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Economic Water Productivities Along the Dairy Value Chain in South Africa: Implications for Sustainable and Economically Efficient Water-use Policies in the Dairy Industry

Enoch Owusu-Sekyere *, Morné Erwin Scheepers, Henry Jordaan

Department of Agricultural Economics, University of the Free State, PO Box/Posbus 339, Bloemfontein 9300, South Africa

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ABSTRACT

The global water scarcity situation is a major issue of concern to sustainable development and requires detailed assessment of water footprints and water productivities in all sectors of the economy. This paper has analysed economic water productivities along the dairy value chain in South Africa. The findings reveal that the value added to milk and water as it moves along the value chain varies from stage to stage; with the highest value being attained at the processing level, followed by the retail and farm gate levels, respectively. Milk production in South Africa is economically efficient in terms of water use. Feed production accounts for about 98.02% of the total water footprint of milk with 3.3% protein and 4% fat. Feed production is economically efficient in terms of cost and water use. Value addition to milk and economic productivity of water are influenced by packaging design. Not all economically water productive feed products are significant contributors to milk yield. Future ecological footprint assessments should take into account the value added to output products and economic water productivities along the products' value chain, rather than relying only on water footprint estimates.

1. Introduction

The global water scarcity phenomenon has become a major issue of concern to governments, organisations, policy-makers, water-users and water managers. A significant proportion (two-thirds) of the world's population faces difficulties in getting freshwater (Mekonnen and Hoekstra, 2016). The pressure on freshwater resources arises as a result of population growth, climate change, pollution of existing water resources, urbanisation, among other things (Jefferies et al., 2012). In many parts of the word, quantities of water supply do not meet the quantity demanded by the various sectors of the economies. Food production has been identified as the major user of the available scarce water resources; accounting for about 86% of all global water use (IWMI, 2007). However, given the fact that food production is vital for human survival and the essential role that water plays in food production, there is the need to design strategies and methods to make efficient use of water in all sectors, particularly in agriculture which uses most of the world's water. Based on this, two internationally accepted concepts of water footprint have been developed; the water footprint concept as described by Hoekstra et al. (2011) and the Life Cycle Assessment (LCA) as described in the ISO standards. The water footprint (WF) approach introduced by Hoekstra (2003) is gaining prominence because it gives a comprehensive assessment of freshwater use, and quantifies and maps water consumption and pollution in relation to production or consumption. The concept of water footprint in the Life Cycle Assessment approach (LCA) has also been applied in many studies (Ridoutt et al., 2014; Zonderland-Thomassen et al., 2014).

Various authors have assessed water footprints of products in the agricultural sector. Ridoutt et al. (2014) and Zonderland-Thomassen et al. (2014) assessed the water footprint of beef cattle and sheep production systems in Australia and New Zealand, respectively. In China, water availability footprint of milk and milk products from large-scale farms has been assessed by Huang et al. (2014). Matlock et al. (2012) examined the potential water use, water stress, and eutrophication impacts from US dairy activities. Environmental impacts associated with freshwater consumption along the life cycle of animal products was analysed by De Boer et al. (2013) in the Netherlands. Amarasinghe et al. (2010) assessed water footprints of milk production in India. Water footprint analyses of milk production in Germany and Argentina have been examined by Drastig et al. (2010) and Manazza and Iglesias (2012), respectively.

The growing body of literature is limited to quantification of water footprint indicators and, to some extent, the environmental impact. The economic aspect of water footprint indicators has received little attention, particularly in the semi-arid and arid regions of southern Africa. Meanwhile, Hoekstra et al. (2011), and Pérez-Urdiales and García-

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* Corresponding author.
E-mail addresses: kofiwusu23@gmail.com (E. Owusu-Sekyere), MorneErwinScheepers@gmail.com (M.E. Scheepers), JordaanH@ufs.ac.za (H. Jordaan).

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Valiñas (2016) indicated that economic water efficiency and water-efficient technologies are very important to ecologically sustainable environmental policies. Existing studies on economic water productivities are limited to that of Chouchane et al. (2015) who assessed the economic water and land productivities related to crop production for irrigated and rain-fed agriculture in Tunisia. Similar assessments have been done for case studies in Morocco and Kenya (Mekonnen and Hoekstra, 2014; Schyns and Hoekstra, 2014). Zoumides et al. (2014) also included economic water productivity when assessing the water footprint of crop production and supply utilization in Cyprus. It is clear that the focus has been on economic water productivities of crops, with no similar research being done in the livestock sector. To the best of our knowledge, no known study has evaluated the economic productivity of water along the dairy value chain. Therefore, current knowledge is insufficient to understand whether, how and why water users and managers along the dairy value chain might shift to more sustainable and economically efficient production patterns.

The present paper contributes to filling this gap in knowledge by assessing the economic water productivity along the dairy value chain in South Africa. We estimated economic water productivity for milk and important feed crops because evidence shows that a significant proportion of water usage in the dairy sector goes into feed production. This will be the first step towards an assessment of economic water productivities for feed crops and dairy products, particularly in Africa. The economic water productivity is the value of the marginal product of the agri-food product with respect to water (Chouchane et al., 2015; Molden, 2007; Playan and Matoes, 2006). The economic productivity gives an indication of the income that is generated per cubic metre of water used. The economic water productivity is calculated in two steps. First, the physical water productivity (in kg/m^3 of water) is calculated by dividing the yield (kg) by the water footprints (m^3) of the product. In the second step, the economic productivities (US$/$m^3$ of water) of the product are calculated by multiplying the physical water productivity (kg/m^3) of each product by their monetary value (US$//kg).

2. Methodology

2.1. Conceptual and Empirical Framework

The concept of the Global Water Footprint Standard of the Water Footprint Network was employed in this study. The water footprint network approach adopted gives a distinction between green, blue and grey water used along the value chain (Berger and Finkbeiner, 2010; Hoekstra et al., 2011). The calculations of blue, green and grey water footprints of the feed crops and milk followed the terminologies and procedures set out in The Water Footprint Assessment Manual (Hoekstra et al., 2011). The blue water footprint ($WF_{proc,blue}$, m^3/tonne) is estimated as the blue component in crop water use (CWU_{blue},m^3/ha), divided by the crop yield (Y, tonne/ha) in relation to the feed crops. This is specified as:

$$WF_{proc,blue} = \frac{CWU_{blue}}{Y} \quad (\text{volume/mass}) \tag{1}$$

The green water footprint (WF_{green}, m^3/tonne) is calculated in a similar manner as the blue water footprint. The green water used for feed crop production and natural vegetation for pastoral grazing constitute the total green water footprint considered along dairy value chain because we found that no green water is used at the processing and retailing stages of the dairy value chain. The final calculated green water footprint is an indicator of the total amount of rainwater that was evapotranspired by the crop and incorporated into the crop.

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \quad (\text{volume/mass}) \tag{2}$$

The crop water use component of Eqs. (1) and (2) is defined as the sum of the daily evapotranspiration (*ET*, mm/day) over the complete growing period of the feed crop (Hoekstra et al., 2011). This is expressed as:

$$CWU_{blue,green} = 10 \times \sum_{d=1}^{\text{lgp}} ET_{blue,green}(volume/area) \tag{3}$$

The blue and green water evapotranspiration is denoted by $ET_{blue,green}$. The water depths are converted from millimetres to volumes per area (m^3/ha) by using the factor 10. Summation is done over the complete length of the growing period (lgp) from day one to harvest (Hoekstra et al., 2011). Grey water footprints ($WF_{proc,grey}$, m^3/tonne) of the feed crops are estimated by taking the chemical application rate for the field per hectare (AR, kg/ha) and multiplied by the leaching-run-off fraction (α). The product is divided by the difference between the maximum acceptable concentration (c_{max}, kg/m^3) and the natural concentration of the pollutant considered (c_{nat}, kg/m^3). The result is then divided by the crop yield (Y, tonne/ha). This is expressed empirically as:

$$WF_{proc,grey} = \frac{(\alpha \times AR)/(c_{\max} - c_{nat})}{Y} \quad [\text{volume/mass}] \tag{4}$$

In the study area, fresh water used in cleaning the processing facilities was recycled and later used for cleaning the cattle runs and the floor of the dairy parlour. The dairy processing water thus becomes grey water in the effluent pond and was accounted for according to the grey water methodology. The grey water emanating from the faeces and urine of the lactating cows was estimated with the use of an effluent sample analysis, and the volume measured as the flow into the effluent pond. After estimating the blue, green and grey water footprints, they were summed up to obtain the total water footprint.

After calculating the water footprint of the feed crops, we calculated the marginal water productivities for the feed crops. In estimating the water productivities for the feed crops, a distinction was made between crop yield from rainfall and that of irrigation. Once such distinction is made, water productivities can be discussed in terms of green and blue water. The blue water productivity is described as the incremental yield attained due to irrigation divided by the blue water footprint or the volume of blue water consumed (Hoekstra, 2013). This is expressed as:

$$WP_{blue} = \frac{Yt_{blue}}{ET_{blue}} \tag{5}$$

where Yt_{blue} is the crop yield under irrigation, and ET_{blue} is the evapotranspiration of blue water. Green water productivity, on the other hand, can be defined as the crop yield obtained from rainfall only, without irrigation, divided by the total green water used by the crop (Hoekstra, 2013). This is specified as:

$$WP_{green} = \frac{Yt_{green}}{ET_{green}} \tag{6}$$

where Yt_{green} is the crop yield under rain fed conditions only, and ET_{green} is the evapotranspiration of green water that would have occurred without irrigation. Crop yield under rain fed conditions only (Yt_{green}), according to Chouchane et al. (2015) and Doorenbos and Kassam (1979) can be calculated as:

$$\left(1 - \frac{Y_a}{Y_m}\right) = RF_y\left(1 - \frac{ET_a}{CWR}\right) \tag{7}$$

where RF_y is a yield response factor, Y_a is the actual crop yield in kg per hectare, and Y_m is the maximum yield attainable at optimum water level. ET_a denotes the actual crop evapotranspiration measured in millimetres per period, whereas CWR is the crop water requirement in millimetres per period. The total water productivity then becomes the sum of blue and green water productivities for the feed crops:

$$Total\ WP = WP_{green} + WP_{blue} \tag{8}$$

Regarding the primary product (milk), the chain-summation approach was used to estimate the water footprint since our focus was only on milk and not a variety of derived dairy products (Hoekstra et al., 2011). The water footprint of milk consists of direct and indirect water footprints (Mekonnen and Hoekstra, 2010a). The water footprint for the output product (processed milk with 3.3% and 4% fat) is denoted by $WF[\Upsilon]$. The output product (Υ) is produced from x inputs. Let x inputs be numbered from $i = 1\ldots.\ x$. Assuming that x inputs are used to produce only Υ dairy product. The output product's (Υ) water footprint is represented as:

$$WF_{prod}[\Upsilon] = \frac{\sum_{i=1}^{x} WF_{proc}[i]}{P[\Upsilon]} \quad (\mathrm{m}^3/\mathrm{tonne}) \tag{9}$$

where $WF_{prod}[\Upsilon]$ denotes the total water utilized in order to produce Υ. The water footprint of input i is represented by $WF_{prod}[i]$ and $P[\Upsilon]$ is the production quantity of product Υ. Given that $WF_{prod}[\Upsilon]$ is measured in m^3 per tonne; the physical water productivity (PWP) of the output product Υ is expressed in kilograms per cubic metre ($\mathrm{kg/m}^3$) and specified as:

$$PWP(kg/m^3) = \frac{1}{WF_{prod}[\Upsilon](m^3/tonne)} * 1000 \tag{10}$$

After calculating the physical water productivity, the economic water productivity for the output product Υ is then attained by multiplying the physical water productivity by the monetary value added to Υ per kilogram. Various authors in recent literature have used producer prices as a proxy for value added in estimating economic water productivities due to difficulties in getting data for estimating value added to the products investigated (Chouchane et al., 2015; Schyns and Hoekstra, 2014; Zoumides et al., 2014). However, this paper adds some novelty in our economic water productivity estimates by moving a step further to calculate the value added to milk along the dairy value chain as well as some important feed products for our productivity estimates. As the main product moves along the value chain, value is added at each stage. Hence, we estimated the value added to milk at the farm gate, processing or wholesale and retail levels in order to ascertain the point along the dairy value chain where most value is added. The value added to the out product (Υ) was estimated by deducting the cost per kilogram of Υ from the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain (Crafford et al., 2004). Thus, the value added to the output product (Υ) is the total revenue from the product minus the cost of all intermediate inputs employed in the production of Υ. We denote the value added to Υ at a particular stage of the value chain as $\mathrm{VAD}_{ivc}[\Upsilon]$ and expressed empirically as:

$$\mathrm{VAD}_{ivc}[\Upsilon] = \mathrm{Re}_{ivc}(\Upsilon)\text{-}\mathrm{Co}_{ivc}(\Upsilon) \qquad \mathrm{ZAR/kg} \tag{11}$$

where $\mathrm{Re}_{ivc}(\Upsilon)$ is the sales revenue obtained from selling one kilogram of Υ at each stage of the value chain and $\mathrm{Co}_{ivc}(\Upsilon)$ is the cost of all intermediate inputs employed to produce a kilogram of Υ. $\mathrm{Co}_{ivc}(\Upsilon)$ consists of the cost of water usage, capital, land, labour, feed, taxes, veterinary, transport, packaging, fuel, repairs and maintenance, etc. The total value added ($\mathrm{TVAD}[\Upsilon]_{vc}$) along the complete value chain was calculated by summing the value added at each stage of the value chain. This is specified as:

$$\mathrm{TVAD}_{vc}[\Upsilon] = \sum_{i=1}^{3} \mathrm{VAD}_{ivc} \qquad \mathrm{ZAR/kg} \tag{12}$$

The value added to water as the product moves along the value chain can be expressed as the ratio of the value added to the output product (Υ) at each stage of the value chain over the quantity of water utilized at the respective stages (Crafford et al., 2004). Given the value added to the output product (Υ) along the value chain, marginal contribution from water MVAD[water] is specified as:

$$\mathrm{MVAD[water]_{vc}} = \frac{\mathrm{VAD_{ivc}}}{\mathrm{WU_{ivc}}} \tag{13}$$

$\mathrm{VAD_{ivc}}$ denotes value added to the product at i stage of the value chain and $\mathrm{WU_{ivc}}$ is the quantity of water used at i stage of the value chain. We then expressed the economic water productivity as:

$$\mathrm{EWP}\left(\mathrm{ZAR/m^3}\right) = \mathrm{PWP}\left(\mathrm{kg/m^3}\right) * \mathrm{VAD(ZAR/kg)} \tag{14}$$

The economic water productivity (EWP) is expressed in ZAR[1]/m^3. The procedure for estimating the physical and economic water productivities for the output product was applied to estimate the physical and economic water productivities for the feed crops.

2.2. Data

Both primary and secondary data pertaining to the South African dairy sector were used. Primary data on cost and revenue expenditures on feed products and raw milk were obtained from dairy agribusiness companies who form part of the South African Milk Processors' Organisation (SAMPRO), and Milk South Africa (Milk SA). Milk SA was established in 2002 to oversee the South African dairy industry. These organisations consist of dairy producers and processors, who produce different dairy products for the local and international market. These companies consist of both commercial dairy and processing plants where milk is processed and bottled. Data on price consisted of producer, wholesale and retail prices. Secondary data on feed production, inputs cost, water usage for feed crops and servicing water used in the dairy industry were attained from SAMPRO, Milk SA and Van Rensburg et al. (2012). Van Rensburg et al. (2012) assessed water utilization for important field and forage crops. The dairy producers considered have feed calculation systems with electronic recordkeeping and as such accurate data on feed composition and the quantities fed to animals were available. The data obtained were aggregated and average values were used in further calculations. The electronic feed calculator records information on quantities of the various feed products and ingredients in feed ration, moisture content, dry matter, nutritional values of the inputs and the complete ration for the lactating cows. Data obtained from these sources were used to calculate the volumes of blue, green and grey water utilized in milk production. Our estimated water footprints for feed crops such as maize, soy and sun flower were compared to the estimates obtained by Mekonnen and Hoekstra (2010a) for South Africa. Secondary data on prices of feed crops were obtained from Bureau of Food and Agricultural Policy and Southern Africa (BFAP).

3. Results and Discussion

3.1. Water Footprint, Marginal and Economic Water Productivities of Feed Products

Table 1 presents the water footprints of key feed products included in a balance ration formulated for dairy cows. We estimated blue, green and grey water footprints for these feed stuffs in order to ascertain which of them uses more water. The results show that high protein concentrates (HPC) and yellow maize meal had the highest total water footprints, while oats silage had the lowest. Among all the feed crops,

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[1] Average exchange rate for December 2015: US$1; ZAR 15.05.

Table 1
Water footprint of main feed products in a complete ration for dairy cows.
Source: Author's calculations, 2015.

Feed products	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Lucerne hay	217,942	263,165	99,682	580,788
Oats Silage	103,587	23,397	9965	136,948
Sorghum Silage	122,421	107,529	18,031	247,981
Maize Silage	188,961	179,215	28,872	397,047
Yellow maize meal	0	2,256,175	195,969	2,452,143
HPC	74,643	2,512,770	47,560	2,634,972
Soybean cake	53,400	1,662,502	8797	1,724,698
Sun flower cake	21,207	850,268	38,800	910,274

HPC: High Protein Concentrate.

lucerne hay and maize silage had the highest blue water footprints. In terms of green water, high protein concentrate and yellow maize meal had the highest footprints, respectively. In all instances, the grey water footprint was lower than both blue and green water footprints, with the exception of yellow maize meal and sun flower cake. Additionally, maize meal and lucerne hay recorded the highest grey water footprints.

Prior to the estimation of economic water productivities of the feed products, their dry matter contribution and marginal water productivities were calculated for a balance ration providing an average of 26.32 kg of dry matter per day for dairy cows and the results are presented in Table 2. It must be emphasised that water productivities were estimated for the main feed stuffs and ingredients. Out of the 26.32 kg of dry matter (DM) supplied, 28.42% representing 7.48 kg was provided by yellow maize meal. High protein concentrate (HPC) contributed 18.47% (4.86 kg) to the total dry matter. Lucerne hay and maize silage contributed 16.03% and 14.78%, respectively to the dry matter. Sorghum and oat silage also contributed 9.80% and 3.99% of the total daily dry matter, respectively. This result implies that yellow maize meal, high protein concentrate and lucerne hay are very important contributors to dry matter for dairy cows, not excluding the other feed stuffs. In order to arrive at meaningful conclusions, we estimated the marginal contribution of the individual feed products to the total milk output. The total average milk yield per year for the dairy farms considered for this study was 13,197 t. The results reveal that yellow maize meal is the highest contributor to yearly milk yield. Similarly, we found that high protein concentrate and lucerne hay are the second- and third-highest contributors to the yearly milk yield, respectively. Maize silage contributed 14.78% of the total yearly milk output, with the lowest contribution coming from oat silage. Soybean and sun flower cakes are incorporated into HPC and not fed to the animals separately, so we did not estimate separate contributions to dry matter for these feed ingredients.

After estimating the contribution to yield from the individual feed crops, water productivities of the feed products were estimated by dividing their contribution to yield by their respective water footprints. The results are presented in the last column of Table 2. The findings show that feed products such as sorghum silage, maize silage, oats silage and lucerne hay have high marginal water productivities. However, expressing water productivities in physical terms is not sufficient to meaningfully explain the economic benefits of water-use. Hence, we estimated economic water productivities which give insight to the economic benefits of water usage in the feed production sector. The results are presented in Table 3. The value added to the feed crops and ingredients were estimated for economic and policy purposes. In terms of value addition, the results show that more value is added to high protein concentrate and yellow maize meal, as ZAR 6.91 and ZAR 4.39 are attained from these feed products, respectively. This is followed by lucerne hay, sorghum and maize silages, respectively. The least value added is associated with oats silage. The results generally suggest that the production of all the feed products considered is economically efficient since the monetary value attained from them is positive. However, the value added varies from product to product.

The results in Table 3 further revealed that sorghum silage and lucerne hay are the top two feed products which have high economic water productivities; as every cubic metre of water used in producing sorghum silage and lucerne hay results in ZAR 8.72 and ZAR 6.82, respectively. This is followed by yellow maize meal and high protein concentrate (HPC); as every cubic metre of water used in their production yields about ZAR 6.71 and ZAR 6.43, respectively. Maize silage had the least economic water productivities. The above results provide vital information for livestock feed producers and water users along the dairy value chain as to which feed crops or products are economically efficient to produce in terms of water use and profitability. Notwithstanding this, the contribution to dry matter and milk yield should be taken into consideration in order to attain higher proceeds. For instance, the total economic water productivity estimates and contributions to milk output indicate that feed products such as yellow maize meal, high protein concentrate and lucerne hay are very economical in terms of water and have high contributions to milk yield. Hence, profit-maximising dairy farmers and feed manufacturers with sustainable and efficient water-use objectives can focus more on such feed products which are good contributors to milk yield and have high economic water productivities.

Despite the high economic water productivity of sorghum silage, our findings indicate that its contribution to milk yield is low, relative to feed products such as maize meal, HPC and lucerne hay. This implies that not all economically active feed products are significant contributors to milk output. Similarly, maize silage has low economic water productivity and somewhat low contribution to milk output. Therefore, dairy farmers can replace it with feed products such as triticale silage

Table 2
Dry matter contribution and marginal water productivities of main animal feed products in a complete ration for dairy cows.
Source: Author's calculations, 2015.

Feed products	Total WF (m^3/year)	Kilogram of dry matter per day	Percentage contribution to milk output[a]	Actual contribution to yearly milk output (tonnes)	Marginal water productivities (kg/m^3)
Lucerne hay	580,788	4.22	16.04	2117	3.64
Oats Silage	136,948	1.05	3.99	527	3.84
Sorghum Silage	247,981	2.58	9.80	1293	5.22
Maize Silage	397,047	3.89	14.78	1950	4.91
Maize meal	2,452,143	7.48	28.42	3750	1.53
HPC	2,634,972	4.86	18.47	2437	0.93
Other ingredients	1,409,485	2.24	8.50	1122	0.80
Total	7,859,363	26.32	100	13,197	20.87

[a] Average dry matter to milk yield ratio for South Africa: 1 kg DM: 3.8 output Mekonnen and Hoekstra (2010b).

Table 3
Value addition and economic water productivity of main feed products.
Source: Author's calculations, 2015.

Feed products	Marginal water productivities (kg/m^3)	Value added (ZAR/kg)	Economic water productivities (ZAR/m^3)
Lucerne hay	3.64	ZAR 1.88	6.84
Oats Silage	3.84	ZAR 1.37	5.22
Sorghum Silage	5.22	ZAR 1.67	8.72
Maize Silage	4.91	ZAR 1.66	3.25
Yellow maize meal	1.53	ZAR 4.39	6.71
HPC	0.93	ZAR 6.91	6.43

Average exchange rate for December 2015: US$1; ZAR 15.05.

which is known to have high contribution to milk output and economic water productivities (Cosentino et al., 2015).

3.2. Water Footprint and Physical Water Productivity of Milk Produced and Processed in South Africa

Table 4 presents the water footprint and physical water productivities of milk produced and processed in South Africa. The results show that the total yearly water footprint for producing 13,196.58 t of milk with 3.3% protein and 4% fat is 1024.95 cubic meters per tonne. Based on this figure, we estimated the physical water productivity of milk along the complete dairy value chain to be 0.98 kg per cubic meter. Precisely, green water footprint constitutes 862.20 cubic meters per tonne whereas blue and grey water footprints constitute 96.99 and 65.76 cubic meters per tonne, respectively. This suggests that green water (84.12%) forms the largest constituent of the total water footprint of milk, followed by blue water (9.46%) and grey water (6.42%) footprints, respectively. In terms of physical water productivities, the results indicate that 10.31 kg of milk is attained from every cubic meter of blue water used, whereas 1.56 kg of milk is obtained from every cubic meter of green water utilized. The results further show that about 80.92% of the total yearly water footprint in the dairy industry in South Africa is attributed to feeding lactating cows only, whereas 17.10% is utilized for feeding non-lactating cows. This indicates that about 98.02% of the total water footprints along the dairy value chain go into feeding of animals. This concurs with the findings of Mekonnen and Hoekstra (2010b) who opined that more than 95% of the water footprints of animal products relates to water used for feed production. The remaining amount constitutes the water consumed by the live animals and servicing water used at the processing stage.

3.3. Value Additions and Economic Water Productivities of Milk at Different Stages and for Different Packaging Designs

For dairy producers with profit maximization and water sustainability objectives, the value generated from their production inputs and economic water productivities are very important to their production decisions. For instance, inputs such as blue water use is directly associated with production costs and may be limiting dairy production (Chouchane et al., 2015). This implies that particular attention should be paid to activities that result in higher value addition and economic water productivities, while focusing on making rational and efficient use of water in order to be economically productive along the dairy value chain. Hence, we have estimated the value added to milk as it moves along the dairy value chain in order to determine the point along the dairy value chain where most value is added. Given the value added along the value chain, we conducted sensitivity analysis for economic water productivities of milk at different stages of the value chain and for different packaging sizes. We considered one litre and three litres packaging sizes with different sales revenue per kilogram. The results are presented in Table 5. The results show that a total value of ZAR 12.11 is added to a kilogram of milk when packaged in 1 l bottle, relative to ZAR 9.04 per kilogram of milk when packaged in 3 l bottle. This implies that more value is attained when milk is packaged in smaller sizes.

Along the value chain, our results show that more value is added to milk at the processing or whole sale level irrespective of the packaging size, as indicated by the amounts of ZAR 5.84 and ZAR 4.01 per kilogram of milk for one and three litres packages, respectively and relative to the other stages along the value chain. The second highest value is added at the retail level where ZAR 4.70 and ZAR 3.46 per kilogram of milk were added to one litre and three litres packaging sizes, respectively. At the

Table 4
Water footprint and physical water productivity of milk in South Africa.
Source: author's calculations, 2015.

Parameters	Yield (tonne/year)	Blue WF (m^3/year)	Green WF (m^3/year)	Grey WF (m^3/year)	Total WF (m^3/year)
Drinking water					
Lactating cows		31,153.12			31,153.12
Non-lactating animals		15,556.67			15,556.67
Feed production water					
Lactating cows		707,552.50	5,342,213.00	400,040.00	6,449,805.50
Non-lactating animals			1,362,837.00		1,362,837.00
Total yearly water usage		754,262.29	6,705,050.00	400,040.00	7,812,642.50
Yearly Milk Production	7776.69				
Total yearly production WF		96.99 m^3/t	862.20 m^3/t	51.44 m^3/t	1010.63 m^3/t
Service water					
Service		–	–	188,960.50	188,960.50
Yearly milk processed	13,196.58				
Total yearly servicing water		0 m^3/t	0 m^3/t	14.32 m^3/t	14.32 m^3/t
Total water footprint		96.99m^3/t	862.20 m^3/t	65.76 m^3/t	1024.95 m^3/t
Physical water productivity		10.31 kg/m^3	1.56 kg/m^3	15.21 kg/m^3	0.98 kg/m^3

Table 5
Value additions to milk as it moves along the value chain and economic water productivities of milk at different stages and different packaging sizes.
Source: Author's calculations, 2015: 1 l of milk = 1.033 kg.

Stage of value chain	Value addition (ZAR/kg)		Economic water productivity (ZAR/m^3)	
	1 Litre packaging	3 Litres packaging	1 Litre packaging	3 Litres packaging
Farm gate	1.57	1.57	1.55	1.55
Processing/whole sale	5.84	4.01	5.72	3.93
Retail	4.70	3.46	4.61	3.39
Total	12.11	9.04	11.88	8.87
Total physical water productivity (farm gate)				0.99 kg/m^3
Total physical water productivity (wholesale and retail levels)				0.98 kg/m^3

Average exchange rate for December 2015: US$1; ZAR 15.05.

farm gate level, we found that an amount of ZAR 1.57 each was added to milk for both packaging sizes considered. It worth noting that the value added to milk at the retail level for one litre packaging size is higher than the value added to the three litres packaging size at the processing or wholesale level. Generally, the results indicate that milk production is economically efficient since the revenue attained at each stage of the value chain exceeds the cost incurred.

Regarding economic productivity of water, the results show that the economic water productivity of milk packaged in one litre bottle is ZAR 11.88 per cubic meter, whereas that of the three litres package is ZAR 8.87 per cubic meter. This means that every cubic metre of water used to produce one kilogram of milk with 3.3% protein and 4% fat, yields ZAR 11.88 and ZAR 8.87, when packaged in one litre and three litres respectively. The implication from this finding is that milk production in South Africa is economically efficient in terms of water usage since the value attained from every cubic meter of water used exceeds its cost. At the production stage where larger proportion of water is used, our results indicate that every cubic meter of water utilized results in ZAR 1.55. Water use is highly economical at the processing stage; as every cubic meter of water used in the production of a kilogram of milk with 3.3% protein and 4% fat, resulted in ZAR 5.72 and ZAR 3.93, respectively for one litre and three litres packaging sizes. At the retail level, every cubic meter of water utilized yielded ZAR 4.61 and ZAR 3.39, when milk is packaged in one litre and three litres respectively. The above results indicate that water use along the dairy value chain is very productive at the processing and retail levels. The type of packaging sizes used for selling the dairy product has a bearing on the value addition and economic water productivity estimates.

4. Conclusions

The current global water scarcity situation and the pressure on governments, organisations, policy-makers, water-users and water managers to develop sustainable and economically efficient water-use policies require rigorous assessment of water footprints and water productivities in all sectors of the economy that use water. Water footprint assessment in the agriculture and food sectors has emerged as a vital sustainability indicator. The present paper has contributed to earlier water footprint studies in South Africa and Africa as a whole by adding the economic aspect of water use along the dairy value chain. The study focused on the economic productivity of water along the dairy value chain, starting from feed production to the final product.

Our findings have important economic and efficient water use implications for actors along the dairy value chain. In terms of water use, we conclude that the highest proportion of water utilized along the dairy value chain goes into feed production. Different feed products have different water footprints. This suggests the need for water footprint assessment of different feed products to identify the ones that are higher users of the existing scarce water resources. Given the blue water scarcity situation in South Africa, our findings suggest that feed products such as lucerne hay, maize silage and sorghum silage are higher consumers of blue water resources. However, judging these products based on their water footprint estimates alone will be biased. Hence, our findings have highlighted the contributions of the feed products to milk output. Yellow maize meal, high protein concentrate and lucerne hay are the top three feed products with high contribution to milk output, respectively. Hence, dairy livestock producers should pay particular attention to these feed products when formulating ration for dairy cows, with the aim of attaining high milk yield, which in turn will lead to low water footprints, high value addition and economic water productivities.

Although feed production uses the highest proportion of water along the dairy value chain, our assessment of value addition and economic water productivities of the feed products proves that the production of the feed products are economically efficient in terms of cost and water use. The economic implication of this finding is that the revenue attained from producing the feed crops and the value added to water along the dairy value exceeds the cost incurred. Hence, we conclude that dairy livestock farmers or producers are economically efficient in their production. The findings further provide vital information for livestock feed producers and marketers on the feed products which are more profitable, as our results indicate that the value added to the feed products vary from product to product. High economic values are associated with high protein concentrate, yellow maize meal, lucerne hay, and sorghum and maize silages, respectively.

Of further importance from our study is the findings which point to the fact that not all economically water productive feed products are significant contributors to milk yield. Feed products such as yellow maize meal, high protein concentrate and lucerne hay appear to be very economical in terms of water and have high contribution to milk yield, with positive value addition. Maize silage has low economic water productivity and somewhat low contribution to milk yield and as such we suggest that dairy farmers can substitute it with a better option such as triticale silage which is known to have high contribution to milk yield and economically productive in terms of water use. This provide the rationale for profit-maximising dairy farmers with sustainable and efficient water use objectives to reconsider their dairy livestock feed formulation by incorporating more of the feed products with good contribution to milk output and economic water productivities.

We further conclude that the value added to milk as it moves along the value chain varies from stage to stage, with the highest value added at the processing level, followed by retail level and the farm gate, respectively. Albeit, our estimates suggest that milk production at each stage along the value chain is economically efficient in terms of cost and water use. From marketing point of view, our findings suggest that more value is added to milk and water when packaged in smaller sizes. This connote that the type of packaging design used at the processing level of the dairy value chain has an influence on value addition and economic water productivity estimates.

We generally recommend that future research on estimations of ecological footprints and economic productivities of ecological indicators such as water should not focus only on quantifying the footprint indicators. Rather, researchers should take into account economic water productivities and the monetary value added to the product along its value chain since it gives meaningful economic implications. In order to be sustainable and economically productive in water use, all water users and managers along the dairy value chain can rely on such context-specific and concrete research outcomes to reduce the pressure of animal feed production on fresh water use in the livestock sector, while maintaining milk yield and profitability. The findings provide detailed insights into profitability and economically productive water-use in the dairy industry. We suggest that policy makers, water users and managers along the dairy value chain should not rely on water footprint estimates alone to judge the industry.

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