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Assessing the Blue and Green Water Footprint of Lucerne for Milk Production in South Africa

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Abstract: The Global Water Footprint Standard approach was used to calculate the volumetric blue and green water footprint indicator for lucerne production as important feed for dairy cows in a major lucerne production region in South Africa. The degree of sustainability of water use then was assessed by comparing water use to water availability for the region. The results show a volumetric water footprint indicator of 378 m^3/tonne of lucerne. Of the total blue and green water footprint, 55% is green water footprint and 45% is blue water footprint. Thus, albeit in a major irrigation area of South Africa, the largest component of the total water requirement is met by effective rainfall. The assessment of sustainability of water use showed that the period when lucerne requires irrigation water furthermore corresponds to the period where the water scarcity index is smaller than 100%. The water footprint thus is considered sustainable from an environmental perspective. This research proves the benefit of using context specific data to assess the water footprint of a crop, and the importance of a sustainability assessment in a water footprint assessment to generate information useful for informing water users and managers towards sustainable freshwater use.

Keywords: water footprint; sustainable water use; South Africa; lucerne production; agriculture

1. Introduction

Water footprint is emerging as an important sustainability indicator in the agriculture and food sectors [1]. It is a relatively new concept well situated to contribute towards the efficient use of fresh water and refers to the volume of freshwater used to produce a product. It is measured throughout the value chain of the product, from the inputs up to the point where the end product reaches the consumer [2]. Hoekstra *et al.* [2] distinguish between three categories of water footprint: blue, green, and grey. The first is defined as the surface and groundwater that is consumed (water that has evaporated and the water that was incorporated into the product) along the value chain of a product. All the rainwater that does not become run-off, but is consumed, represents the green water footprint. The grey water footprint is defined as the volume of freshwater needed to reduce the pollutants to ambient levels. The water footprint thus contributes a measurable representation of the volume of freshwater that is used to produce food products. Since the mid-2000s, a large number of water footprint assessments were undertaken globally; with the Water Footprint Network leading research endeavours on this topic. Very few studies of this nature had been performed for semi-arid to arid regions of southern Africa.

South Africa is a water scarce country and is ranked 30th in the world in terms of water scarcity [3]. Rapid population growth and increasing variability in rainfall has led to tighter water supply in many parts of South Africa where the water demand often exceeds the supply. Irrigated agriculture in South Africa is using roughly 40% of the exploitable runoff [4]. Other estimates suggests that agricultural production use as high as 60% of the available water [3]. Irrigated agriculture proves to be a major user of freshwater in South Africa. With such a high proportion of the water used by the agricultural sector, there is increasing pressure from government and others on agriculture to use less water while maintaining crop yields. This problem is compounded by the fact that the direct contribution of the agricultural sector to the economy of South Africa is regarded to be low: less than five percent of the Gross Domestic Product (GDP) since the early 1990s [5]. Of the different agricultural industries, those concerned with the production of animals and animal products are of relatively higher importance, contributing about 40% to the gross value of agricultural production [5]. The dairy industry is relatively important from an economic perspective: about 14% to the gross value of animal production [5]. In addition to the direct contribution to the economy, the dairy industry also employs a large number of people in the rural areas. According to an industry overview of the dairy industry in South Africa, this sector consists of about 4000 milk producers who in turn provide employment to 60,000 farm workers. A further 40,000 people have indirect employment in the rest of the dairy value chain [6]. It is thus clear that the South African dairy industry is very important from a socio-economic perspective.

Problematic for a country like South Africa is that the production of animals and animal products are well documented to be inefficient in the allocation of freshwater given the volume of water needed to produce animal products [7,8]. Up to 98% of water allocated is needed to produce feed for the animals globally [7,9]. And Phalow, Snowball, and Frazer [10] report that the production of fodder crops in South Africa, along with maize, is one of the main users of the freshwater resource. Of the different industries involved in the production of animals and animal products, the dairy industry is especially dependent on irrigated agriculture to grow feed. Lucerne is a major feed crop, and is exclusively produced under irrigation. In light of the above, it is crucially important to understand the degree of sustainability with which freshwater is used to produce lucerne for dairy production.

A limited number of studies consider the water footprint of dairy production. Ridoutt *et al.* [1], De Boer *et al.* [11], Manazza and Iglesias [12], and Cosentino *et al.* [13] explored the impact of dairy production on freshwater resources of Australia, the Netherlands, Argentina, and Italy, respectively. They followed a Life Cycle Assessment (LCA) approach to calculate a water stress index as a proxy for the impact of dairy production on their respective freshwater resources. It is important to note that the LCA-approach does not consider rainwater that was consumed by crops, nor does it consider the grey water footprint. Their focus is solely on the volume of surface and groundwater that is consumed by the product. Others applied the Global Water Footprint Standard (GWFS) of Hoekstra *et al.* [2] to calculate the water footprint of dairy production. This includes, amongst others, Mekonnen and Hoekstra [7] who assessed the water footprints of dairy products for a number of different nations; and Murphy *et al.* [14] who explored the water footprint of dairy production in Ireland. The GWFS approach does consider rainwater when calculating the water footprint of dairy products, and also the grey water footprint. The GWFS approach thus aims to include all components of freshwater use when assessing the impact of production on the freshwater resource. Important to note is the fact that the focus of those who applied the GWFS approach was on a national scale and also mainly emphasised the volumetric water footprint indicator (the volume of freshwater that was consumed through the production of the dairy products). The challenge such an emphasis poses is the absence of information on the degree of sustainability with which freshwater was used to produce the product. Information is needed on the degree of sustainability of the water footprint in order to accurately and effectively inform water managers and water users towards the sustainable use of freshwater for food production.

The aim of this study is to explore the blue and green water footprint of lucerne production for use as animal feed in the dairy industry, taking into account water scarcity within a specific lucerne production region. It focuses on establishing the blue and green water footprint of lucerne production in Vaalharts, a major lucerne production region of South Africa. The volumetric green and blue water footprint indicators are calculated from measured crop water use. The water footprint is then interpreted in the context of water availability in order to gain insight into the degree of sustainability with which water is used to produce lucerne for milk production.

2. Methods and Data

2.1. Methods

This research is based on the Global Water Footprint Standard of the Water Footprint Network reported in Hoekstra *et al.* [2].

2.1.1. Calculating Volumetric Blue and Green Water Footprint Indicators of Growing Lucerne

The water footprint of a growing crop is the sum of the process water footprints of the different sources of water. Hoekstra *et al.* [2] explain the water footprint of the process of growing a crop (WF_{proc}) as:

$$WF_{proc} = WF_{proc,blue} + WF_{proc,green} \text{ (volume/mass)} \tag{1}$$

where $WF_{proc,blue}$ is the blue crop water footprint and $WF_{proc,green}$ is the green crop water footprint. The blue crop water footprint refers to the total amount of irrigated water that evaporates from the field over the total length of the crop's growing period, while the green crop water footprint is the total volume of rainwater that evaporates from the field during the same period [2].

The blue water footprint ($WF_{proc,blue}$, m^3/tonne) is calculated as the blue component in crop water use (CWU_{blue}, m^3/ha), divided by the crop yield (Y, tonne/ha) (Equation (2)). Similarly, the green water footprint (WF_{green}, m^3/tonne) is calculated as the green component in crop water use (CWU_{green}, m^3/ha), divided by the crop yield (Y, tonne/ha) (Equation (3)):

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

$$WF_{proc,green} = \frac{CWU_{green}}{Y} \text{ (volume/area)} \tag{3}$$

Blue and green crop water use (CWU, m^3/ha) is the sum of the daily evapotranspiration (ET, mm/day) over the complete growing period of the crop:

$$CWU_{blue} = 10 \times \sum_{d=1}^{lgp} ET_{blue} \text{ (volume/area)} \tag{4}$$

$$CWU_{green} = 10 \times \sum_{d=1}^{lgp} ET_{green} \text{ (volume/area)} \tag{5}$$

ET_{blue} and ET_{green} represent the blue and green water evapotranspiration, respectively. 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 [2].

After the calculation of the volumetric water footprint indicator, the next step is to assess the degree of sustainability of the water footprint to get an indication whether or not water use within the catchment is ecologically sustainable.

2.1.2. Assessment of Sustainability of Water Use

The blue WF is considered to be unsustainable if the blue WF exceeds blue water availability in a particular catchment. For the purpose of assessing the sustainability of the blue WF, the blue WF and blue water availability have to be determined for a particular catchment. Moreover, seasonal variation in water use and run-off implies that the water footprint and water availability have to be determined for the particular catchment at specific time intervals: normally monthly. Hoekstra *et al.* [15] defines blue water availability (WA_{blue}) in a catchment x in a certain period t as the difference between the natural run-off in the catchment (R_{nat}) and environmental flow requirement (EFR):

$$WA_{blue}[x,t] = R_{nat}[x,t] - EFR[x,t] \text{ (volume/time)} \tag{6}$$

Thus, when the blue WF exceeds the blue water availability in a certain period and catchment, the EFR is not met for that period and catchment. The EFR represents the volume and timing of water flows required to sustain freshwater ecosystems and human livelihoods, failing to meet the EFR implies unsustainable water use.

Following Hoekstra *et al.* [2] and Gerbens-Leenes & Hoekstra [15], the sustainability of the blue WF is assessed by means of a blue water scarcity index (WS_{blue}):

$$WS_{blue}[x,t] = \frac{\sum WF_{blue}[x,t]}{WA_{blue}[x,t]} \tag{7}$$

$WS_{blue}[x,t]$ is the blue water scarcity index for a particular catchment during a particular period of time; $\sum WF_{blue}[x,t]$ is the sum of the blue water footprints of all the blue water that was used in the catchment for a particular period of time; and $WA_{blue}[x,t]$ is the blue water availability as defined above. The blue WF is considered to be unsustainable if $WS_{blue}[x,t]$ is greater than one in a particular catchment for a particular period of time [2]. A catchment where $WS_{blue}[x,t]$ is greater than one at a particular period of time is considered a hotspot [2] and requires intervention to ensure the sustainable use of freshwater in that specific catchment.

2.2. Data

The research reported in this paper is based on data compiled by Van Rensburg *et al.* [16]. Measurements were taken over four periods in two seasons (two winters and two summers) from July 2007 to June 2009.

2.2.1. Crop Water Use

The Vaalharts irrigation scheme is situated between the Vaal River and the Harts River in the South African Northern Cape Province and falls within the Lower Vaal Water Management Area (WMA) within the Orange River Basin. Vaalharts is located in a summer rainfall area. The Vaal River is the main supplier of water to the irrigation scheme [16]. Several measuring sites were selected in order to establish accurate representation of the irrigation scheme. No irrigated field is the same and each of the measuring points was seen as a unique opportunity to obtain information on water and salt management practices by farmers at Vaalharts. Measuring points were therefore selected to include a variety of bio-physical conditions at root zone scale as to represent differing irrigation water qualities, soil types, crops, irrigation systems, and artificially drained soils.

Measuring points with dimensions of 4 m × 4 m were set up in a crop field. In fields with artificial drainage systems, two measuring points were established: one on the drainage line and the other some distance away depending on the line spacing and type of drainage system. Two neutron access tubes (2000 mm), one piezometer (perforated 63 mm PVC tubes and 3000 mm deep) and a rain gauge were installed at each measuring point [16].

Actual rainfall was measured with rain gauges placed on the surface of the soil with a 6 m^2 cleared area around each rain gauge in order to prevent interference by the crop. The rainfall was converted to represent the effective rainfall. These rain gauges were also used to compare the irrigation applied, with the net irrigation measured in the soil.

Soil water content was measured with a calibrated neutron probe. The depth of the water table was measured manually by using an electronic device, while the volume of drainage water flowing from the artificial drainage systems was measured with a bucket and converted to L· min^{-1} [16]. The measurements were then used to complete the water balance and to calculate the evapotranspiration of the crop.

2.2.2. Lucerne Biomass Production

In order to get an accurate representation of the true biomass production of the measuring sites, a 4 m × 4 m (16 m^2) plot was measured in each of the fields where the measuring sites were located. Every time the farmer harvested the lucerne, the 16 m^2 plot was manually cut with a sickle and the freshly cut or "wet" lucerne was carefully collected and weighed immediately before any moisture loss occurred. Once the lucerne of the trial plot was weighed, a sample was weighed and taken to be dried in order to obtain the dry matter (DM) production. The representative sample was then placed in a drying oven at 100 °C until no further weight loss is observed. The final weight of the sample is considered to be the DM of the sample. Once the DM is determined the moisture content of the representative sample was calculated, as all weight loss at that point can be attributed to the moisture loss.

Assuming that the whole field had the same moisture content prior to cutting, the percentage moisture loss of the sample was used to obtain the DM production of the 16 m^2 plot. This DM production was then multiplied with a factor of 625 in order to obtain the total DM or biomass production of a hectare. This process was duplicated at each measuring site, every time the lucerne producer cut the entire field.

3. Results and Discussion

3.1. Volumetric Water Footprint Indicator of Lucerne Production in Vaalharts

Blue and Green Water Footprint of Lucerne Production

Table 1 provides a summary of water use information per season at the measuring points at Vaalharts. "ET crop" refers to crop evapotranspiration and is an indication of the water requirement of the crop. "R" in Table 1 represents effective rainfall, "I" effective irrigation, and "IR" irrigation requirement to supplement effective rainfall to meet the crop water requirement.

Table 1. Summary of water use information per season at the measuring points at Vaalharts.

	ET Crop (mm)	R (mm)	I (mm)	IR (mm)
Average	1157	633	605	524

Table 1 shows that lucern requires 1157 mm of water per year. During the period under consideration the effective rainfall was 633 mm for the year, with effective irrigation amounting to 605 mm for the year. The irrigation requirement was 524 mm per year. The information reported in Table 1 is used next to calculate green and blue crop water requirement, green and blue crop water use, and green and blue water footprints for the production of lucerne at Vaalharts. The results are reported in Table 2.

First, the total crop water requirement (ET_{crop}) is divided into green crop water requirement (ET_{Green}) and blue crop water requirement (ET_{Blue}). ET_{Green} for producing lucerne at Vaalharts is the minimum between effective rainfall and crop water requirement. Table 1 shows that effective rainfall (633 mm) is less than crop water requirement (1157 mm), hence ET_{Green} is considered to be 633 mm per year. The blue crop water requirement (ET_{Blue}) of a growing crop is the minimum of the crop water requirement and the effective irrigation. Irrigation requirement (IR) is the difference between the crop water requirement and the effective rainfall. The IR of 524 mm is smaller than the effective irrigation (602 mm) and therefore the ET_{Blue} of producing lucerne in Vaalharts is 524 mm per year. After the crop water requirements have been calculated, the next step was to convert it into a spatio-temporal dimension.

Table 2. Summary of the blue and green water footprint of producing lucerne in Vaalharts.

ET_{Crop}	ET_{Green}	ET_{Blue}	CWU	CWU_{Green}	CWU_{Blue}	Yield	WF	WF_{Green}	WF_{Blue}
mm/period				m^3/ha		t/ha		m^3/t	
1157.2	633	524.19	11570	6330	5240	30.59	378.18	206.9	171.28

The ET_{crop}, ET_{Green}, and ET_{Blue} in Table 2 are expressed in depth per year and have to be converted to a spatio-temporal dimension by multiplying the numbers by a factor of 10. Crop water use (CWU) in a spatio-temporal dimension thus is 11,570 $m^3 \cdot ha^{-1}$. Similarly, CWU_{Green} and CWU_{Blue} in a spatio-temporal dimension were calculated to be 6330 $m^3 \cdot ha^{-1}$ and 5240 $m^3 \cdot ha^{-1}$, respectively. Thus, in order to produce one hectare of lucerne at Vaalharts, a total volume of 11 570 m^3 water is required; 6330 m^3 is met in the form of rainfall, while the remaining 5240 m^3 is required in the form of supplementary irrigation.

Water footprints are normally expressed in terms of water per unit of production. The green- and blue water footprints thus have to be converted to m^3 per tonne of output. Given a lucerne yield of 30.59 t/ha, the Green water footprint (GW_{Green}) amounts to 206 $m^3 \cdot t^{-1}$, and the blue water footprint (GW_{Blue}) amounts to 171.28 $m^3 \cdot t^{-1}$ for the production of lucerne at Vaalharts. The results reported in Table 2 thus show that, in order to produce one tonne of lucerne at Vaalharts, 206 m^3 of rainfall, and an additional 171.28 m^3 of irrigation water is required.

The water footprint of lucerne production at Vaalharts compares very favorably to that of lucerne production in Saudi Arabia. Multsch *et al.* [17] reported a water footprint of Alfalfa production of 1887 $m^3 \cdot tonne^{-1}$. The large difference may be attributed to the drier climate in Saudi Arabia compared to Vaalharts in South Africa.

The volumetric water footprint indicator by itself, however, does not provide any information regarding the degree of sustainability with which the water is used to produce lucerne. Next follows the results from the environmental sustainability assessment to interpret the water footprint within the context of available water. This offers an understanding of the degree of sustainability of the water footprint.

3.2. Environmental Sustainability of the Blue Water Footprint

Data for the assessment of the environmental sustainability of the WF_{Blue} were obtained from Hoekstra and Mekonnen [18]. Figure 1 indicates the monthly blue water footprint (WF), the monthly blue water availability (WA) and the monthly blue water scarcity (WS) for the Orange River Basin within which Vaalharts is situated.

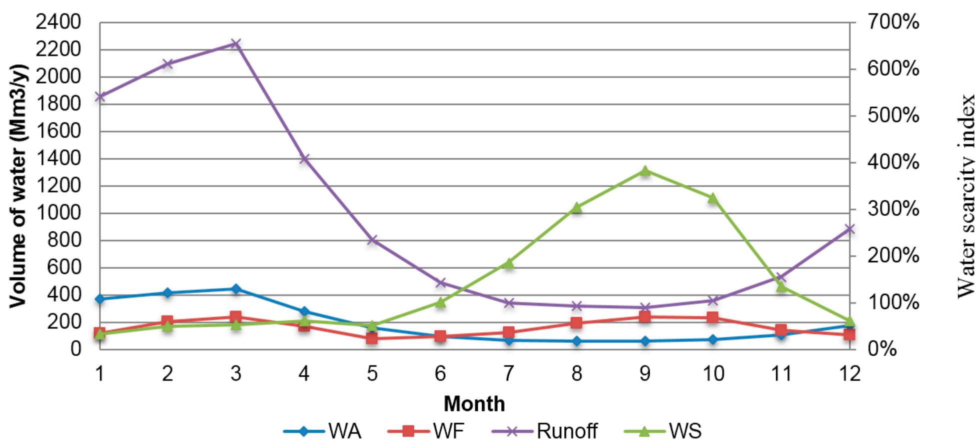

Figure 1. Monthly blue water scarcity of the Orange River basin.

Figure 1 shows that the blue water availability (WA) exceeds the blue water footprint (WF) from December through May, resulting in a water scarcity index (WS) of smaller than 100%. During these months, blue water scarcity is deemed to be low and sufficient water is available to satisfy the environmental flow requirements. A water scarcity index smaller than 100% during the summer and autumn months (December to May), imply that water use may be considered ecologically sustainable. It is noted that Vaalharts is located within a summer rainfall area. The period of low water scarcity thus correspond to the rain season and the period right thereafter.

During the months of June to November, however, the blue water footprint exceeds blue water availability. In June and November the blue water scarcity index is between 100% and 150%, which imply moderate blue water scarcity. Moderate blue water scarcity suggests that the runoff is slightly modified and the environmental flow requirements are not met. July, in turn, experiences significant blue water scarcity with a water scarcity index between 150% and 200%. Significant blue water scarcity implies that the runoff is significantly modified and does not meet the environmental flow requirements. Alarmingly, August, September, and October have water scarcity indices exceeding 300%. The blue water footprints exceed 40% of the natural runoff during these months, implying that runoff is seriously modified and environmental flow requirements are not met.

The fact that the water scarcity index is greater than 100% in 6 of the 12 months of a year suggests that the Orange River basin is a hot spot. The large water scarcity index in 4 of the 12 months is a major cause for concern. When considering the production of lucerne in this hot spot, it has to be noted, however, that the time periods when lucerne has larger requirement for freshwater fall in the summer months (December to February) when evapotranspiration is high. Consequently, the production of lucerne at Vaalharts may still be considered a sustainable use of freshwater.

4. Conclusions

The aim of this study was to assess the water footprint of lucerne production for use as animal feed in the South African dairy industry, taking into account water scarcity within the main lucerne production region in South Africa. Based on the results from this research it is concluded that, although a substantial amount of freshwater is used, water use for lucerne production at Vaalharts is environmentally sustainable. The blue water abstracted for lucerne production does not modify the natural run-off significantly, and the environmental flow requirement is met. Interestingly, although lucerne production is dependent on irrigation water, the green water footprint is the largest component of the total water footprint of lucerne production at Vaalharts. The producers prove to use rainfall effectively for the production of lucerne in the study area. By effectively using rainfall, the lucerne producers decrease the pressure on the scarce blue water resource. Especially in semi-arid and arid regions around the world, land management practices associated with improved water storage capacity of the soil may contribute significantly towards decreasing the demand for blue water, hence the pressure on the scarce freshwater resource.

Importantly, the results show the importance of interpreting water use behavior within the context of water availability in order to get an accurate understanding of whether or not the behavior of water users could be considered environmentally sustainable water use. While a specific agri-food industry may be considered to be a major user of freshwater, interpreting the water use behavior within the context of water availability will provide more insight into the degree of environmental sustainability of the water use. Especially in arid and semi-arid regions around the world, where water intensive agricultural practices may form an integral part of the livelihoods of a nation, it is important to understand the environmental sustainability of activities in terms of water use before making recommendations for changing behavior solely aimed at decreasing the amount of water used. Such changes may have substantial social and economic implications for the nation under consideration. It is, however, important to know the degree of environmental sustainability with which freshwater is used for economic activities to inform and guide policy makers, water managers, and water users towards the sustainable use of freshwater.

The temporal variation in freshwater requirement and blue water scarcity prove the importance of recognising temporal variations when interpreting the volumetric water footprint indicator within the context of water scarcity. Ultimately, it may be concluded that the nature of the data that were used in this research allowed for an accurate measurement of the water footprint of lucerne production at the particular location (Vaalharts); and for making concrete, context specific recommendations for decreasing the pressure of lucerne production on the freshwater resource at that particular location. In order to allow for concrete, context specific recommendations for changing water use behaviour towards sustainable freshwater use, researchers should strive to get context specific information for water footprint assessments.

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