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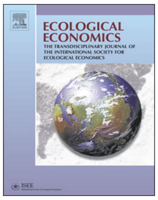

Economic Water Productivities Along the Dairy Value Chain in South Africa: Implications for Sustainable and Economically Efficient Water-use Policies in the Dairy Industry

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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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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