Efficiency of water use in a dairy industry: a case study from Campo Largo, Brazil

Nicole F. Neumann, Lucas A. Neumann, Paulo Belli Filho and Jorge M. R. Tavares

ABSTRACT

This paper aims to (i) quantify water use during the milk production process in a farm in southern Brazil, (ii) propose measures to reduce it, and (iii) elaborate and subsequently implement educational and structural measures promoting water-use efficiency and final disposal of the manure produced. The research was conducted during 6 months and it was divided into three field stages. The first stage identified and quantified the multiple uses of water during milk production, using water meters. In the second stage, reduction measures were implemented to reduce the water use. Finally, in the third stage, a series of educational and structural measures were elaborated with the validated measures. The average water disappearance (intake + waste) measured was 98 $L{\cdot}cow^{-1}{\cdot}d^{-1}$, decreasing to 83 $L{\cdot}cow^{-1}{\cdot}d^{-1}$ and 91 $L{\cdot}cow^{-1}{\cdot}d^{-1}$ at the second and third stages, respectively. The modification of the cleaning and disinfection process was the most efficient measure, saving 8.5 litres per day. The potential saving of all the measures combined was 17 $L{\cdot}cow^{-1}{\cdot}d^{-1}$. Seeking to increase even more the water economy, the resulting series of recommended measures covered the whole cycle of water disappearance in the milking process.

Key words | milk cattle breeding, mitigating measures, water use efficiency

Nicole F. Neumann (corresponding author)
Department of Environmental Science,
IHE Delft – Institute for Water Education,
2611 AX Delft,
The Netherlands
E-mail: *nifneumann@gmail.com*

Lucas A. Neumann
School of Agrarian and Veterinary Medicine,
Pontifical Catholic University of Paraná,
80215-901 São José dos Pinhais,
Brazil

Paulo Belli Filho
Department of Sanitary and Environmental Engineering,
Federal University of Santa Catarina,
88040-970 Florianópolis,
Brazil

Jorge M. R. Tavares
School of Agriculture (ESA),
Polytechnic Institute of Beja,
Portugal

INTRODUCTION

Dairy cattle milk production was the livestock activity that most contributed to the economy of southern Brazil, contributing 5.7% of Brazil's gross domestic product in 2017 (Ministério da Agricultura Pecuária e Abastecimento 2019). Over recent years, the high costs in some livestock activities e.g., swine and poultry, have been leading to a paradigm shift for dairy cattle production. In this way, sustainability has acquired a fundamental role in livestock, especially in milk production (VanderZaag *et al.* 2018), since it is also one of the activities that most requires water in the daily decision-making processes (Robinson *et al.* 2016).

Water is the most important dietary essential nutrient for dairy cattle, compounding 85% to 88% of the produced milk (Osborne 2006; Kume *et al.* 2010; VanderZaag *et al.* 2018). It is indispensable for life and fundamental to the maintenance of thermal and osmotic balance, metabolic processes, lactation, growth, and digestion (Beede 2012; Schütz *et al.* 2019). Besides the intake, water plays a central role during the milk production process since it is used in the disinfection of the animal's udder, used as an evaporative cooling mechanism and in the cleaning of equipment, facilities and floors (Robinson *et al.* 2016; VanderZaag *et al.* 2018).

The importance of water for dairy milk production is evident. However, limited data can be found when it comes to quantifying water uses during milk production. If the farmers and other stakeholders do not have these data, it is very challenging to analyse whether the water is being efficiently used and identify where to improve and reduce

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its consumption. To aggravate the situation, most Brazilian farmers appear to have a lack of information or no concern about water-use efficiency (WUE) and protection of water sources in industrial farm units. The main reason for water-use inefficiency is access to water at a low price or even for free by producers, once they use an artesian well system and/or catch from natural hydrous bodies in their property. Another reason is the privileged availability of water resources in Brazil, with 13% of the world's available fresh water (Engle & Lemos 2010).

One result of the water-use inefficiency is a hydric deficit that could exhibit severe consequences such as: the reduction of river flow, the salinization of irrigated areas and the degradation of wild habitats (Food and Agriculture Organization 2011; United Nations World Water Assessment Programme 2015). Since agricultural activity is responsible for the global consumption of 92% of fresh water, the concept of WUE in milk production is of international interest (Nardone *et al.* 2010; Hoekstra & Mekonnen 2012).

Another direct impact is the significant production of manure during the milk production process, consisting of urine, faeces and waste water. In most cases, the manure is disposed of in soil and/or eventually percolates to superficial and underground water bodies. The consequences to water bodies are: the increase of the biochemical oxygen demand and posterior decrease of the oxygen dissolved; increase in the concentration of suspended and dissolved solids; eutrophication and proliferation of water-borne diseases (Ramos *et al.* 2006). To overcome this, a solution is to apply the circular economy to milk production, where the waste becomes a resource; in this way, manure could be used as an energy source of biogas once treated by an anaerobic digester (Jurgilevich *et al.* 2016). Manure-to-energy projects enhance the sustainability of production, as they reduce the greenhouse gas emissions and can replace fossil fuels associated with electricity generation (Cuéllar & Webber 2008; MacDonald *et al.* 2009). Additionally, they benefit the farmer by avoiding purchases of electricity.

In this context, the present research aimed to obtain a water budget based on a real case, in order to guide farmers on how to obtain a greater WUE during the milk production process. The specific aims are: (i) identify and quantify the water uses, (ii) propose measures to minimize them, and (iii) elaborate and subsequently implement educational and structural measures for the WUE and the final disposal of the manure produced.

REVIEW OF LITERATURE

The quality and quantity of water consumed by the animal is an important factor since it influences the dairy's health, and the volume and the quality of produced milk (limiting outbreaks of disease such as mastitis); a low intake implies a reduction of milk production (Meyer *et al.* 2004; Kume *et al.* 2010; Schütz *et al.* 2019). The water intake by a dairy cow varies according to physiological phase, diet composition (dry matter intake) and environmental factors. A cow's behaviour, the drinker's characteristics, temperature and humidity of the air also affect animal water intake. A water intake ranging from 90 to 120 $L{\cdot}cow^{-1}{\cdot}d^{-1}$ has been recommended for dairy cows in lactation (Osborne 2006).

Previous researchers have studied and developed mathematical equations to predict the animal water intake. Appuhamy *et al.* (2016) analysed 55 studies and mathematical models, obtaining an average of water intake between 76 to 81 $L{\cdot}cow^{-1}{\cdot}d^{-1}$ and an average milk yield of approximately 28 $L{\cdot}cow^{-1}{\cdot}d^{-1}$. However, little has been done to collect data and produce real farm-scale water budgets. Water budgets embrace the different dairy farm water uses, local climatic conditions and specific dairy farm management practices (VanderZaag *et al.* 2018). Therefore, collecting data on a farm-scale could help farmers to ensure optimal water supply for the cattle, assist water footprint assessments and enhance awareness of water conservation (Robinson *et al.* 2016; VanderZaag *et al.* 2018).

VanderZaag *et al.* (2018) recorded the water use on a small farm over the period of 1 year. The authors observed variations in water disappearance related to the number of lactating cows in production. In addition, the authors reported variations due to the location of the animal group (indoors or outdoors), season (fall, winter, summer, spring) and temperature humidity index (THI).

As important as adopting strategies to save water during production is to demonstrate and explain the results of water disappearance for the farmers and personnel. Based on questionnaires sent to 17 farmers in Canada, Robinson *et al.* (2016) concluded that the majority acknowledged water conservation as a future concern; however, there was still a lack of knowledge on which strategies for saving water could be used on farms.

METHODS

Farm characteristics

The experimental procedures were conducted during a period of 6 months, from January 2017 to July 2017, at a dairy farm in Campo Largo, south of Brazil. The farm has an area of 36 hectares and its production system is natural pasture with a supply of silage produced at the field farm (Figure 1).

During the experimental period, the number of lactating cows varied from 42 to 57 (Jersey and Holstein Friesian breeds). Daily, the cows ate and drank water freely at the drinking spots located in the farm's pastures. The animals moved to the next pasture field every 40 minutes in order to preserve the grass. Following that, they were taken to the preparation room where they received silage for 30 minutes. The milking process was performed mechanically inside the milking room, consisting in two lines working in series (free-stall system), being carried out three times per day. After

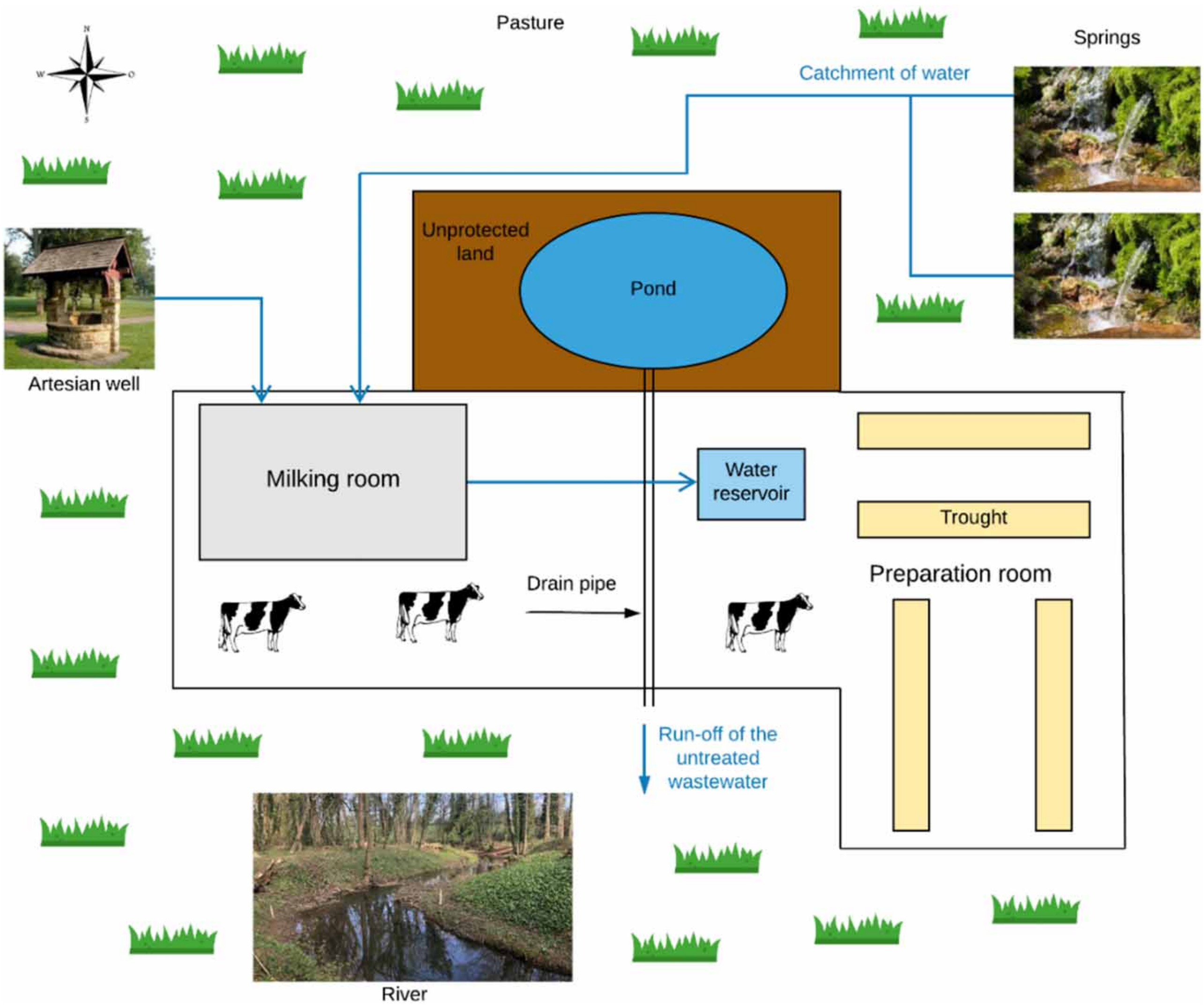

Figure 1 | Layout of the dairy farm.

each milking, the animals returned to the pasture while the preparation and milking rooms were scraped and washed.

The producer uses three different water sources in milk production: an artesian well near the farm building and two springs that source the northeast part of the property. The volume of water captured on each spring is not controlled and has no cost since the main use is for small family agriculture.

Data collection

The daily data for water disappearance was collected following the methodology presented by Tavares *et al.* (2014). Data on temperature and relative humidity data were obtained from the website of the Brazilian National Institute of Meteorology (INMET). The daily precipitation used in the study was downloaded from the Itaqui and Bateias meteorological stations, due to their proximity to the farm (approximately 9 to 11 km) (Instituto das Águas do Paraná 2017). The mean value for each meteorological station was calculated for the interval months from January to April of 2017; in May, only the data from the Itaqui station were used due to the absence of values from the other station.

Experimental design

The experiment period was divided into three stages. The first stage was developed in January 2017, to identify and quantify the different water uses on the farm. A total of three water meters were installed: the first in the pipe of the water tank that feeds the milking room; the second in the pipe prior to the pressure pump used to clean the external rooms; and the last was installed in the inlet pipe of the reservoir-drinker in the preparation room. The water meters were read daily at 19:30 by the farmer. The second stage (from 15 February to 15 April) aimed to apply water consumption reduction measures, both educational and structural, to increase WUE. The water consumption reduction measures applied to the external yards and preparation room were as follows: seal the leaks in the reservoir in the preparation room using epoxy mass; install a flow controller at the reservoir; replace the hose tip used to wash the external areas, increasing the system pressure and reduce the flow; decrease the number of wet washes at external areas (three to one) and change in the pre-milking room the cleaning and disinfection; and unblock the pipeline that drains the waste produced from the external area to the pasture. In the milking room, the measures applied were the replacement of some pressure registers that showed signs of wear and uncontrolled water leaks. The water meters' readings and their statistical analysis were maintained. In this way, it was possible to determine which measures influenced the decrease of water disappearance. In the third stage, a series of recommendation measures to enhance the WUE at its full cycle were elaborated: from catchment to final disposal. The series included pre-projects of protection of water springs used to catch water, a system of capture and storage of rainwater, an evaporative cooling mechanism and a horizontal subsurface flow constructed wetland.

Statistical analysis

The daily data were collected for 150 days ($n = 150$) and analysed using the software SigmaPlot© 13.0. Due to the great difference in water volumes and the consumptions from milking and preparation rooms were analysed separately. Multiple linear regression tests were used to verify the relation ($P < 0.05$) between daily water disappearance at each room with: (1) environmental variables (temperature and relative humidity); (2) intervention time after implementation of measures; (3) amount of wet washes; (4) daily precipitation; (5) a new employee from May; (6) pressure register replacement; (7) number of animals. Continuous variables were introduced in the model in linear, quadratic and quintile fashion (five equal parts) to achieve the best fit to the test. It is important to highlight that the use of groups, in any number, decreases the variability (dispersion) of the data; i.e., it goes towards the center of the distribution, whether working with the average or median. By doing this (grouping), the average/median value moves towards the center. This 'straightens' the curve and gives, then, linearity. As a result, this helps to better define an observation pattern by giving the analysis more robustness. As a disadvantage, the grouping can separate similar units and result in heterogeneous classes, grouping different units and separating similar units. To minimize this effect, instead of using only three or four groups (tertiles or quartiles), it was opted to analyse using quintiles. For the qualitative variables (new employee, placement of a flow controller), the value was assigned 0 (zero) for the days without these variables and 1 (one) for the days with the interference of these variables. Therefore, two different models were developed to verify the influence of those variables on water disappearance at each room. For that, 150 data points were used for daily measurements of water disappearance in the rooms (primary data). For the environmental variables (average daily temperature and relative humidity) obtained from the closest meteorological station (secondary data), it was 149 points. Regarding the number of wet washes ($n = 150$), the daily average, was used ranging from 1 up to 3.

RESULTS

Water disappearance

The first stage (January 2017) consisted in diagnosing the water disappearance at the dairy farm, evaluating all the production processes without interfering in the daily activities. The total water intake in the milking room was on average 872 $L{\cdot}d^{-1}$, and 3,666 $L{\cdot}d^{-1}$ in the preparation room. The water disappearance was 98 $L{\cdot}cow^{-1}{\cdot}d^{-1}$ and the average milk yield was 31 $L{\cdot}cow^{-1}{\cdot}d^{-1}$. Figure 2 presents the daily water disappearance in each room evaluated during the first and second stages.

Table 1 shows the impact of different variables on the water disappearance in the preparation room. For the milking room, the impact is presented on Table 2. During the second stage, the reduction measures applied to this room were: seal the leaks in the reservoir in the preparation

Table 1 | Impact of different variables on the water disappearance in the preparation room ($L{\cdot}cow^{-1}{\cdot}d^{-1}$)

Variable	Rough	Adjusted
Days of study	-1.0×10^{-4}	-1.9×10^{-4}
Number of wet washes	1.2×10^{-3}	4.3×10^{-3}
Temperature in quintile	9.3×10^{-4}	-4.1×10^{-3}
Relative humidity in quintile	-1.2×10^{-3}	-3.4×10^{-3}

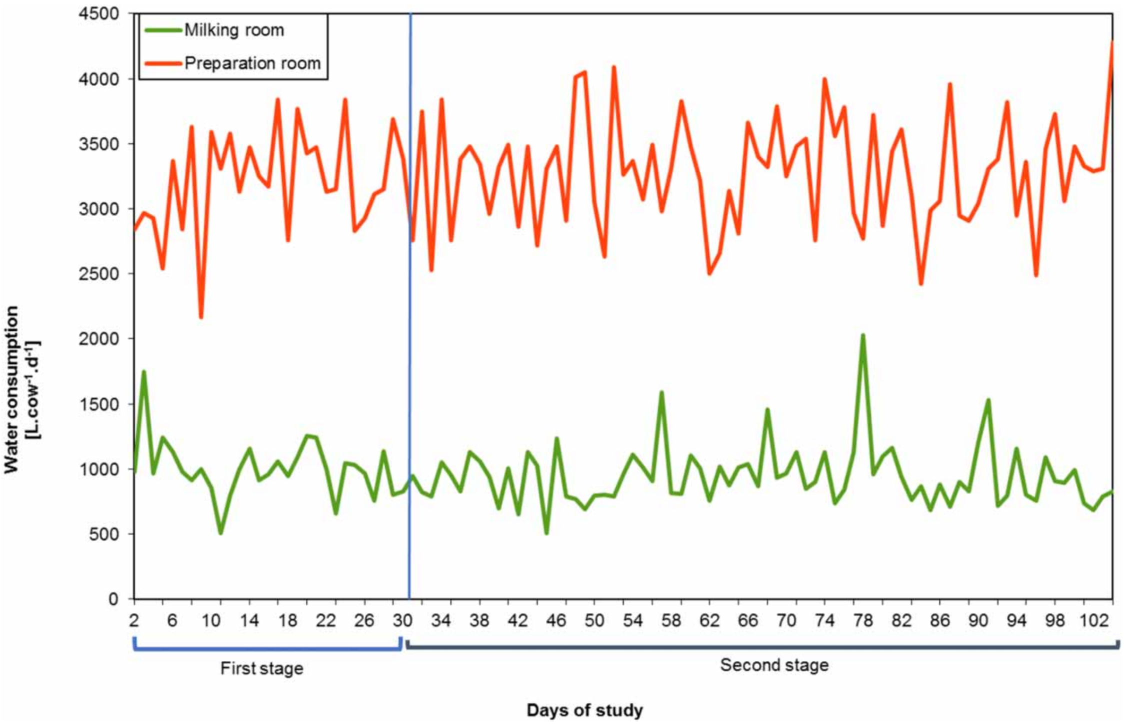

Figure 2 | Evolution of daily water disappearance during the first and second stages.

Table 2 | Impact of different variables on the water disappearance in the milking room ($L·cow^{-1}·d^{-1}$)

Variable	Rough	Adjusted
Days of study	3.7×10^{-1}	4.1×10^{-1}
Number of cows (per day)	-1.0×10^{-1}	-1.8×10^{-1}
Interaction days of intervention and number of cows	2.2×10^{-2}	6.0×10^{-2}

room using epoxy mass; install a flow controller at the reservoir; replace the hose tip used to wash the external areas, increasing the system pressure and reducing the flow; decrease the number of wet washes at external areas (three to one) and change in the pre-milking room the cleaning and disinfection; and unblock the pipeline that drains the waste produced from the external area to the pasture.

Modelling the water disappearance

Through the statistical tests, models of water disappearance were developed in this study for each room (preparation and milking room). The environmental variables (ambient temperature, relative humidity and precipitation) were adjusted in quintiles. Equation (1) shows the adjusted mathematical model expression, for the water disappearance in the preparation room, on a daily basis per lactating cow. Regarding the milking room, Equation (2) shows the final adjusted expression, for the water disappearance, on a daily basis per lactating cow.

$$Wpr = 9.63 \times 10^{-2} - (1.87 \times 10^{-4} d) + (4.33 \times 10^{-3} ww) - (4.11 \times 10^{-3} t) - (3.38 \times 10^{-3} u) - (9.6 \times 10^{-4}\, pr) \quad (1)$$

$$Wmr = 10.201 - (0.177n) + (0.06 I_{d-n}) + (0.414d) \quad (2)$$

where: Wpr – water disappearance in the preparation room ($L·cow^{-1}·d^{-1}$); d – days of intervention (days); ww – amount of wet washes (units); t – ambient temperature in quintiles (°C); u – relative humidity in quintiles (%); pr – daily precipitation in quintiles (mm). Wmr – water disappearance in the milking room in quintiles ($L·cow^{-1}·d^{-1}$); n – number of cows (units); I_{d-n} – interaction days of intervention in quintiles and number of cows.

DISCUSSION

Water disappearance

During the first phase, both rooms' consumptions presented variations related to the number of lactating cows in production (dynamic system – cows that give birth are not milked, and thus do not contribute to commercialized milk). This variation was also observed by VanderZaag *et al.* (2018), having, on average, a use of water destined for cleaning the milking room of 932 $L·d^{-1}$, that being higher than on Campo Largo's farm. Also, VanderZaag *et al.* (2018) noted small differences in the cleaning practice performed by different farm personnel. In the present study, the authors observed that during bank holidays and weekends, the water disappearance had a slight variation. This was related to the different employees that executed the milking and cleaning processes during those days.

Comparing the index with the results of Appuhamy *et al.* (2016), Campo Largo's farm has higher water disappearance and higher milk yield. The difference in the milk yield might be related to the farm's great somatic cell count index, which has been awarded several times by institutions of the sector in the south of Brazil. Yet, as great somatic cell count is obtained when there is little milk contamination by bacteria, the high water-disappearance in the milking room may also be a cause for this good index. In this sense, a sensitive approach from the researcher side is required when interfering in the milk production; reducing the number of wet washes could jeopardize the milk quality.

Due to the theory of normative conduct (Schultz *et al.* 2007), there was noted in the first stage a tendency of reduction in water disappearance. During the training period for both farmer and farm workers, it was reported that water disappearance presented values above those indicated in the literature and, because of that, a change of habits and reduction measures was needed. The effect of this training period was a decreasing volume of almost 1.9 $L·cow^{-1}$ for every 10 days. Therefore, sharing the results of water disappearance monitoring with the farmers and personnel is of great importance for WUE. Furthermore, by showing and explaining the reduction measures, the present study aimed to overcome the difficulty pointed out by Robinson *et al.* (2016).

Looking at Tables 1 and 2, it is observed that the number of wet washes was the most impacting variable on the water disappearance in the preparation room: each wet wash suppressed decreased 4.3 L·cow^{-1}·d^{-1} (decreasing the number of wet washes: reduction measure validated). However, it is important to note that employees reported difficulties in adapting this activity to the day journey at the farm, especially on rainy days. As the floor of the external area is uneven, rainwater associated with the manure accumulated increased the risk of animals slipping and, consequently, of serious injuries. It was reported that the problem was mitigated after the improvement of pond water drainage to the pasture (unblocking the pipe). After the sealing of slits and holes at the reservoir and the installation of a flow controller (reduction of leakage and water overflow), water disappearance decreased by 1.3 m^3·d^{-1}. In the second stage, when the minimization measures were applied, the water disappearance per animal decreased by 15.8% in comparison with the previous phase. It is important to highlight that the preparation room was responsible for 80% of the farms' water disappearance.

As expected, the environmental variables (temperature and relative humidity) exercised a high impact on the water disappearance, although the precipitation was not significantly relevant ($P = 0.057$). On warm days (outside thermal neutrality), milk cattle ingest more water to regulate basal metabolism. Small deviations may have occurred in relation to the temperature and relative humidity since they are secondary data (Table 3).

In the milking room, the reduction measures applied during the second stage were the replacement of pressure registers that showed signs of wear and uncontrolled water leaks (Table 2). Statistically, the measures applied to the milking room were not significant ($P > 0.05$). The intervention time increased water disappearance. The number of producing animals was significant for the final adjusted equation ($P = 0.007$).

Water disappearance in the third stage followed a decreasing tendency. This is evidence of the efficiency of the structural and educational measures implemented (for example, the reduction of wet washes per day). However, compared with the second stage, the water disappearance increased by 8.8% (from 83 to 91 L·cow^{-1}·d^{-1}).

Structural and educational measures

After data validation (second stage), during the development of the third stage a series of structural and educational measures was proposed (e.g. training of the farm workers to change the cleaning and disinfection procedures) to improve the WUE throughout milk production. Additionally, this series included the validated reduction measures: reduce the wet washes during the cleaning process; seal the leaks in the reservoir in the preparation room; install a flow controller at the reservoir; replace the hose tip used to wash the external areas; train the farm personnel. Regarding the structural measures, the first is the protection of the water springs used to catch water. It includes identifying the type of spring, cleaning, protecting the surroundings and reforesting to avoid erosion.

The second structural measure is the collection and storage system for rainwater, which aims to reduce hydric pressure on the water springs currently used to supply the farm's needs (Figure 3). Although the water demand is higher than the volume captured, it already allows the producer to potentially replace approximately 15% of the daily water used. To collect and store the rainwater, the system considered the roof area of the deposit machines in the farm due to its length and location near a 10 m^3 water reservoir. The design of the rainwater system was carried

Table 3 | Deviations in the ambient temperature (°C) and relative humidity (%) during each phase

	t (°C)			*u* (%)		
Stage	**Maximum**	**Average**	**Minimum**	**Maximum**	**Average**	**Minimum**
1st stage	32	26	20	93	66	32
2nd stage	32	25	16	96	65	33
3rd stage	28	21	15	97	68	38

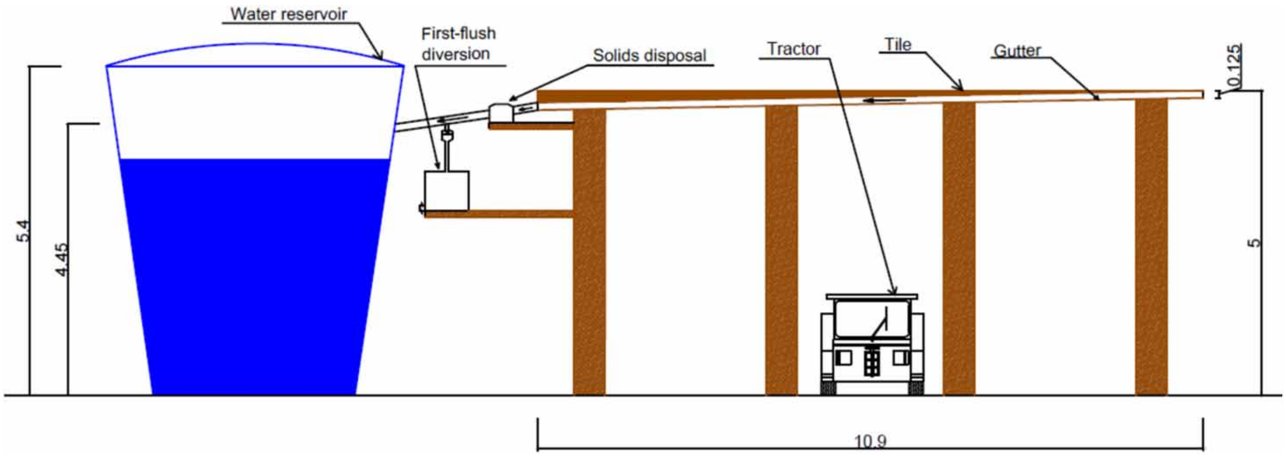

Figure 3 | Proposed measure: collection and storage system for rainwater (without scale).

out following the Brazilian Technical Standards. To measure the monthly volume of available rainwater, the average monthly precipitation data of the meteorological station closest to the farm was used (Instituto Das Águas Do Paraná 2017); the collection area was measured on site; and the other variables, runoff coefficient (*C*) and efficiency of the system (η capture factor), were chosen according to the literature (Tomaz 2003). The monthly available volume obtained was 16 m^3. For volume sizing, the volume of water demand was used to wash the floors of the preparation room, as this use does not require a high quality of water. Thus, a monthly volume of 99 m^3 was obtained.

One of the uses of water observed on the farm was the hose bath of the cows, performed by the workers, on hot days. To suppress this use, an evaporative cooling system was proposed associated with a shaded area. The system will be located at the troughs, in the preparation room. This location choice can avoid production losses of milk, as water intake influences milk yield (Kendall *et al.* 2006). The system will be installed in the troughs, mounted 0.5 m below the roof with a 10.8 m-long PVC pipe, the spacing between the 1 m nozzles. The water flow rate will be 30 L·h^{-1}, with the duration of the system blinking cycle equal to 16 minutes (14 min 35 s pause and 1 min 25 s drive) (Matarazzo 2004). The water used will be provided from the pre-project for the abstraction and storage of rainwater.

Currently, after using water to wash the animals on the days outside thermal neutrality, external area cleaning or other production uses, manure flows to the pasture without receiving the proper treatment. The final disposal, very common in Brazil, can lead to the contamination of nearby water sources and soil. To solve this situation, the construction was advised of a horizontal flow constructed wetland proceeding from a decantation tank as pre-treatment (Sezerino *et al.* 2015) (Figure 4). Due to the absence of data for the physical–chemical characteristics of manure on the farm, the value of biological oxygen demand (5 days) was adopted according to Knight *et al.* (2000). The other variables needed for the wetland sizing were also chosen in accordance with the literature and Brazilian legislation. The resulting wetland has a surface area of 34 m^2. The length will be five times the width – piston flow, according to research presented by Sezerino *et al.* (2015). Its total depth will be 1.15 metres. The project foresees the entrance and exit zones with gravel, while the filter material will be composed of sand.

Practical applications

Collecting the data from a real-scale farm allows identification of the main water uses during the production of milk. This data permits an assessment of where the strategies to save water should focus: if it is during distribution of water from the catchment, milking process, cleaning of external areas, hose bath of the cows, leakage of the reservoir, etc. The next step is to study simple and easily applied measures to save water, i.e. change the cleaning protocol of the external areas always monitoring the water disappearance. It is important to highlight the role of the direct agents involved: personnel and farmers. As stated, by Robinson *et al.* (2016), in many cases they are aware of

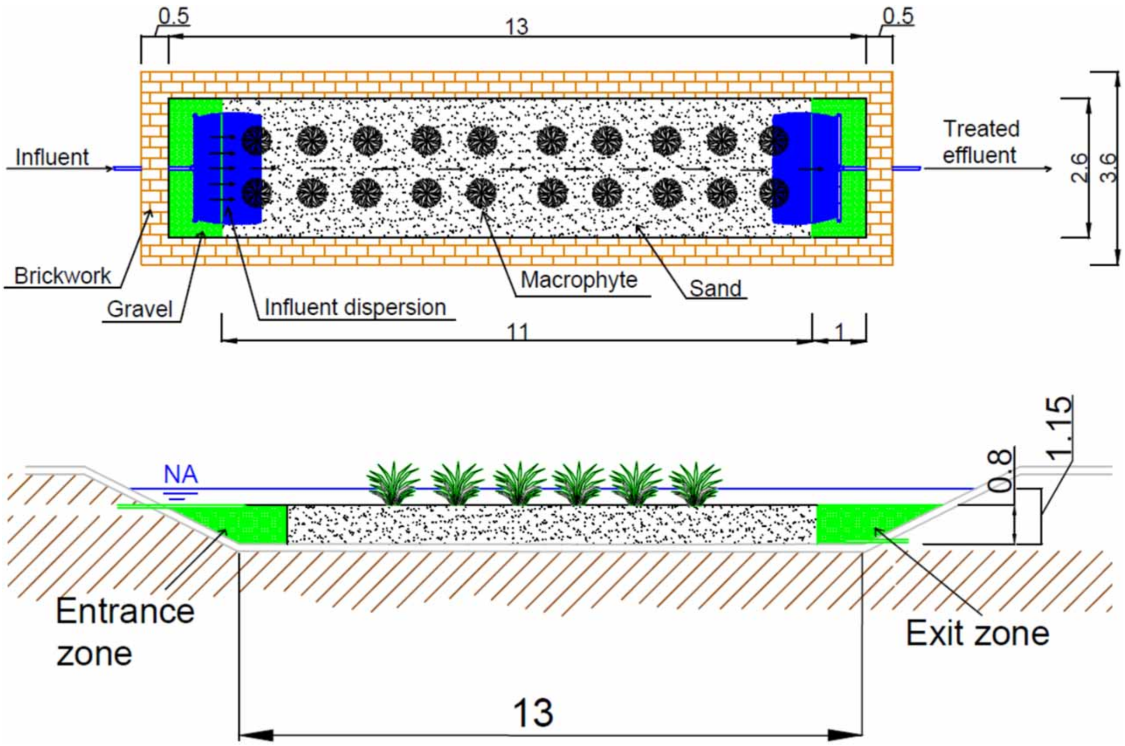

Figure 4 | Proposed measure: horizontal flow constructed wetland (without scale).

the importance of saving water resources for the future, but do not know how to implement water conservation strategies. Training and showing the results of the reduction measures to the farmers and personnel could motivate and, potentially, increase the savings.

Further investigations could approach the volumetric water footprints of the farm, an important sustainability indicator in the agricultural and food sectors (Murphy *et al.* 2017). In addition, more local farms could be investigated in order to identify the most common water uses. Then, it would be possible to produce a regional guide for the best efficient practices during milk production.

CONCLUSIONS

This research diagnosed the water disappearance and suggested and applied some reduction measures in the milking and preparation rooms of a dairy farm (water disappearance per cow decreased by 15.8% in the second stage). Among the reduction measures applied to reduce the water disappearance in the preparation room, the most effective was the reduction of wet washes from three to one. Although the daily maintenance was challenging, training and, consequently, inducing the normative conduct on producer and farm employees presented a significant impact. Reduction measures applied to the milking room were not statistically significant. Basing on the main water uses during milk production, a guide with structural and educational measures was proposed. It approached the protection of the water springs/sources, the design of a rainwater system, an evaporative cooling mechanism associated with a shaded region and a horizontal flow constructed wetland. Also, the practical guide included the validated reduction measures, becoming an important instrument to help farmers to maintain the minimization measures and reduce their water consumption.

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