Drinking water consumption of cows is influenced by average temperature, the amount of produced milk, the bodyweight of animals, and the quantity of their daily sodium intake. As the geographical distance of the farms is not very long, the average temperatures for the investigated period were almost the same, i.e. temperature difference was no more than 1.8 °C. Digested amount of sodium was the same for the farms (44 g/day). Body weight was determined based on farm measurements. The body weight of the cows ranged from 510 to 790 kg, with a standard deviation of 55 kg between farm results.

The largest difference was detected between the amounts of milk produced per day, and its fat and protein content (Table 1). For a fair comparison, the required amount of water was also given for the amount of fat and protein corrected milk (FPCM). The highest drinking water consumption was for $Farm_{poly}$, and the highest milk yield as well, but when data were converted to FPCM, the milk yield was no longer the highest, so $Farm_{rob}$ became the most favorable value for normalized dairy water demand, i.e. for the production of 1 liter of FPCM at $Farm_{rob}$ use the least drinking water for cows. The protein and fat content values of the milk-based on the feeding methods, and the subspecies of the cows, but in this case there was no difference in the subspecies, only the feeding methods had differences. On $Farm_{pl}$ and $Farm_{poly}$ TMRs were offered including all ingredients required by cows. However, on $Farm_{rob}$ PMR fodder provoked cows to visit feed banks more often. Therefore, feed use of cows on $Farm_{rob}$ improved, as a result of which these cows were able to achieve the lowest normalized water demand.

3.2. Service water use

Using drinking water for service is an important element of the blue WF. Average daily service water consumption (L/day) data can be seen in Table 4.

Table 4 | Service water amount

	$Farm_{pl}$	$Farm_{poly}$	$Farm_{rob}$
Milk tanks (m^3/day)	0.17	0.28	0.43
Pre-milking teat preparation (m^3/day)	2.23	a)	2.68
Inner washing of milking equipment (m^3/day)	1.36	2.88	2.88
Platform & outside part of milking equipment (m^3/day)	3.80	5.70	4.20
TOTAL (m^3/day)	**7.56**	**8.86**	**10.19**
Daily service water use by one cow (m^3/day/cow)	0.0346	0.0167	0.0195
Daily service water use by one milking (m^3/day/milking)	0.0173	0.0055	0.0069

a), teat-preparation applied paper soaked by disinfection detergent, i.e. no water consumption.

Service water consumption for milking includes the amount of water used for external, and internal washing of milking equipment, milk tanks washing, udder preparation, and washing of the floor of the milking parlor. Milk tank washing water amount was primarily influenced by milk tank capacity. $Farm_{rob}$ needed the highest service water for milk tank washing of 2×14,000 L milk tank. Then 25,000 L capacity of milk tank from $Farm_{poly}$, and 9,000 L from $Farm_{pl}$ required lower amounts of service water. Teat preparation on $Farm_{pl}$ was made manually, which requires an average of 5 literss of water per milking, i.e. this meant 2,180 liters water use on $Farm_{pl}$ for udder washing per day. So-called dry teat preparation was used in $Farm_{poly}$; paper soaked in disinfection detergent was used for this purpose. The robot system manual gave data for calculation of water amount for teat cleaning in the case of $Farm_{rob}$. It seemed to be bigger than at $Farm_{pl}$ but the number of the daily milking was much bigger. The number of daily milkings is 436 and 1,461 at $Farm_{pl}$ and $Farm_{rob}$ respectively, i.e., the amount of water used to prepare the udder per milking per day was 5 liters, and 1.8 liter at $Farm_{pl}$ and $Farm_{rob}$ respectively. 1,360 liters of water was needed for the inner washing of the milking system on $Farm_{pl}$. On $Farm_{poly}$, the inner washing of the milking system used 2,880 liters of bluewater, and on the farm, this water amount was also 2,880 liters. These data were given from the manual of the equipment.

For washing platform and outside surface of milking equipment, 3,800 litres of bluewater were used daily on $Farm_{pl}$, 5,700 liters on $Farm_{poly}$, and 4,200 liters on $Farm_{rob}$. Summarizing these data, the daily service water use per cow was calculated: 34.6 liters, 16.7 liters, and 19.5 liters for $Farm_{pl}$, $Farm_{poly}$ and $Farm_{rob}$ respectively. But when the daily service water use was calculated per milking, instead of a number of cows, the results were as follows: 17.3, 5.5, and 6.9 liters for $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$ respectively.

3.3. Blue WF

Applying the blue WF equation from Mekonnen & Hoekstra (2012) (Equation (3)), 40.39 m^3/year/cow was the blue WF on $Farm_{pl}$, 42.85 m^3/year/cow on $Farm_{poly}$, and 36.53 m^3/year/cow on $Farm_{rob}$. (Table 5).

Table 5 | Blue WF results in the case of $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$

	$Farm_{pl}$	$Farm_{poly}$	$Farm_{rob}$
Blue WF of drinking water consumption (m^3/year/cow)	32.04	37.76	35.44
Blue WF of service water (m^3/year/cow)	12.62	6.09	7.11
Total blue WF (m^3/year/cow)	44.66	43.85	42.55
Total blue WF (m^3/year/milking)	22.33	14.61	15.19

The blue WF of drinking represented a significant part of total blue WFs in the case of all farms, and this value per cow was the least at $Farm_{pl}$, meanwhile, the $Farm_{pl}$ had the highest value of the blue WF of service, and the total blue WF as well (Figure 1). Since a significant part of the total blue WF was the drinking water, and there were no big differences between these data among farms, there were no big differences among the total blue WFs as well. Regarding the blue water footprint of service, data showed $Farm_{poly}$ and $Farm_{rob}$ had almost the same value but $Farm_{pl}$ had as higher as twice. The annual total WF per cow was very similar also, and the smallest WF was measured at $Farm_{rob}$ however, if the values referred to the number of milking, $Farm_{poly}$ had the lowest blue WF value.

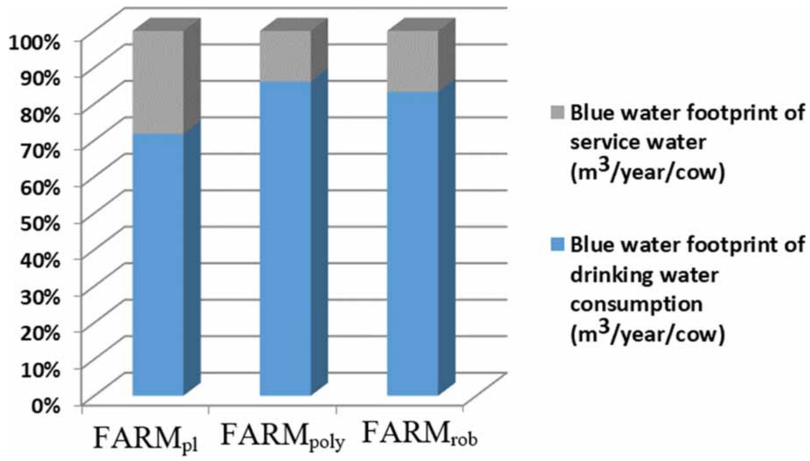

Figure 1 | Percentage distribution of blue WF.

3.4. Gray WF

The basic quantitative data used to calculate the gray WF were essentially the same as the data used for the service blue WF (see Table 4). The key element of calculation was the pollution loading of samples, i.e. their COD. Several samples from the sampling sites were analyzed daily, and the mean values are shown in Table 6.

Table 6 | Results of COD measurements of sampling locations and the average wastewater load

Farm	Sampling location	COD (mg/L)
$Farm_{pl}$	milk tank	550
	inner washing water of milking system	200
	teat preparation	3,600
	platform and outside washing water of milking system	3,600
$Farm_{poly}$	milk tank	600
	inner washing water of milking system	300
	platform and outside washing water of milking system	4,900
$Farm_{rob}$	milk tank	440
	washing robotic system and teat preparation	8,900
	platform and outside washing water of milking system	7,200

The highest COD values are found for the platform, and outside washing of milking system samples, which is understandable since the aim of the floor washing is to remove all contaminants, including feces and urine. In the case of $Farm_{pl}$, even the high COD value of the udder wash water stood out due to the manual wash. During manual washing, not only the teats but also the entire udder were washed, which meant a large, heavily soiled surface. The calculated gray WF values were shown in Table 7. The least amount of platform wash water (Table 4) and the least polluted platform effluent were detected in $Farm_{pl}$. Although $Farm_{poly}$ had lower COD, but the amount of wash water used was higher, so the gray WF for all farms was almost the same for platform washing. In the case of $Farm_{pl}$, in addition to platform washing, the udder preparation increased the size of the gray WF. In the case of $Farm_{poly,}$ no water was used for the teat preparation, so in addition to the decisive role of the floor washing water, the washing water of the milking equipment only slightly modifies the value of the gray WF.

The most obvious reason for the difference in gray WF between farms was due to the washing of the milking (robotic) system detected on $Farm_{rob}$. It had a high gray WF value of 49.68. This value represents more than half of all gray WFs (see. Figure 2), so the gray WF of $Farm_{rob}$ is double the other values (see Table 7). The amount of washing water itself was not the highest, but the COD of it was extremely big, i.e. 8,900 mg/L, meanwhile the other two farms the COD of the milking washing water was 3,600–4,900 mg/L.

Table 7 | Gray WF results of $Farm_{pl}$, $Farm_{poly}$, and $Farm_{rob}$

Farm	Sampling location	Gray water footprint (m^3/day)	
$Farm_{pl}$	milk tank	0.09	22.05
	inner washing water of milking system	0.28	
	teat preparation	7.95	
	platform and outside washing water of milking system	13.73	
$Farm_{poly}$	milk tank	0.17	29.08
	inner washing water of milking system	0.87	
	platform and outside washing water of milking system	28.04	
$Farm_{rob}$	milk tank	0.18	80.22
	milking (robotic) system and teat preparation	49.68	
	platform and outside washing water of milking system	30.36	

The reason for the discrepancy is in the milking system. In $Farm_{pl}$ and $Farm_{poly}$, the parallel and polygon milking machines were washed after each milking twice or three times a day by hosepipe manually, to remove manure and urine from the platform. In $Farm_{rob}$, the surface of the milking robot was washed with a hosepipe applying

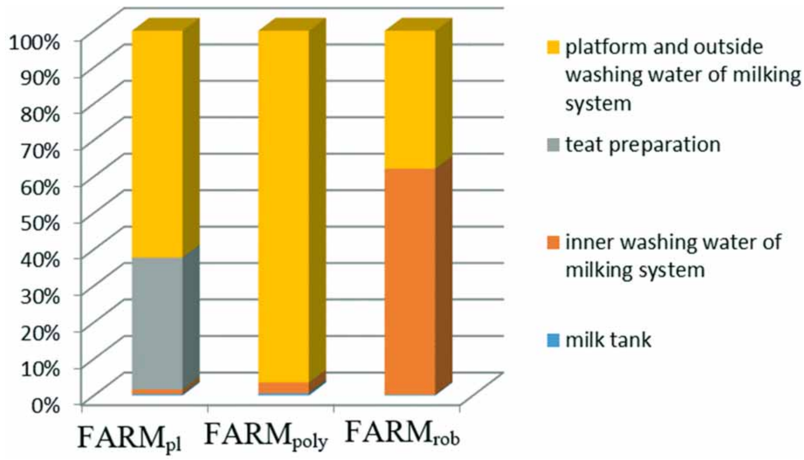

Figure 2 | Percentage distribution of gray WF.

detergent after each cow's milking. Therefore, the amount of wash water is also fundamentally different from other farms, and its COD value is extremely high due to the detergents and milk residue. Clusters of the robotic milking system are washed after each milking (after each cow). Thus, the opportunity of getting infected by subclinical mastitis is decreased. In the case of traditional milking systems such as parallel or polygon, this practice is not typical; it just sometimes occurs. As a result of infection, fat %, crude protein %, protein %, and casein % of milk all increase. The reason for this that the decline in milk yield is much bigger (30%) after infection than a daily net synthesis of mentioned parameters. Leukocytes excreted by immune response will form a high portion of somatic cells. Milking itself is a stressor with a high vacuum level. The robotic milking system milks each teat separately. If one teat is fully milked, the cluster comes off to eliminate overmilking. In the case of a traditional milking system all four clusters remain on teats until milk speed is under a certain value. The udder is not symmetric, as the back two udder parts are bigger including more milk. Therefore, the front udder parts are empty while milking is still going on. This is the biggest difference between robotic and traditional milking systems in the context of gentleness.

3.5. Discussion of drinking and service water use results

Ibidhi & Ben Salem (2020) calculated the average drinking and servicing water for lactating cows, which were 24.8 m^3/year/cow for drinking water consumption, and 26.64 m^3/year/cow for service water use. In this research it was 35 m^3/year/cow for drinking water consumption, and 8.614 m^3/year/cow for service water use. The reason for difference in drinking water could be the different drinking equipment and process or that the Tunisian dairy breed is much more tolerant against heat stress than the Holstein Friesian breed. Water consumption of a stock is influenced by three main factors: water quality, environmental factors, and stock characteristics: species, type, age, and production (NSW 2014). Furthermore, it is very important to bear in mind that there are no homogenous individual water requirements. Water intake is determined by the physiological state, state of pregnancy, lactation, feeding, temperature, water supply, keeping circumstances, and environmental stress (FAO 2018). The difference in service water use could be because this study focuses on service water use of the milking parlor, and the Tunisian study included cooling of cattle to decrease heat stress, and also cooling water need of milk tanks. Between 1999 and 2008, 3.94 liters was the average bluewater requirement for producing 1 kg of milk (Drastig *et al.* 2010). In this study, 2.49 liters was the average water use of the three investigated farms for producing 1 kg of milk. Boguniewicz-Zablocka *et al.* (2019) certify this result as well by identifying that 1–10 m^3 of water is used to produce 1 m^3 of milk. Service water use was 22 L/cow/day measured by Chapagain & Hoekstra (2003), which was similar to 20.87 L/cow/day calculated in this research.

3.6. Discussion of water use results of milking technology

There are just a few comprehensive assessments on water use of milking parlors (Palhares & Pezzopane 2015). AgricultureVictoria (2019), found that rotary and swing-over dairies could recycle a much bigger amount of water compared with double herringbones. This study also identified that in Farm$_{poly}$, the herringbone-structured milking parlor used 1.2 m^3/day more water than the parallel type (Table 4). Washing water use of the platform and outside part of milking equipment used the most amount of water from sevice water use, which certified the findings of Usva *et al.* (2013). Krauß *et al.* (2015) highlighted that cleaning methods for milking equipment and milk tanks are computer-controlled thus these have constant water use. However, cleaning water use of milking parlor depends on the area, worker, system, and farm management. Efficient management of servicing water could reduce blue WF of milk by up to 4% (Ibidhi & Ben Salem 2020). Based on another study by Wankhade *et al.* (2021), water use of milking bucket milking equipment was 42 L/cow/day. Compared to this in this research parallel milking equipment used 34.6 L/cow/day polygon milking equipment used 16.7 L/cow/day, and robotic milking equipment used 19.5 L/cow/day of bluewater. That means that from investigated farms the most water-efficient milking equipment is polygon milking equipment, less efficient is robotic milking equipment, and the least efficient is parallel milking equipment. However, all types of milking equipment are better in water-saving than bucket milking equipment. Krauß *et al.* (2016) reported more water usage for cleaning purposes in the herringbone parlor system. This was certified by this study's results, but with slight differences. The differences can occur due to surface size differences.

3.7. Discussing blue WF results

Krauß *et al.* (2015) underlined that increasing milk yield increases the water productivity of milk. This was certified in this study, as the farm with the highest average milk production achieved ($Farm_{poly}$ with 37 l average milk production) the best productivity of milk 2.8 $L_{water}/L_{milk.}$ The $Farm_{pl}$ with the lowest average milk production (26 L average milk production) achieved the worst productivity of milk (3.45 L_{water}/L_{milk}).

CONCLUSIONS

Our work aimed to find reasons for the difference in water use and WFs of studied dairy farms, considering milking technologies. The hypothesis of this work was that there is a correlation between milking technology and WF. Measurement-based analyses showed that our basic hypothesis was correct. The value of the gray WF is determined by the milking system. There is no significant difference between the blue WF values for cows on the farms studied. Drinking water accounts for the largest share of total blue WFs, 71 86, and 83% on $Farm_{pl}$ $Farm_{poly}$ and $Farm_{rob}$ respectively. It depended primarily on the milk yield, i.e. in our case, it depended on the method of feeding. Service water use is the part where savings can be achieved. In the case of $Farm_{pl}$, which uses a parallel milking system, the amount of service water, and thus the footprint of bluewater is the highest, more than twice as much as polygon or robotic service water amount. It can also be seen from the figure that milking using a robot is less advantageous in water use than polygon milking. The gray WF was the most favorable for $Farm_{rob}$, where robot milking is used, which is consistent with Thomson's (2018) studies. The biggest difference is caused by the robotic washing system. Here rinsing/washing was also used, even if it was short, but after each cow, it was done in addition to the daily detergent washes.

All in all, the polygon milking arrangement is most advantageous from the point of view of the WF, beating the parallel milking arrangement, and much better than robotic milking.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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