



Virtual water requirement of cow milk production under two different dietary strategies

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Received: 1 December 2019; Accepted: 1 January 2020

ABSTRACT

Nutritionists have liberty to choose various feeds for formulating a balanced ration depending upon the nutritive value, availability and feed cost. Although final target in an alternative ration is to obtain similar energy, protein and other nutrients, it would be favourable to consider virtual water (VW) requirement which must be spent while making a balanced ration. This paper compared two isonitrogenous and isocaloric balanced dairy cow rations for their VW requirements. VW in the maize silage-based ration was greater than that of alfalfa and wheat straw-based diet (39.73 versus 34.45 m³). It was also found that by-product feeds such as molasses, beet sugar pulp, corn gluten, and soybean meal require a lesser amount of VW, thus, they could be the best candidates to be used as much as conventional main feeds in the ration of dairy cattle for decreasing VW requirement of milk. Using feeds with less water utilization could reduce water requirement for milk production up to 12%.

Keywords: Cow milk, Ration formulation, Water footprint

Annual water consumption in Iran's agriculture sector was estimated at 82.5 bm³ contributing 93.2% of total usage, which was followed by municipal utilization (5.6 bm³). Industrial and miscellaneous usages also accounted for 0.03 and 0.37 bm³, respectively (Keshavarz and Heydari 2004). Therefore, agriculture and crop production demand a more significant amount of water compared to other daily human consumptions. Virtual water (VW) is defined as water that is really consumed in the process of production (Allan 1998, Wichelns 2001, Chapagain and Hoekstra 2004). It depends on many factors such as the method of production, geographic location, duration of production and efficiency of water utilization in the production process (Hoekstra and Hung 2002). For example, producing 1 kg of grain requires 1–2 m³ of water, while meat production requires four to 30 times more water per kg of meat (Allan 1998, Pimentel and Pimentel 2003, Qadir *et al.* 2003).

From 1970 to 2012, drought caused almost 680,000 deaths, due to the severe African droughts of 1975, 1983 and 1984. Wheat and maize are two main grains in the human and livestock diet, which are produced in remarkable quantity with worldwide production of 771.1 and 1,037.8 million tonnes for wheat and maize (Hancock 2012). These grains require about 1,159 and 710 m³/tonne of VW, respectively (Zimmer and Renault 2003). Thus, reducing grain wastages and their optimal utilization may play a very important role in the protection of water resources

(Khoramivafa *et al.* 2016).

Major water requirements for cow milk production include daily water consumption of lactating dairy cows; water utilization for cleaning which is used for different purposes such as milking, cleaning and disinfection of milking machine, parlor, etc. and virtual water consumed for producing dietary feeds. Virtual water which is utilized for feed production, accounts for about 99.64% of total daily requirements which indicates a massive contribution in total VW needs for milk production.

Although animal nutritionists select feeds mainly based on the availability and price, there is possibility and flexibility to formulate different balanced rations for a particular type of animal. Virtual water requirements of cattle feeds vary from 2.01 m³/kg in alfalfa to 5.6 m³/kg in molasses. Therefore, it is possible that different dairy cows' rations may result in different virtual water requirement for milk production. This means if there are remarkable differences between dietary strategies in total water requirements for milk production in a worldwide scale, dairy farms may play a very significant role in reducing water consumption within the agriculture sector and therefore objective of the present work was to assess the above hypothesis in two simulated lactating cow diets.

MATERIALS AND METHODS

To estimate virtual water required for cow milk production, two different rations were balanced according to NRC (2001) for a 780 kg Holstein dairy cow consuming 29.4 kg/d of DM and producing 45.0 kg/d of milk containing

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Table 1. Ingredients and nutrients of rations (% DM)

Item	Ration	
	Ration 1	Ration 2
Corn silage	36.65	—
Alfalfa hay	—	11.32
Wheat straw	2.65	14.85
Barley grain	14.25	20.25
Corn grain	13.46	20.42
Soybean meal	7.56	1.35
Canola meal	6.70	0.68
Corn gluten meal	2.49	—
Molasses	1.19	3.55
Beet sugar pulp	8.12	9.45
Wheat bran	0.53	3.38
Cottonseed	3.28	6.41
Fish meal, Anchovy	—	0.34
Urea	0.33	0.57
Salt Mineral	0.96	0.98
Potassium bicarbonate	0.26	0.27
Potassium iodide	0.10	—
Calcium carbonate	0.36	—
Phosphate deflourinated	0.32	0.34
Zinc sulfate	0.21	—
Vitamin premix ²	0.76	0.74

Ration 1, Corn silage and wheat straw; Ration 2, alfalfa hay and wheat straw; ²Vitamin premix contained Vitamin A (2.5 IU/kg), Vitamin D (0.4 IU/kg) and Vitamin E (1000 IU/kg).

3.70% fat and 3.30% protein. Rations contained either corn silage and wheat straw or alfalfa and wheat straw. Therefore, there were two assumed groups of treatment which they had different concentrate formulation (Table 1). The NDF contents of both rations were similar.

Virtual water for producing feedstuffs was collected from different published studies conducted in various places of

Table 2. Chemical composition and virtual water of rations¹

Diet nutrient balances	Ration 1	Ration 2
DM (%)	30.00	29.60
Crude protein (%)	15.90	15.90
RUP (%)	6.20	6.20
RDP (%)	9.70	9.70
MP allowable milk (kg/day)	45.10	45.00
Neutral detergent fiber (%)	31.74	32.70
Forage NDF (%)	18.60	16.60
ADF (%)	18.50	19.90
NE (Mcal/kg)	1.51	1.51
Energy allowable milk (kg/day)	47.00	46.10
ME (Mcal/kg DM)	2.43	2.43
Ca (g/Kg DM)	3.00	3.00
P (g/Kg DM)	2.00	2.00
VW (m ³ /day) ²	39.73	34.45

¹Calculated values using NRC model. Both groups of animals assumed to consume on average 29.43 kg DM/d. Ration 1, Corn silage and wheat straw; Ration 2, alfalfa hay and wheat straw.

²Calculated based on virtual water requirement of different feed production presented in Tables 3, 4 and 5.

Table 3. Virtual water (VW) requirement for forage feeds production

Feed	Yield (kg/ha)	VW (m ³ /kg)	Reference
Alfalfa hay	20021±5019	2.01±0.91	(Keshavarz and Heydari 2004, Hoseini <i>et al.</i> 2016, Zareabyaneh <i>et al.</i> 2015, Srairi <i>et al.</i> 2009, Starr and Levison 2014, Chapagain <i>et al.</i> 2003, Brown <i>et al.</i> 2009, Mubako 2011)
Corn silage	45,000	4.25	(Hoekstra 2003)
Wheat straw*	5,436	2.5±0.31	(Khoramivafa <i>et al.</i> 2016, Sun <i>et al.</i> 2013, Keshavarz and Heydari 2004, Hoseini <i>et al.</i> 2016, Ramezani <i>et al.</i> 2016, Nikbakht shahbazi 2018, Chapagain <i>et al.</i> 2003, Brown <i>et al.</i> 2009, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002)

¹One tonne of wheat grain can yield 0.80 tonne of wheat straw (Dai 2016).

the world and the average value of reported VW for a specific feed was calculated to make a more reasonable estimation of VW for each feed (Tables 3, 4 and 5). No VW was subjected to some mineral and vitamin supplements used in these diets, which made an insignificant contribution in the ration (3.33%). For calculating the virtual water of by-product, first, we consider the amount of water for producing the original crop and next VW was calculated by considering the by-product yield from the main food/feed. Because rations should not have any difference in DM content, the amount of water which was needed to adjust DM of the rations was counted for final VW of rations, after balancing all nutrients. The amount of water for drinking and cleaning part was assumed to be 2.93 and 0.676 (L/kg milk), respectively according to Kraub *et al.* (2016) estimation (Table 6).

RESULTS AND DISCUSSION

Since the 1990s, the public attention on water management and especially on water related to food production has been increased. The importance of virtual water at the global level has increased doubling for cereals and tripling for meat between 1993 and 2020 (Rosegrant and Ringler 1999). Therefore, the management of virtual water embedded in the food is important, especially in regions where access to water is limited (Renault 2003). Table 2 shows the chemical composition and the virtual water calculated for both rations. As shown, the rations were formulated to have the same chemical composition. Moreover, because there were different feeds in two rations, they showed different VW (39.73 versus 34.45 m³). To our knowledge, this was the first time that the amount of VW

Table 4. Virtual water (VW) requirement for protein feeds production

Feed	Yield (kg/ha)	VW (m ³ /kg)	Reference
Canola meal ¹	637±31	16.39±9.26	(Amini and Porhemmat 2017, Ramezani <i>et al.</i> 2016, Starr and Levison 2014, Chapagain <i>et al.</i> 2003, Zimmer and Renault 2003)
Corn gluten ²	415	1.97±0.38	(Khoramivafa <i>et al.</i> 2016, Sun <i>et al.</i> 2013, Lim <i>et al.</i> 2017, Nikbakht shahbazi 2018, Ramezani etedali <i>et al.</i> 2016, Srairi <i>et al.</i> 2009, Chapagain <i>et al.</i> 2006, Hoff <i>et al.</i> 2014, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002)
Cotton seed	17822±9134	3.28±1.63	(Zimmer and Renault 2003, Chapagain <i>et al.</i> 2003, Hoekstra and Hung 2002)
Fish meal		1.8	(Pahlow <i>et al.</i> 2015)
Soybean meal ³	3681.82	2.37±0.53	(Starr and Levison 2014, Chapagain <i>et al.</i> 2003, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002)
Wheat bran ⁴	1699	4.43±0.36	(Khoramivafa <i>et al.</i> 2016, Sun <i>et al.</i> 2013, Keshavarz and Heydari 2004, Hoseini <i>et al.</i> 2016, Ramezani etedali <i>et al.</i> 2016, Nikbakht shahbazi 2018, Chapagain <i>et al.</i> 2003, Brown <i>et al.</i> 2009, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002)

¹One kg of canola can yield 450 g canola meal (<https://www.feedipedia.org/node/52>); ²One tonne of corn can yield 50 kg of corn gluten (www.starch.dk/isi/starch/glutenmeal.asp); ³5.5 kg of soybean can yield 4.5 kg of soybean meal (Irwin 2017); ⁴One tonne of wheat can yield 0.25 tonne wheat bran (Sibakov *et al.* 2013).

is considered to formulate the ration without any significant difference in chemical composition. The main reason for the higher VW in the maize silage-based ration is that the greater amount of VW is utilized for producing maize forage compare to alfalfa and wheat straw as shown in Table 3 (4.25 m³/kg, 2.01 m³/kg and 2.30 m³/kg for maize forage, alfalfa hay and wheat straw respectively).

Tables 4 and 5 present the utilization of water for the production of protein and energy parts of concentrate. Among the protein sources (Table 4), canola meal production consumed a greater amount of water compared to other feeds (16.39 m³/kg). Within high energy feeds, barley was a major water consumer (2.70 m³/kg). As it can

Table 5. Virtual water (VW) requirement for energy feeds production

Feed	Yield (kg/ha)	VW (m ³ /kg)	Reference
Barley	3727±922	2.70±0.34	(Nikbakht shahbazi 2018, Hoseini <i>et al.</i> 2016, Zareabyaneh <i>et al.</i> 2015, Ramezani etedali <i>et al.</i> 2016, Srairi <i>et al.</i> 2009, Chapagain and Hoekstra 2003, Brown <i>et al.</i> 2009, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002)
Sugar beet pulp ¹	1887.44	5.6±0.03	(Keshavarza and Heydari 2004, Hoseini <i>et al.</i> 2016, Zareabyaneh <i>et al.</i> 2015, Zimmer and Renault 2003, Ibidhi and Salem 2019)
Corn	8307±1947	1.87±0.36	(Khoramivafa <i>et al.</i> 2016, Sun <i>et al.</i> 2013, Lim <i>et al.</i> 2017, Nikbakht shahbazi 2018, Ramezani etedali <i>et al.</i> 2016, Srairi <i>et al.</i> 2009, Chapagain and Hoekstra 2003, Hoff <i>et al.</i> 2014, Mubako 2011, Zimmer and Renault 2003, Hoekstra and Hung 2002, Ibidhi and Salem 2019)
Molasses ²	1887.44	5.6±0.04	(Keshavarz and Heydari 2004, Hoseini <i>et al.</i> 2016, Zareabyaneh <i>et al.</i> 2015, Zimmer and Renault 2003)

¹One tonne of sugar beet can yield 50 kg of dried sugar beet pulp (Heuze *et al.* 2019); ²One tonne of sugar beet can yield 50 tonnes of molasses (Heuze *et al.* 2018).

be seen in Table 4, we found more variation on the amount of water utilization for canola in reported values which is related to different factors such as the irrigation system, cultivation system, harvest system, soil fertility, farmer's practice and amount of annual rainfall (Srairi *et al.* 2009). Therefore, it is necessary to improve irrigation system to save water consumption in the agriculture sector.

On an average, the amount of virtual water utilized for producing the protein part of the concentrate is higher than the forage and energy feeds. Interestingly, by-product feeds such as molasses, beet sugar pulp, corn gluten, and soybean meal require a lesser amount of VW; they could be the best candidates to be used in the ration of dairy cattle for decreasing VW requirement of milk.

Total VW for one kg cow milk production under two different dietary scenarios was calculated and given in Table 6. As mentioned earlier, virtual water consumed for producing dietary feeds contributed to the main component of VW consumption for milk production. Eastridge *et al.* (2017) formulated diets for lactating dairy cows based on three types of forage (Corn silage alone, corn silage, and

Table 6. Total virtual water (VW) for milk production from different sources¹

Item	Ration 1	Ration 2
Milk yield (kg)	45.00	44.90
Fat (%)	3.69	3.70
Protein (%)	3.30	3.30
Dietary VW (m ³ /kg milk)	1.0670	0.94
Cleaning water (m ³ /kg milk) ¹	0.0006	0.0006
Drinking water (m ³ /kg milk) ¹	0.0029	0.0029
Sum	1.07	0.95

¹ Ration 1, Corn silage and wheat straw; Ration 2, alfalfa hay and wheat straw.

wheat straw or alfalfa) and they found that feeding with similar amount of forage NDF concentrations resulted in same animal performance and ruminal fermentation. Kleinschmit *et al.* (2007) also examined three forage strategies (corn silage, alfalfa hay and their mixture) in feeding of lactating dairy cows and they found no significant difference in 4% fat corrected milk of treatment groups.

According to FAO (2018), total milk production in the world was 810,652 thousand tonnes, which needed a considerable amount of water. In this study, it was tried to introduce a ration that consumed a lesser amount of water without any functional reduction in cow's performance or economic disadvantage by using it. Scenario analysis indicated that using feed with less water utilization can reduce water requirement for milk production up to 12% (Table 6). There is a significant amount of water utilized in the whole world milk production; however, according to research of Ibidhi and Salem (2019) considering eight dairy cattle farms, it was revealed 16% reduction in water consumption used for milk production.

Based on the equation developed by Kraub *et al.* (2016), a lactating dairy cow with 50 kg daily milk yield drinks 146.71 L water per day at a mean environmental temperature of 35°C. They also estimated an average of 33.8 L water (per day per cow) for cleaning purposes. It was found that 1.0 m³ of water is required to produce 1 kg of milk under Australian semi-arid but it is not a fixed value as it can be seen in Table 6. Ration 2 which was based on alfalfa and wheat straw (CS) can reduce the whole VW for milk production below 1.0 m³. These matters displayed a difference, which was attributed to sorts of feed elements of ration and slaughter weight of the animal (Singh *et al.* 2014).

Our study confirmed the result of Singh *et al.* (2014) which indicates that livestock water requirement for drinking and washing was very low (3.6%) in comparison with feed and fodder production, while the livestock water productivity varied widely with their rearing system (extensive vs. intensive system) and animal species.

It can be concluded from the present study that by providing sufficient nutrients to animal through balanced rations but containing feeds which needed lower water for their production, it could be possible to reduce water requirement for milk production up to 12%.

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