SUSTAINABLE WATER USE FOR TOBACCO PRODUCTION

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Abstract

South Africa is a water scarce country, and there is increased pressure on the scarce freshwater resource. Water footprints have emerged as a useful indicator to report water consumption associated with a product. Additionally, when interpreting water footprints in the context of water scarcity in the production regions, important judgement can be made about the sustainability with which water is used to produce the product. This study aimed to assess the water footprint of tobacco in a key tobacco production region in South Africa, and to assess the water scarcity situation in that region to allow for judgment of the sustainability with which water is used to produce tobacco in that region. The results show that 1551 m^3 of water is used to produce one ton of tobacco, of which about 60% is sourced from effective rainfall. The remaining 40% is met through supplementary irrigation. The period when tobacco requires most water corresponds with the period where the blue water scarcity index is less than 100%, suggesting that tobacco production in that particular region is sustainable from a water use perspective.

1. Introduction

The agriculture sector in South Africa contributes to economic growth, food security and environmental sustainability, while adding value to raw materials (DAFF, 2010; DWA, 2013). The Central Intelligence Agency (CIA) (2016) has reported that, in South Africa, approximately 80% of the total available land surface is useful for agricultural production. However, of the total agricultural land surface, only 12.5% is fertile and 0.4% is planted with permanent crops (DRDLR, 2017). Crop production accounts for 13% of South Africa's surface area, of which 1.3 million hectares are under irrigation (DAFF, 2016).

The tobacco industry has been under pressure over the past decades in South Africa. Along with the decline in the area cultivated with tobacco, the numbers of primary producers and tobacco processors have decreased (DAFF, 2016). Notwithstanding this, the tobacco market contributed approximately R22.4 billion in excise duty and VAT to the government, and R23 billion to the country's GDP, in 2017 (TISA, 2017). The DAFF (2016) has reported the industry as having a market value of R28.8 billion per annum, and as providing 8 000 to 10 000 job opportunities in the agricultural sector, and more than 179 000 among wholesalers and retailers. Tobacco is one of the agricultural commodities that can be considered as an important cash crop in terms of an economic perspective.

The tobacco value chain consists of various stages, from farm requisites suppliers to the end-users of processed tobacco products, such as cigarettes, snuff and pipe tobacco (DAFF, 2016). Water is used throughout the value chain, with the primary tobacco production stage being the largest user of water (FAO, 2017). The fact that the tobacco industry is exploiting vast volumes of water to produce tobacco products should be used to focus an emphasis on the use of freshwater, from the environmental and economic points of view.

According to the Water Footprint Network (WFN), a water footprint is a useful indicator of freshwater use that takes into account both direct and indirect water uses (Chapagain and Hoekstra, 2008; Hoekstra *et al*., 2011). It can be estimated for a product, a process step, a business, a country or in an international context, and considers three types of water – blue, green and grey water (Chapagain and Hoekstra, 2008; Hoekstra *et al*., 2011).

Agricultural irrigation merits serious consideration with regard to improving existing water uses to ensure that water is available for future use (DAFF, 2011). Water resources should be allocated in a sustainable manner that ensures efficiency in the use of water (Hoekstra *et al*., 2017). This not only involves merely the productive use of water, but also includes social, economic and environmental determinants that objectively aim at obtaining the equitable, efficient and sustainable use of water (Hoekstra *et al*., 2012). In order to address the sustainable and efficient use of South Africa's scarce water resources, the government's water management policy emphasises the concern to redress the imbalances in water allocation and accessibility (DWA, 2013). This study is formed with the aim to promote a management approach that would enable water users to attain an efficient level of water use, as well as increasing the contributions of large water users to the economic growth of South Africa (Hoekstra *et al*., 2017).

Conventionally, the main focus is typically placed on reducing the effects of agriculture on freshwater through improving the technical aspects of irrigation and drainage (Deurer *et al*., 2011). However, the use of water footprints will provide information that could be used to address water situations through regional trade policies and to better inform end-user attitudes. Moreover, Mekonnen and Hoekstra (2014) have highlighted the point that a water footprint can be a useful instrument for benchmarking actual WFs in certain regions, or even at a field level, to certain reference levels, and can provide a basis for formulating WF reduction targets, aimed at reducing water consumption and pollution per unit of crop.

In South Africa, there is insufficient scientific knowledge available to effectively inform water users, managers and policymakers regarding the sustainable use of freshwater for tobacco production. The use of a water footprint indicator for crop production enables a comparison to be made of the actual WFs in specific areas, and even at field level to a certain degree, and this could lead to the formulation of WF reduction potentials, with the purpose of reducing water consumption and pollution per unit of the crop. Numerous studies, such as those conducted by Sibert and Döll (2010); Brauman *et al*. (2013); Ercin *et al*. (2013); and Pahlow *et al*. (2015), have revealed that the WFs of crops vary extensively within and across regions.

Measuring water availability and its vulnerability would be important in defining and implanting water management in the continuously changing environment. For example, Wan *et al*. (2017) provided a quantitative assessment of the WF components for crop production, based on data from period 1996–2005, and Hoekstra *et al.* (2011) have investigated the volumetric water indicators for South Africa’s crop production. To address water security, freshwater resources are classified into three categories: blue, green and grey water (Ercin and Hoekstra, 2014). The blue WF calculates the volume of surface and groundwater consumed, and the green WF measures the volume of rainwater stored in the soil as soil moisture during the growing period of the crop. The grey WF calculates the volume of freshwater required to assimilate the nutrients and pesticides that leach and run off from crop fields and flow into the surface or groundwater, based on existing ambient water quality levels (Mekonnen and Hoekstra, 2011). However, no studies have yet been developed to measure a water footprint assessment of tobacco production in South Africa. There is no scientific-based evidence of the water footprint of tobacco available for informing water users and policymakers regarding the sustainable use of water for tobacco production.

The aim of this study is to assess the water footprint of irrigated tobacco production in order to gain insight into the volume of freshwater that is used to produce tobacco, and whether it can be sustainably produced from a water use perspective.

2. Data and methods

2.1 Data

This research was conducted in the Loskop Irrigation Scheme in the Mpumalanga province of South Africa. The Loskop Irrigation Scheme is in the Olifants River System. The Olifants River System begins just within and to east of the Gauteng province, and the main stem flows in a northerly direction. After flag Boshielo Dam, it changes direction eastwards, and after cutting through the Drakensberg Mountains, enters the Kruger National Park near Phalaborwa, and then flows further east to the Mozambican border (DAFF, 2016). Just beyond this border is the Massingir Dam in Mozambique (DAFF, 2015). Further downstream, the Olifants River joins the Limpopo River (Bjorn *et al*., 2018). Before the Olifants River reaches the Mozambican border, the Letaba River joins with it. The Olifants River Catchment covers approximately 54 570 km^2 (Bjorn *et al*., 2018).

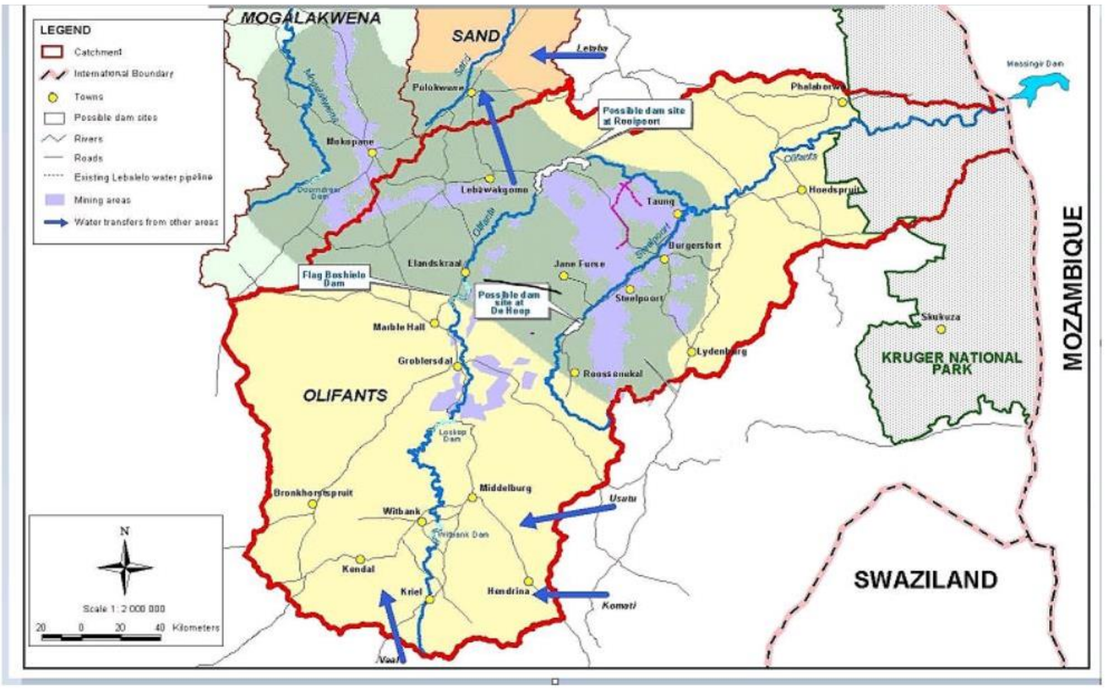

Figure 1: Layout of the water flow from the Olifants River Basin in the Mpumalanga province

Source: Google maps (2018)

The Olifants River is a major tributary of water to the Loskop Dam (25º 26' 57. 05'' S 29º 19' 44. 36 E), situated in the Mpumalanga province of South Africa (DAFF, 2011). The Loskop Dam is the main water supplier to the Loskop Irrigation Scheme (study area). The scheme falls within the summer precipitation areas (DWA, 2015). The annual rainfall for the scheme is estimated to be more than 700 mm (DAFF, 2015). Between November and February, the long-term rainfall for the region is normally more than 40 mm per month, with a mean of

59 mm (DAFF, 2016). The long-term maximum temperature between November and February for Loskop is 31 °C, while the minimum temperatures vary between 14 and 17 °C (DWA, 2015). During the winter months, the maximum temperature is around 20 °C, with the mean minimum temperature just above 0 °C (DWA, 2015). The Loskop Irrigation Scheme is ranked as the second largest irrigation area in South Africa, made up of 25 600 ha, with a total of about 480 km of irrigation channels, as reported by the Loskop Irrigation Board in 2010 (DAFF, 2011). DWA (2009) estimated that the water supply for the irrigation scheme is withdrawn from the upper-hypolimnia of Lake Loskop, which is then conducted to crops through the use of two concrete channels. The lengths of these two channels are approximately 46 km (the short channel) and 330 km (the long channel) (DWA, 2009).

CROPWAT 8.0 (Allen *et al*., 1998) was used to model the water balance data for the calculation of the water footprint of tobacco. It includes a simple water balance model that enables a simulation of crop water stress conditions and estimations of yield reductions, based on well-established methodologies for the determination of crop evapotranspiration (FAO, 1998), yield responses to water (FAO, 1979), and irrigation and rainfall efficiencies. In addition, the program facilitates the development of irrigation schedules for various management conditions that calculate the measures of scheme water to supply for different crop patterns (FAO, 2016). The CROPWAT 8.0 program (Allen *et al*., 1998) can also be applied to examine farmers' irrigation practices and to predict crop performance under both rainfed and irrigated agriculture (FAO, 2016).

2.2 Methods

Water footprint accounting

The water footprint of a growing crop is comprised of the sum of the process water footprints of the different sources of water (Hoekstra *et al*., 2011). Hoekstra *et al*. (2011) demonstrated the water footprint of the process of growing a crop (WF) as:

$$WF_{green+blue} = WF_{blue} + WF_{green} \qquad \text{Equation 1}$$

where WF_{blue} is the blue crop water footprint (m^3 / ton) and WF_{green} is the green crop water footprint (m^3 / ton).

The WF_{blue} is expressed as the blue component in crop water use (CWU_{blue}), divided by the crop yield (Y) (Equation 2). Similarly, the green water footprint ($WF_{,green}$) is measured as the green component in crop water use (CWU_{green}), divided by the crop yield (Y) Equation 3

$$WF_{blue} = \frac{cwu_{blue}}{Y}$$ Equation 2

$$WF_{green} = \frac{cwu_{green}}{Y}$$ Equation 3

Blue (CWU_{blue}) and green (CWU_{green}) crop water use (measured in m^3 / ha) is the sum of the daily evapotranspiration of surface and ground water, and the green water resources respectively over the complete growing period of the crop:

$$\mathbf{CWU}_{\mathbf{blue}} = 10 \times \sum_{d-1}^{lg\,p} \mathbf{ET}_{\mathbf{c,blue}}$$ Equation 4

$$\mathbf{CWU}_{\mathbf{green}} = 10 \times \sum_{d-1}^{Lg\,p} \mathbf{ET}_{\mathbf{c,green}}$$ Equation 5

ET_{blue} and ET_{green} are the blue and green water evapotranspiration amounts, respectively. The water depths are converted from millimetres to volumes per area (m^3/ha) with the use of a factor of 10. The total is calculated over the complete duration of the growing period (lgp), from day one to harvest (Hoekstra *et al*., 2011).

Blue water scarcity and the production of tobacco

The Olifants River System is classified as one of the most stressed catchments in South Africa (DAFF, 2016). It has been reported that the river cannot supply sufficient water to meet the present and future demands from agriculture, residential developments, industry, mining and the environment (DWA, 2015).

The Olifants River had already showed a negative water balance in 2004 (Havenga, 2007). This means that more water is being abstracted from the river than is available, and as such, the negative water balance is estimated to amount to −242 million m^3 per annum by the year 2025 (DAFF, 2016). There are approximately 2 500 dams in the Olifants River Catchment, 90% of which have a volume of less than 20 000 m^3, while the thirty dominant dams have capacities of more than 2 000 000 m^3 (Buermann *et al*.,1995; Ashton, 2010; Thiam *et al*., 2015). According to Leonard *et al*. (2015), irrigation constitutes the largest use of groundwater in the catchment. Blue water is used extensively to irrigate the crops; therefore, the focus will be placed on the sustainability assessment on the blue water availability in the basin (Ercin and Hoekstra, 2014).

Using the methodology of Hoekstra and Mekonnen (2012), a blue water scarcity index was calculated as an indicator of the relationship between the blue water footprint and the water availability in the catchment. An index in excess of 100% implies that more water is used than what is available, meaning that the environmental flow requirement is not completely met. For the purpose of assessing the blue water scarcity, the blue WF and blue water availability were determined for the particular catchment (Mekonnen and Hoekstra, 2012). 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. According to Hoekstra *et al*. (2011), blue water availability (WA_{blue}) in a catchment x in a certain period t is the difference between the natural run-off in the catchment (R_{nat}) and the environmental flow requirement (EFR), calculated as follows:

$$WA_{blue}\ [x,t] = R_{nat}[x,t] - ERF[x,t] \qquad \text{Equation 6}$$

Thus, when the WF_{blue} exceeds the blue water availability in the catchment during a certain period, the EFR is not met for that period. The EFR indicates the volume and timing of water flows required to sustain freshwater ecosystems and human livelihoods. Failing to meet the EFR implies an unsustainable water use in the catchment (Hoekstra *et al*., 2011).

Following Hoekstra *et al*. (2009) and Mekonnen *et al*. (2015), the blue water scarcity was assessed by means of a blue water scarcity index (WS_{blue}):

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

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 (Hoekstra *et al*., 2009). 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 (Mekonnen *et al*., 2015). A catchment where WS_{blue} [x, t] is greater than one at a particular period of time is regarded to be a hotspot (Mekonnen and Hoekstra, 2012; Hoekstra *et al*., 2011) and needs intervention to ensure the sustainable use of freshwater in that specific catchment.

3. Results and discussion

3.1 Water footprint of tobacco

Table 1 below sets out a summary of water used to produce tobacco at Loskop Irrigation Scheme. ET_{crop} (mm / growing period) refers to crop evapotranspiration and is an indication of the water requirement of the crop. Eff_{rain} (mm/growing period) represents effective rainfall, Eff_{Irr} (mm/growing period) represents effective irrigation, and IR is the irrigation requirement to supplement effective rainfall in order to meet the crop water requirement.

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 191 mm is smaller than the effective irrigation (199 mm) and therefore the ET_{Blue} of producing tobacco in Loskop is 191 mm per growing period.

Table 1: Summary of ET, CWU, Yield and WF of tobacco production at Loskop Irrigation Scheme

ET_{crop}	ET_{green}	ET_{blue}	CWU_{green}	CWU_{blue}	Yield	WF_{green}	WF_{blue}	$WF_{green+blue}$
mm/growing period			m^3/ha		ton/ha	m^3/ton		
465	274	191	2740	1910	3	913	638	1551

Notes: ET is shown for crop, green and blue, CWU for green and blue, and WF for green, blue, and green+blue.

The ET_{crop}, ET_{green}, and ET_{Blue} reflected in Table 1 above are expressed in depth per growing period and have to be converted to volume of CWU by multiplying the ET by a factor of 10. The CWU_{Green} and the CWU_{Blue} were calculated to be 2740 m^3/ha and 1910 m^3/ha, respectively. The $CWU_{green+blue}$ thus amounts to 4650 m^3/ha. Thus, a total volume of 4650 m^3 of water is used per hectare to produce tobacco at Loskop Irrigation Scheme. Of the total volume, 2740 m^3 is met in the form of effective rainfall, while the remaining 1910 m^3 is required in the form of supplementary irrigation.

By dividing the CWU (green and blue) by the Yield, the WF_{green} and the WF_{blue} were calculated to be 913 m^3/ton and 638 m^3/ton, respectively. The $WF_{green+blue}$ thus added up to 1511 m^3/ton. Accordingly, in order to produce one ton of tobacco at Loskop Irrigation Scheme, 1511 m^3 of water is used. Effective rainfall constituted about 60% (913 / 1511) of the total volume of water that was used to produce tobacco. Thus, while rainfall does meet a large part of the volume of water that is required to produce tobacco, a significant volume of irrigation water is still required to cover the shortfall in order to meet the crop water requirement.

Mekonnen and Hoekstra (2010) estimated the global average water footprint of tobacco (*Nicotiana tabacum)*, and found the global average $WF_{green+blue}$ to be 2000 m^3/ton. The WF_{green} accounts for more than 70% of the global average $WF_{green+blue}$. Effective rainfall thus is an important source of water for tobacco production, globally, and so too at the Loskop Irrigation scheme. The smaller water footprint found in this study may be attributable to the relatively higher yields that were used in the calculation of the water footprint, compared with those used in the calculation by Mekonnen and Hoekstra (2010).

3.2 Blue Water Scarcity at Loskop Irrigation Scheme

Figure 2 below depicts the water scarcity situation in the Olifants Catchment in order to give insight into the water availability during the peak growing season.

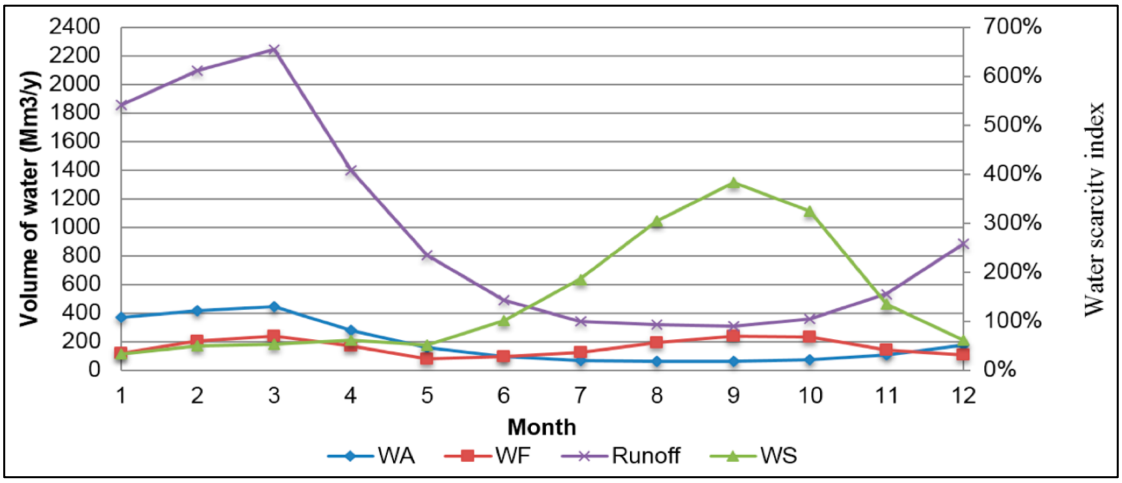

Figure 2: Water Availability, Water Footprint, Runoff, and Water Scarcity in the Olifants River Basin, 1996-2005

Notes: The above shows the Water Availability (WA), Water Footprint (WF), Runoff, and Water scarcity (WS) over the years for the Olifants River Basin in South Africa, using data for the period 1996-2005.

Figure 2 shows that the blue water scarcity index exceeds 100% during the months between June and November. A water scarcity index in excess of 100% implies that more water is used than what is actually available for use. As such, the water users in the Olifants Catchment are tapping into the environmental flow requirement during those months. From October, there is an increase in runoff because of the start of the rainy season. The increase in runoff, in turn, increases the water that is available for use, and hence decreases the water scarcity index.

When considering tobacco production at the Loskop Irrigation Scheme, the planting period (September to November) corresponds with the period when blue water scarcity is high. The growth stages (group, vigorous and mature) when the water requirement is high (Peng *et al.*, 2015), however, occur during the period when the water scarcity index is less than 100%. Thus, the main growing period of tobacco at Loskop Irrigation Scheme corresponds with the period when water scarcity is not a problem.

4. Conclusions and recommendations

A water footprint is expressed in terms of water per unit of production. The results showed that the green water footprint of tobacco is higher than the blue water footprint of tobacco production is. Given a tobacco yield of 3 ton/ha, the WF_{green} amounted to 912 m^3/ton, and the WF_{blue} amounted to 637 m^3/ton for the production of tobacco at Loskop. Therefore, the results indicate that in order to produce one ton of tobacco at Loskop, 912 m^3 of rainfall and additional 637 m^3 irrigation is required. It is concluded that effective rainfall does contribute substantially towards meeting the water requirement of tobacco production in the Loskop Irrigation Scheme.

Tobacco production in the study area shows a lower water footprint than the global averages reported by Mekonnen and Hoekstra (2011). Mekonnen and Hoekstra (2011) reported a global average water footprint of 2 000 m^3/ton, compared with a water footprint of 1 550 m^3/ton in this study. Based on the global comparison, tobacco production in South Africa may be considered an efficient use of the limited freshwater resource. Regardless of being smaller than global averages, it is crucial to assess the water footprint indicator in the context of water availability in various production areas. Only then can strategies be formulated regarding the sustainable use of freshwater for the tobacco production in South Africa. Moreover, local, context-specific information is required to inform all the role-players involved in the production of tobacco products about the sustainable use of freshwater.

Based on the results, the following recommendations were made:

- Farmers should utilise crop residues and mulches to decrease soil water evaporation and enhance nutrient recycling.
- Enhanced irrigation methods, such as drip and subsurface irrigation, should be used to improve water use efficiency.
- It is of importance for future researchers to conduct a sustainability assessment with local, context-specific information in order to acquire a more accurate indication of sustainability, because the monthly blue water data provided by Hoekstra and Mekonnen (2011) did not take into account the water in dams and inter-basin water transfers.
- A water footprint is composed of three components, being the blue, green and grey water footprints. The grey water footprint should be assessed in future research at the Loskop Irrigation scheme to calculate the total water footprint of tobacco production.

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