Journal of Innovative Agriculture and Social Development

journal homepage: https://rdpublishers.com/journals/index.php/jiasd

Article

Estimation of water requirement and water use efficiency in typical dairy farms in Bangladesh

Mohammad Mohi Uddin [a*], Mst. Nadira Sultana [a], Amrin Akter [a], Mashrufa Tanzin [a,b], M. Salauddin Palash [c]

[a] Integrated Dairy Research Network (IDRN) Research Group, Department of Animal Nutrition, Bangladesh Agricultural University

[b] Rural Development Academy (RDA), Bogura

[c] Professor, Department of Agribusiness and Marketing, Bangladesh Agricultural University

ARTICLE INFORMATION

Article history:
Received 07 February, 2022
Received in revised form 23 February, 2022
Accepted on 25 February, 2022

**Corresponding author:*
Mohammad Mohi Uddin
mohammad.uddin@bau.edu.bd

ABSTRACT

The objective of this study was to estimate the different ways of water use to calculate water use efficiency (WUE) in the dairy production system and to identify the main drivers of water use efficiency (WUE) in Bangladesh's typical dairy farming system. In this study, the methodology developed by the International Farm Comparison Network (IFCN) was applied which consists of three pillars: Typical Farm Approach (TFA), Technology Impact Policy Impact Calculations (TIPICAL) model, and Dairy Networking Approach (DNA). Using the IFCN panel approach, two typical farms were selected: BD-2 cow farm (Bangladesh 2 cow farm) and BD-14 cow farm (Bangladesh 14 cow farm). These two typical farms were modeled using the IFCN global water footprint model, the water footprint model is built within the TIPICAL model. The results showed that the average water requirement for one kg of milk production is 2400 liters of which 98% of the water use used through feeds and fodder. About 2% of water is used through drinking water and service water. The water use efficiency of BD-2 and BD-14 are 0.22 and 0.26, respectively. Finally, small-scale production farm (BD-2) needs more water requirement/kg of milk as they rear a small number of animals with low productivity than large-scale typical farming system (BD-14) with high productivity. The finding of this study revealed that increasing milk productivity and effective use of the feeds and fodder are the main ways to be efficient in water use and thus can reduce the pressure on the water for milk production.

Keywords: Typical Farm, TIPICAL model, water use efficiency, Bangladesh, milk production

1. Introduction

Globally, dairy is a major source for 1 billion people which eventually provides milk to 7 billion consumers. In the case of Bangladesh, 1.52 million dairy farmers, of which 41% of household (small-scale), 49% family (medium), and 10% business (large farms). The average family member per dairy farm is 5 and the total dairy farm in Bangladesh is 1.52 million which implies that dairy farming is linked with the livelihood of 7.6 million people. The remaining 158 million people are consumers. Globally more than 100 million dairy farms are smallholder (1-30 cows) which is decreasing at a rate of 1.7% since 2012 (IFCN, 2019). This is not yet reflected in Bangladesh because rural livelihood and household nutrition is linked with household dairy, and hence, daily earning is more important than being profitable. This implies less sustainability in dairy farming unless the farmers shift their focus to being profitable and competitive locally and globally.

On the other hand, water availability in the future is the world's most emerging issue in a foreseen climate change all over the world. Thus, the increasing population growth (6.5 billion of the present population will reach 9 billion in 2050 of which 8 billion in developing countries), changing eating patterns for better-testing food, and a concomitant increase in water use for agriculture (67-87%) (Rosegrant et al. 2002) are considered as the key drivers for increased competition for scarce agricultural water resources. This is a big challenge for Bangladesh, India, and China, due to excessive withdrawal of the groundwater through irrigation.

As recently, a structural change towards intensification has been observed in dairy farming in Bangladesh, which causes increased use of input (i.e., purchased feeds along with increased feed production) to produce more milk. This might have a direct effect on water use. The Time Magazine in 2010 showed that Water will be similar to "Oil" in 2050 and according to Water Meteorological Organization (WMO), approximately 500 million people will face an acute shortage of water in 2050 (The Daily Kaler Kantho, 2022). The research on water requirement and water use efficiency has not been done substantially. Water use is an environmental sustainability indicator is based on how efficiently water is used to produce a unit of milk. In 2050, there will need double the amount of milk than now, hence will require double the amount of water. In contrast, water availability is decreasing, and the rate of water pollution is increasing. Nevertheless, the rain pattern and climatic shock are also taking place globally including in Bangladesh. Considering one hand, high demand for milk for the provision of high-quality animal protein and on the other hand, high demand for water for dairy production, therefore, in this study we are digging deeper into water use and water requirement to produce a unit of milk production.

The expected increase in milk demand in Bangladesh by 9% (IDRN, 2020) in 2030 compared with the current time. Agriculture farming needs to be used as an adaptation strategy for water management that ensures food and water security. However, the water problem is a part of agriculture including livestock production in different regions and different farming systems both in developed and developing countries along with Bangladesh. As water is a vital component that is needed in the largest quantity by livestock and dairy itself. Water resources are lessening day by day; however, inadequate water may cause adverse effects on milk production and dairy cattle growth. According to WFN (2012), water requirement estimation for sustainable production and consumption of milk and/or services in local pertinence turn into results which not beyond the questions and uncertainty. The global water requirement of 1000 liters per liter of milk production (WFN, 2012) is highly important to understand to what extent and how close this requirement is to the case of Bangladesh. This could be well explained if the knowledge of the local context of the water use and water-related activities can be attributed to a good understanding of the water. The regional water scarcity and water stress index is the key determinants that explain that milk production using a large volume of water or consumption of a higher amount of water can lead to a less environmental impact compact in one region compared to where the scarcity is less intense compared with the regions where the water scarcity is high (Ridoutt et al., 2010). This instigates to estimate of how much water is needed to produce a unit of milk in the context of Bangladesh. Adequate consideration of water use in typical dairy production and dairy farming systems is the best way to communicate and promote the competitiveness of the dairy farm in Bangladesh.

Estimation of the WUE using the consistent approach might make it possible to obtain strategic insights which are pertinent to the existing dairy farming and dairy sector. The findings of this type of study might substantially support dairy farmers to become more efficient in WUE through better management. This will, later on, would help to achieve an environmentally sustainable milk production system in Bangladesh. Nevertheless, the state of art on water use research in the domain of natural resource knowledge on WUE would be helpful to different stakeholders to design a sustainable water management strategy in dairy farming. Based on the foreseen outcomes of the study, it would be possible to adopt water use in dairy farming systems and other sectors of agriculture with reducing water stress at the local level. Therefore, research on water requirement and water use efficiency bears significant importance to provide an updated water use framework in Bangladesh. The requirement of water and water use efficiency would be helpful for future water management strategies. This research has taken a step forward in the measurement of water requirement and water use efficiency in typical dairy farms in Bangladesh. Therefore, the objective of this study is to analyze different segments of water use to calculate water use efficiency (WUE)/kg milk in the dairy production system and to identify the main drivers of water use efficiency (WUE) in BD typical dairy farming system.

The estimation of water use, water use efficiency, and water footprint are highly complex as the water use at the dairy farm is relatively less monitored and recorded. Among various methods available globally, the International Farm Comparison Network (IFCN) developed recently (Sultana et al., 2014 and Sultana et al., 2015) global water footprint methodology for typical dairy farms globally. This research has applied the IFCN water footprint methodology (Sultana et al, 2014 and Sultana et al., 2015). This method considers the dairy farm, its operation, economics, feeds and feeding, and detailed input use. This method also considers the concept of the Typical Farm Approach (TFA) and Networking Approach (Uddin et al., 2010).

2. Material and Methods

2.1. Research methods and data collection

Water requirement in milk production can simply be defined "as the total volume of freshwater that is used either directly or indirectly to produce a kg of milk (Hoekstra et. al. 2009)". In Bangladesh, "dairy farming is a part of mixed farming and a predominant source of income for rural livelihoods. Dairy farmers also depend on the imported virtual water from outside and within the region in the form of concentrate and roughage feed. Dairy farming is involved to use of direct water consumption and is also water that is embedded in cultivated green fodder, grain, and its by-products that are supplied to the cattle for producing milk. As water becomes more and more scarce and dairying is high-water intensive, no study has so far been done to quantify WUE in the dairy production system. The method that is used in this study considers: a) virtual water use for home-grown feed and feed brought in at the farm b) drinking water as well as, and c) service water used on the farm. The estimation of virtual water for feed consumption is the sum of the total water that is needed to cultivate the feed ingredients water and water that is used for feed mix preparation. At the same pace, the service water is the water that is needed to shower, to clean the dairy cattle, and stables as well as other utensils.

2.2. Data description

A pre-designed and pre-tested questionnaire called input sheet (INP) within the IFCN Typical Farm was used to collect data from the typical dairy farms in Bangladesh. A face-to-face interview technique, transect study, pre-panel help survey, and panel study were used. The panel study is defined as the modified Delphi Technique (Custer et al., 1999) where the data collection is cross-checked and validated through a panel of experts before being used for further analysis. The estimation of a production function requires all input terms of water used for producing milk and output data (total milk production) at the farm level.

2.3. Study design

This study was conducted in the region of central, north, and northwest parts of Bangladesh (Figure 1). These regions have various characteristics of milk production, support services, and other resource endowments (Uddin et al., 2010).

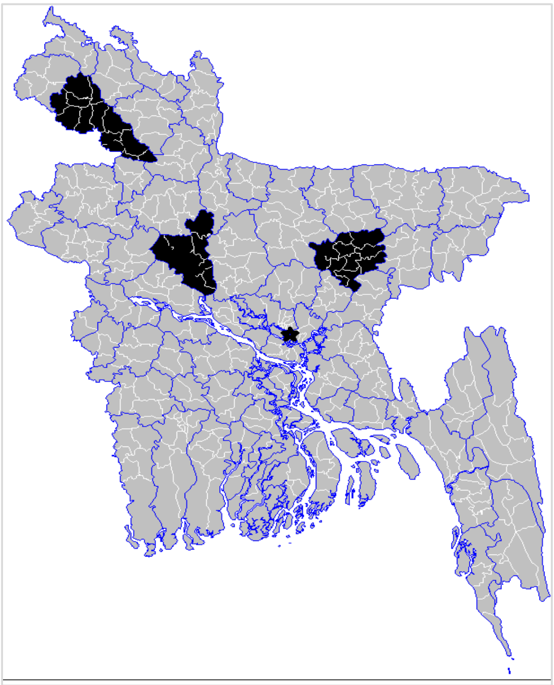

Figure 1. Administrative Map of Bangladesh including the study areas

2.4. Functional unit

The definition of a functional unit (FU) is one of the main steps of the LCA methodology (ISO, 2006b). Therefore, milk is being corrected for fat and protein content (ECM, energy corrected milk) which was used to express as a functional unit to standardize and allow different systems to be treated functionally equivalent.

2.5. Methods of water requirement and water use efficiency

Regarding data, all the data were taken from a field survey of 218 dairy farms in Bangladesh from different dairy production systems in three regions (Dinajpur, Sirajganj, and Kishoregonj). To calculate the volume of water consumed from feed and other inputs, the co-efficient was used (Sultana et al., 2014 and 2015). In Bangladesh, the by-product of cereal crops is mostly used as feed and fodder which are the key inputs for producing milk. For example, farmers generally grow rice crops, but they use rice straw as feed for cattle which is normally a by-product of rice (i.e., crop residues). Now question leads to how is water allocated for rice straw? To answer this question, the allocation approach between main and by-product in relation to the revenue generated from them is being used as the total water as it was used in the study of Sultana et al., (2014). Therefore, water is allocated according to the value of rice and rice straw.

2.6. How to approach water use efficiency in the dairy production system

The definition of efficiency is always referred to as a ratio or percent efficiency which represents the percentage or ratio of output divided by input. That means any farming system can produce output from a unit of input, it is also a ratio of output to input. Therefore, water use efficiency was defined as the amount of milk (ECM milk i.e., energy corrected milk) produced from a typical dairy production system per unit of water used. Hence, the main question is: how many kg of ECM milk is produced per cubic meter of water?

Functionally expressed as WUE = TMY/TVW

Where: WUE= Water use efficiency; TMY = Total amount of milk production in ECM as ton; TVW = Total volume of water consumed via input use for the purpose of milk production as the cubic meter.

2.7. Analysis of water requirement and water use efficiency

To analyze water requirement and water use efficiency in typical dairy farms of BD, the IFCN TIPI-CAL model and TIPI-CAL software (TIPI-CAL software version 5.2) were used. The TIPI-CAL model was derived using the principles of the Farm Level Impact and Policy Simulations Model (FLIPSIM) was developed by the Agricultural and Food Policy Centre (AFPC) of the University of Texas A&M. The mathematical programming approach in resource use estimation appears to be more appropriate and fits the reality better than econometric programming (FACEPA, 2008).

Furthermore, the TIPI-CAL model is based on the farm-level simulation approach that considers the detailed specification and representation of good production technology, for example, analysis of all farm inputs, services, and financial parameters of the typical farms. This model has the flexibility to include further modules for specific research questions (Sultana et al., 2014; Sultana et al., 2015; Hagmann et al., 2011). Therefore, TIPI-CAL has been extended to include a water module (called partial Life Cycle Assessment module) for estimating farm-level water requirement and water use efficiency in typical dairy farms in Bangladesh. The TIPICAL Model is extended for Life Cycle Assessment (LCA) for carbon and water footprint which was used in our study.

3. Results and Discussion

3.1. Milk production system and background information analyzed in the study areas

Table 1 shows the main farming system characteristics, especially background information on typical case farms selected through a panel approach. The data collection focused on the typical farms in Dinajpur, Sirajganj, and Kishoreganj. The region has a potential for high-performance dairying if compared with other regions in Bangladesh where cattle are predominantly integrated into the mixed (i.e., livestock and cropping) farming systems to fulfill a variety of functions. As the objective of the study was to assess the typical extent and diversity of water requirement and water use efficiency via input use for milk production.

to 14-cow/farm (BD-14) with the intensity of production was observed. The key determinants of water requirement for milk yield and production system variability can be postulated by breed type, type of feed used, feeds and feeding system, capital and labour inputs, and production technique practiced on the farm.

However, the small- and large-scale cooperative systems vary with the level of inputs and outputs across and within the regions, i.e., differences in input supply (e.g.,

Table 1. Inventory data and farming system characteristics

Variable	Unit	BD-2	BD-14
Background			
Region		Central, north, and northwest	Central, north, and northwest
Altitude	M	16	16
Farmland	Ha	0.4	0.4
Rainfall	m3/ha/year	19350	19350
Mean max. T	ºC	34.5	34.5
Livestock production			
Dairy cows	no.	4	22
Production system		Small-scale,	Large-scale, cooperative
Feeding system		Stall and [1]bathan feeding system	Stall and bathan feeding system
Breed		Local	Crossbred ([2]PMC*[3]HF* or Sahiwal)
Cow’s weight	kg/animal	250	350
Calves	(0-12 months)	1	6
Heifers	(>12-42 months)	0	0
First calving	Months	36	32
Dry period	Days	110	50
Calving interval	Days	440	380
Lactation	Days	330	330
Weaning period	months	3	3
Intensity of production		Low	High
Milk yield in kg	ECM/cow/year	954	1,299
Fat	%	3.9%	3.6%
Protein	%	3.3%	3.3%
Capital Productivity	kg milk/1000 C	9	12
Capital Productivity	cows/1000 C	0.01	0.01
Labour intensity	hour/kg ECM	0.47	0.24

[2]Bathan: a group of animals from cooperative production system are reared for seasonal grazing near the banks of a river, concentrate feed is provided two times in a day. Farmers build temporary cow shed for this purpose during the grazing period, during other times cattle stay in farm barn with stall feeding. [2]HF=Holstein Friesian. [3]PMC = Pabna Milking Cows (high yielding Local breed).

A significant variation about the inputs, herd size and productivity among the farming systems, ranging from a two-cow/farm (BD-2)

feed), source of water and water use level, land and labour allocation, milk production and capital productivity. Due to the varying levels of inputs and productivity (Table 1), farms are clustered into low and high on the intensity of production which is illustrated by the productivity of cows in terms of ECM/cow/year and inputs used such as labour, capital, and feed for producing milk. The small BD-2 farming system is mainly characterized by low productivity household farms which represent 49% of the farm and farmers without having off-farm income and in most cases, women are responsible for serving cattle, feeding poor-quality forages, crop residues, and kitchen waste. On the other hand, the BD-14 farming system is characterized by large and little more specialized compared to the small BD-2 farming system, and this farming is called family farm substantially depends on the income from dairy to the total household income. This BD-14 farm use crossbred dairy cattle that practice stall feeding and a seasonal collective feeding system (Bathan) and employ labour apart from family labour.

3.2. On-farm typical ration and milk yield

The on-farm typical ration is shown in Figure2 on the right-hand side) and milk yield in Figure 2 left-hand side both in natural content and energy corrected (ECM). The milk yield per cow in BD-14 is 21% higher due to a cross-bred, feeding system, and better management. Figure 2 left side shows the feed item used for concentrates (sesame oilcake, mustard oilcake), concentrate by-product (straw, wheat bran, and rice polish), and roughage (grass). The typical ration that is supplied to the BD dairy farms is very simple and consists of a large volume of dry roughage (i.e., rice straw) (approximately 60% DM of the ration) with a little number of concentrates meaning that the dairy cow ration is based on main roughage. The BD-2 farm based on the local breed has a lower milk yield and there is very no concentrate supply as compared to the BD-14.

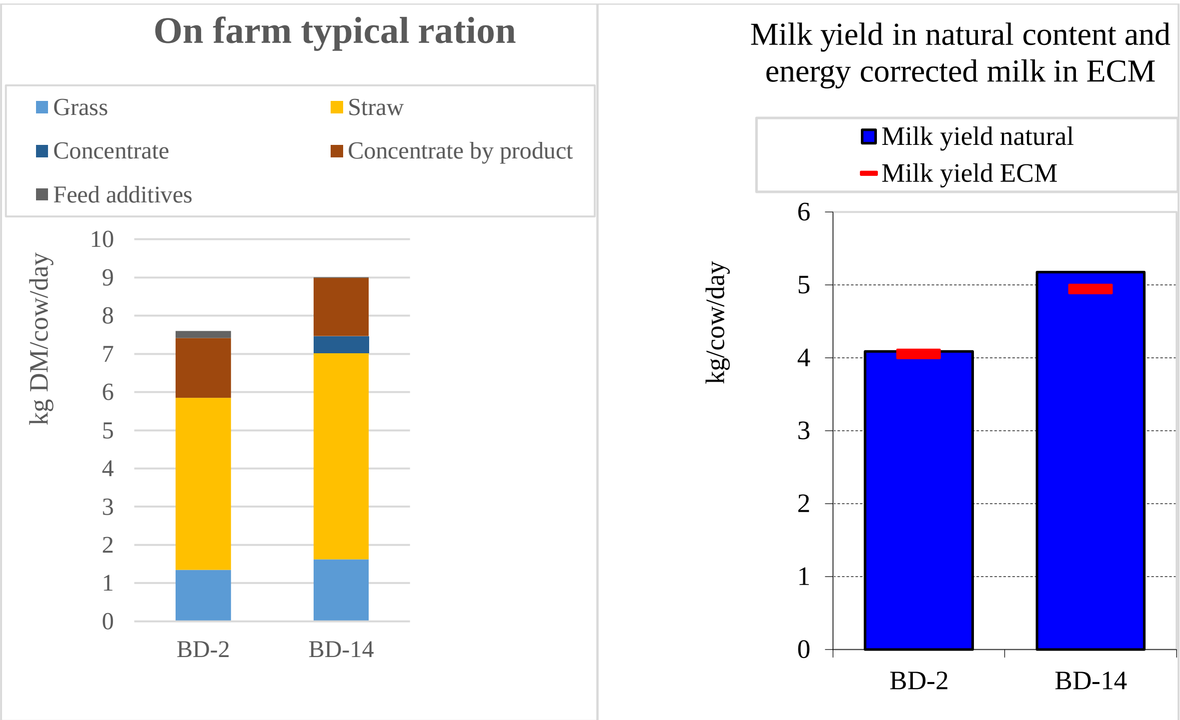

Figure 2. On farm typical ration and milk yield in natural content and energy corrected milk (ECM)

3.3. Drinking water per cow and drivers of water use in analyzed farms

In figure 3 (left-hand side), the BD-2 farm has lower drinking water (50 litre/day) compared to the BD-14 (59 litre/day) due to the high intensity of milk production (Figure 3 right-hand side) and higher dry matter intake per cow as it is shown in the left-handed Figure 2. Figure 3 (right-hand side) shows the highest amount of water use contribution is feed followed by drinking plus servicing water (i.e., cleaning dairy shed, utensils, and dairy animals themselves, etc.). In terms of proportion to total water requirement, 98% of water is used via feed and 2% for drinking and servicing.

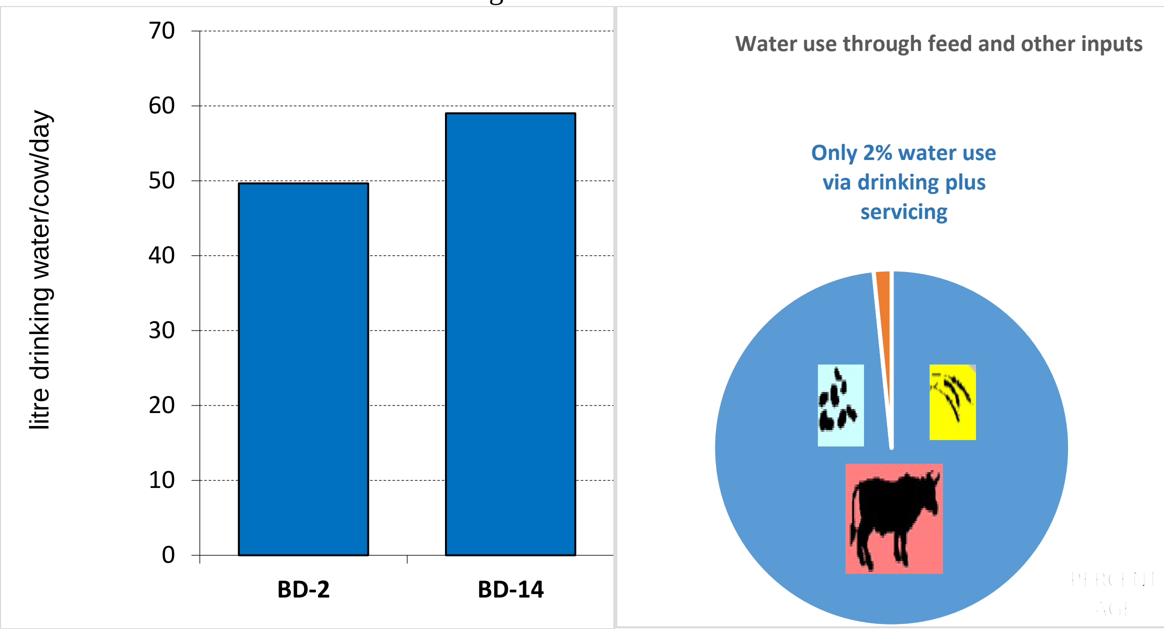

Figure 3. Drinking water and water requirement for milk production.

3.4. Farm level water requirement and water use efficiency

3.4.1 On farm level water requirement

In Bangladesh, which is a developing country, dairying is an integral part of many agricultural production systems and is also a prominent part of the social fabric of many households and communities. Hence, water usage in the dairy sector is considered an integral part of agricultural water resource management. To improve the performance of individual farms as well as the typical farming system, it is urgently needed to have a better understanding of the freshwater demand within specific regions and production system contexts. This required detailed water consumption and water use efficiency studies at the farm level. The study results show in figure 4 that the total water use (liters water/kg milk) of 2692 and 2112 liters for BD-2 and BD-14, respectively. The major driver for water use is the use of water through feed (˜98%) and only ˜2% of water use as drinking and service water which is shown in figure 3 right side. Figure 4 right-hand side shows the proportion of water used for concentrates (sesame oilcake, mustard oilcake), concentrate by-product (wheat bran and rice polish), and roughage (straw and grass). The middle figure shows that water use through concentrate and concentrate by-product is 2622 and 1864 litre per kg ECM of the BD-2 and BD-14, respectively, even though farming systems feeding ration comprises the rice straw and limited amount of green grass (figure 2 left-hand side). While the amount of concentrate and concentrate by-products are used low amount (Figure 2) but the amount of water used is higher through concentrate than roughage because growing cereals need more water (fourth times higher) because cereal is highly water-intensive than forage (sultana et al., 2014 and 2015).

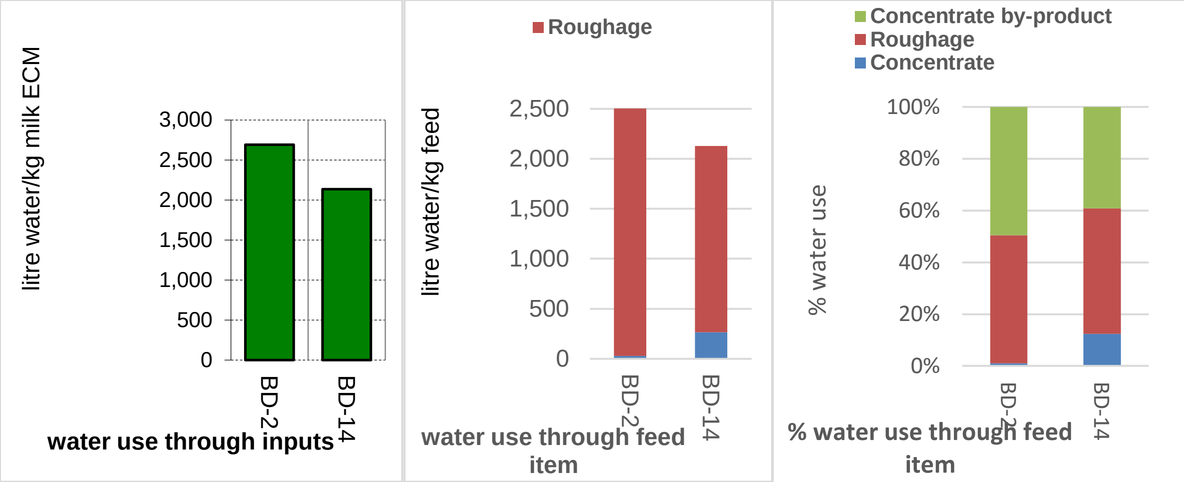

Figure 4 Farm-level water requirement

3.4.2. Water use efficiency and feed efficiency

Figure 5 shows the feed efficiency (kg milk in ECM/kg DM intake) of BD-2 and BD-14 are 0.53 and 0.55, respectively. On the other hand, the water use efficiency of BD-2 and BD-14 are 0.22 and 0.26, respectively. The BD-14 has higher dry matter intake and higher milk yield; therefore, this farm has higher feed efficiency and water use efficiency. Therefore, the higher the feed efficiency, the higher the water use efficiency. Hence, improving feed efficiency and water use efficiency in dairy is important for increasing dairy advantageous outputs.

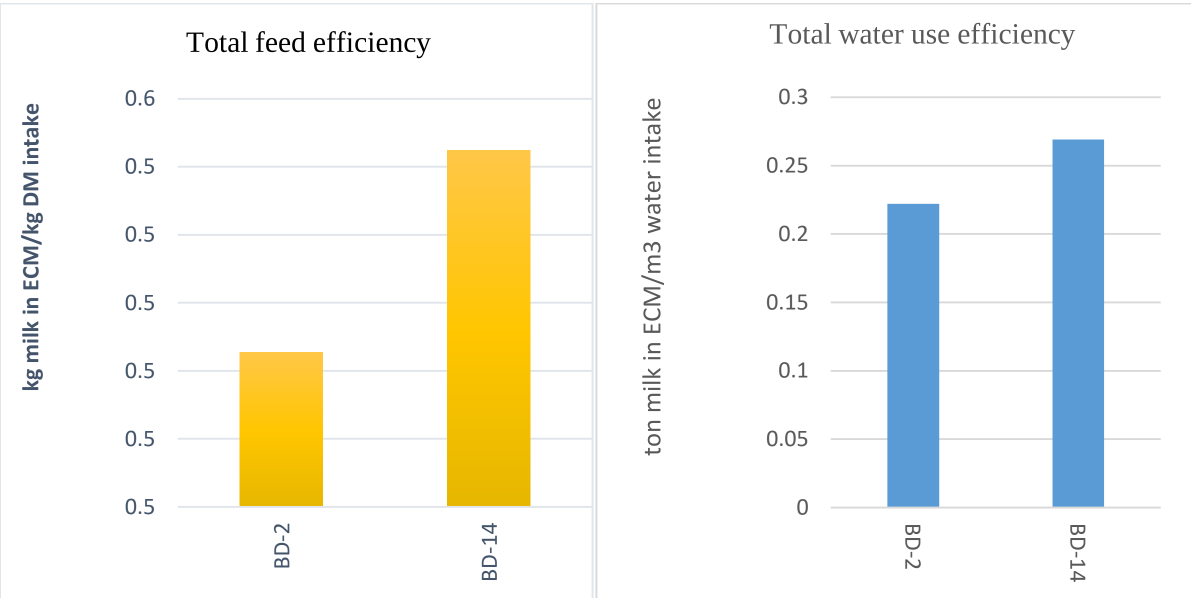

Figure 5. Water use efficiency and feed efficiency

The water use efficiency and water footprint are highly linked with the environmental impact of dairy farming and also play an important role to define the appropriate water policy. According to Riddout and Huang (2012), "the impact of water use in a region of water abundance does not have the same potential to impact human well-being and ecosystem health as water use in a region of water stress"

At the same pace, the estimation of the water use, and water use efficiency might be supportive to the Water Act 2013 in Bangladesh as this act is aiming to ensure the right to access to water by all people (Drinking, portable, water for hygiene, and domestic water use) (WARPO, 2022). Thus, the research on water use and water use efficiency is needed to be extended to cover a wider range of dairy farms and regions, with particular reference to comparing the regions with water abundance and water stress region.

4. Conclusion

The small BD-2 farming system is mainly characterized by small family farms which represent 65-70% of the farm and farmers without off-farm income in most cases, women are responsible for serving cattle and are fed poor-quality forages, and crop residues and kitchen waste. On the other hand, the BD-14 farming system is characterized by a large and little more specialized compared to the small BD-2 farming system. This BD-14 farm organized smallholder's crossbred dairy units which practice stall feeding and a seasonal collective feeding system (Bathan) and employ farm laborers. The typical ration of BD-2 farm mainly consists of rice straw contributing 60% DM of the ration and there is no concentrate supply. The BD-2 farm based on the local breed has a lower milk yield (954 ECM/cow/year) compared to the BD-14 farm-based crossbreed where milk yield (1299 ECM/cow/year).

The major results derived within this research for producing 1 kg of milk in Bangladesh need

- water requirement of approximately 2400 liters of water
- The water requirement for feed is far greater than the water required to meet the drinking plus servicing water in dairy production.
- approximately 98% of water is used through feeds and fodder
- >2% water used through others like drinking water and service water for dairy production.
- the BD-2 farm has lower drinking water (50 litre/day) compared to BD-14 (59 litre/day) due to the high intensity of milk production and higher dry matter intake per cow
- among the different sources of water use, water use through concentrate and concentrate by-product water is larger than roughage
- even with the fact that lower amount of use of concentrate and concentrate by-products at the farm level, the water requirement is high because cereal is highly water-intensive than roughage
- the water use efficiency of BD-2 and BD-14 are 0.22 and 0.26, respectively
- the higher the production efficiency, the higher the feed efficiency
- the higher the feed efficiency, the higher the water use efficiency
- finally, small-scale production farm (BD-2) needs more water per kg of milk as they have a small number of dairy cattle with low productivity than large-scale typical farming system (BD-14) with high productivity.

Increasing the efficiency of water used for dairy could reduce future demands for agricultural water. Therefore, measuring water use efficiency is a time being an approach that can be a good basis for extending this to dig deeper water footprint analysis of the dairy production system in Bangladesh.

Conflict of Interest

Authors declare no conflict of interest.

Acknowledgment

The authors highly acknowledge International Foundation For Science (IFS, Sweden) and the Ministry of Science and Technology (MOST) for providing financial support to materialize this study and the International Farm Comparison Network (IFCN) for access to the Model.

References

AFPC, 2010. The Agricultural and Food Policy Center, Bryan, Texas, USA. http://www.afpc.tamu.edu (accessed 04. 2011).

Custer, R. L., Scarcella, J. A., Stewart, B. R. 1999. The modified Delphi Technique – A rotational modification. Journal of vocational and technical education. Volume 15 No:2

Dhondyal, 1987. Strategic Analysis of the National River Linking Project of India by International Water Resorce Management (IWMI): available at: https://www.google.com.bd/search?tbm=bks&hl=en&q=Dhondyal+1987

FACEPA (Farm Accountancy Cost Estimation and Policy Analysis of European Agriculture). 2008. Cost of production: Definition and Concept, FACEPA.

INEA–Italy. http://www.rica.inea.it/public/it/view_file.php?action=article&id=127&ext=pdf&data_type=application/pdf (accessed 04. 2012).

Hagemann, M., Hemme, T., Ndambi, A., Alqaisi, O., Sultana, M.N., 2011. Benchmarking of greenhouse gas emissions of bovine milk production systems for 38 countries. Anim. Feed Sci. Technol. 166–167: 46–58. doi:10.1016/j.anifeedsci.2011.04.002.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., Mekonnen, M.M., 2009. Water Footprint Manual: State of the Art 2009. Enschede, the Netherlands: Water Footprint Network. http://www.waterfootprint.org/downloads/WaterFootprintManual2009.pdf (accessed 12. 2010)

International Farm comparison Network (IFCN), 2021. Dairy Report 2021. International Farm comparison Network Dairy Research Center, University of Kiel, Germany.

Integrated Dairy Research Network (IDRN), 2020 https://www.idrn-dairy.org/dairy-news/idrn-monthly-update

ISO, 2006b. Environmental management-Life cycle assessment-Requirements and guidelines, ISO 14044. International Organization for Standardization, Geneva, Switzerland.

The Daily Kaler Kantho. 2020. The Daily National Bangla News Paper. Published at 22 March, 2022.

Riddout, B.G., Huang, J. 2012. The environmental relevance-the key to understanding water footprint. PNAS, https://doi.org/10.1073/pnas.1203809109

Ridoutt, B.G., Williums, S.R.O., Baud, S., Fraval, S., Markst, N., 2010. The water footprint of dairy products: case study involving skim milk powder. J. Dairy Sci. 93, 5114–5117.

Rosegrant, M.W., Cai. X., Cline, S.A., 2002. Global Water Outlook to 2025: Averting an Impending Crisis, A Report Summary (Indianapolis, Indiana) 2020. Vision for food, Agriculture and the Environment Initiative, International Food Policy Research Institute (IFPRI), Washington, DC, and International Water Managemnet Institute (IWMI), Colombo, Sri Lanka.

Sultana M N, Uddin M M, Ridoutt B G, Hemme T and Peters K J 2014 Comparison of water use in global milk production for different typical farms. Agricultural Systems129: 9-21

Sultana M N, Ridoutt B G, Uddin M M, Hemme T and Peters K J 2015 Benchmarking consumptive water use of bovine milk production systems for 60 geographical regions: An implication for Global Food Security. Global Food Security 4: 56-68

Uddin, M.M., Sultana, M.N., Ndambi, O.A., Hemme, T. and Peters, K.J. 2010. A Farm Economic Analysis in different Dairy Production Systems in Bangladesh. Livestock Research for Rural Development, 22 (7) 2010, available at: http://www.lrrd.org/lrrd22/7/uddi22122.htm

Water Resource Planning Organization (WARPO), 2022. Bangladesh Water Act 2013. Available at: http://old.warpo.gov.bd/index.php/home/project_details/45#:~:text=The%20Bangladesh%20Water%20Law%20has,treated%20as%20a%20universal%20right.%22

WFN (Water Footprint Network), 2012. http://www.waterfootprint.org/?page=files/home