Water Footprint of Table Grape Production Systems: A Review of South African and Global Studies

A. Sigadla[1], E. Avenant*[2,3], M. Fanadzo[1], G.N. Kangueehi[4] and J.H. Avenant[5]

(1) Cape Peninsula University of Technology, Department of Agriculture, Faculty of Applied Sciences, Private Bag X8, Wellington 7654, South Africa
(2) Stellenbosch University, Department of Viticulture and Oenology, Faculty of AgriSciences, Private Bag X1, Matieland 7602, South Africa
(3) South African Table Grape Industry, P.O. Box 2932, Paarl 7620, South Africa
(4) Namibia University of Science and Technology, Private Bag 13388, Windhoek, Namibia
(5) ARC Infruitec-Nietvoorbij, Private Bag X5026, Stellenbosch 7599, South Africa

Submitted for publication: April 2022
Accepted for publication: July 2022

Keywords: Water footprint, Table grapes, Water-use efficiency, Irrigation requirements

Being a water-scarce country, South Africa (SA) faces several water challenges, including drought and other effects of climate change. Therefore, there is a need to improve water-use efficiency (WUE) by accurately quantifying the water use and WUE of table grape vineyards. The objective of this review is to (i) provide an overview of water footprint (WF) studies conducted on table grape production systems in SA and globally; (ii) identify limitations in current WF assessments of table grape production systems; and (iii) establish a range of WF values for table grape production systems as an indicator of WUE and for use in decision-making regarding sustainable freshwater use. The review has demonstrated that only a limited number of detailed WF studies have been undertaken on table grapes in SA and globally. Region-specific lookup tables for quantifying blue, green and grey water use in table grape production systems are available for three table grape production regions of SA and could be used for future WF assessments. Most global studies conducted on grape WF and WUE were desktop studies and did not include actual field records from production units, nor did they distinguish between different grape types (table, raisin and wine grapes). WF values must be interpreted in context, specifically regarding the water used versus yield, quality and income, as well as the region, climatic conditions, soil characteristics, irrigation and cultivation practices. For future WF and WUE assessments, a more detailed breakdown of water use is recommended, both during the production process and postharvest.

INTRODUCTION

South Africa is a water-scarce country, receiving approximately 470 mm of rainfall per annum compared to the global average of 840 mm (Department of Water Affairs and Forestry [DWAF], 2004). The country faces several challenges to its water resources, including the competition for water due to an increasing population, economic growth and climate change. It therefore is essential to improve water-use efficiency (WUE) (Brand South Africa, 2019). The scarcity of water in most grape-growing regions has consequently made irrigation water a limited resource (Myburgh, 2011a, 2011b). The annual rainfall in SA is too low for dryland (non-irrigated) commercial table grape production, hence this industry's dependence on irrigation (Myburgh, 2011b). Table grape production is characterised by the intensive use of water, which puts pressure on local or regional water resources, particularly in dry regions (Permanhani *et al*., 2016).

The SA table grape industry comprises 21 100 ha (South African Table Grape Industry [SATI], 2021) of vineyards in five regions (Northern Province, Orange River region, Olifants River region, Berg River region and Hex River Valley). It is export driven, brings valuable foreign currency to the country and has directly created more than 14 000 permanent jobs, with 74 000 seasonal jobs in the 2020/2021 season (SATI, 2021).

During the 2017/2018 and 2018/2019 seasons, water available for irrigation in the areas where table and wine grapes are cultivated extensively in SA was severely curtailed, and most producers had to utilise water conservation measures, with extreme cases where vineyards were removed completely (Jarmain, 2020). The main topic of discussion during the post-season analysis of the

**Corresponding author: E-mail address: avenant@sun.ac.za*
Acknowledgements:

DOI: https://doi.org/10.21548/43-2-5120

2018/19 season by the Joint Marketing Forum of the South African Table Grape Industry (SATI, 2019) was the lower production (yield) and quality of table grapes, and the season was described as "the most difficult season ever" (Jarmain, 2020). The past and ongoing pressure on available water resources for agricultural production, including table grape production, has initiated a focus on the sustainable and efficient use of water for crop production, as well as crop water-use efficiency (WUEc), and the crop water footprint (WF) as indicators of sustainable water use.

Water-use efficiency is defined as the total biomass production, shoot biomass or economic harvested yield per unit area in relation to total evapotranspiration (ET), plant transpiration (E) or seasonal water use (irrigation and rainfall) (Chaves *et al*., 2007). The WF of a product is defined as the total volume of freshwater used to produce goods and/or services consumed by the individual, community or business (Hoekstra *et al*., 2011), and is classified into three categories, namely the green, blue and grey WF. The blue WF indicates the quantity of surface or groundwater evaporated or embedded in a product; the green WF indicates the quantity of rainwater evaporated or embedded in a product; and the grey WF indicates the quantity of freshwater needed to integrate the load of pollutants to acceptable levels that will not be harmful to the environment (Hoekstra *et al*., 2011; Mekonnen & Hoekstra, 2011). In terms of table grape production, the WF would be the quantity of water used per kilogram or ton of grapes produced and includes blue and green water used by the grapevine through evapotranspiration (which forms the bulk of the WF), blue and green water used during spray applications in the vineyard and in the pack store, as well as grey water used for the dilution of pollutants.

To date, only a limited number of detailed WF studies have been undertaken in SA (Pahlow *et al*., 2015), and only a few on table grapes (Avenant *et al*., 2017; Kangueehi, 2018; Jarmain, 2020). However, several studies have been conducted on the annual irrigation requirements and application of irrigation to table and raisin grape vineyards in SA. The results indicate that the annual irrigation requirements of table grape vineyards in SA was inconsistent, and ranged from 256 mm to 1 863 mm (Table 1) depending on the region, irrigation practices used, vineyard characteristics and vine vigour. These studies focused only on the use of irrigation water and not on water use throughout the whole table grape production process.

The aims of this review are to: (i) provide an overview of WF studies conducted on table grape production systems in SA and globally; (ii) identify limitations in current WF assessments of table grape production systems; and (iii) establish a range of WF values for table grape production systems that can be used in decision-making on sustainable freshwater use.

WF ASSESSMENT METHODS

Water footprint is an indicator used to assess both direct and indirect water use by a consumer or producer (Egan, 2011). Increasingly, WFs have been used to indicate the effect of water use on production systems (Herath *et al*., 2013). Different methods have been used to calculate WF (Mekonnen & Hoekstra, 2010; Hoekstra *et al*., 2011; Van der Laan, 2017; Jarmain, 2020). These methods differ in terms of how a WF is defined and calculated, as well as how the values are interpreted (Jarmain, 2020). Four of the approaches and methods applicable to agricultural WF assessments are the Global Water Footprint Standard (GWFS), water footprint assessment (WFA) through life cycle assessment (LCA), Water Footprint Network (WFN), and the hydrological-based approach (Table 2).

WF OF TABLE GRAPE PRODUCTION SYSTEMS IN SA

A WF analysis of the Breede River Water Management Area by Pegasus (2010) showed that table grapes offer producers the highest gross income per cubic metre of irrigation water and create the highest number of jobs per unit of water compared to all other crops produced in the catchment area. When the study of Avenant *et al*. (2017) commenced in the 2012/2013 season, Pegasus (2010) was the only publication that could be found on the water footprinting of table grapes in SA. Furthermore, this analysis only included the blue and green water WFs, while no plant-based measurements were reported, and no additional water-use aspects were recorded, such as water used during spraying applications in the vineyard and water used in the pack store.

Pahlow *et al*. (2015) reported a blue WF for grapes of 157 m^3/ton in SA, which was based on a yield of 13.8 t/ha

TABLE 1
Annual irrigation requirements of table grape vineyards under South African conditions.

Cultivar	Irrigation method	Reference
Barlinka	411 mm with drip irrigation to 569 mm with micro-sprinkler irrigation	Saayman & Lambrechts (1995)
Barlinka	663 mm to 741 mm irrigated with micro-sprinklers	Myburgh (1996); Fourie (1989)
Crimson Seedless	460 mm with drip irrigation to 1 863 mm with micro-sprinkler irrigation	Avenant (2019)
Dan-ben Hannah	256 mm with low-frequency drip irrigation to 492 mm with daily pulse-drip irrigation	Myburgh & Howell (2012)
Sultanina	655 mm to 1 348 mm with micro-sprinkler irrigation	Myburgh (2003)
Sunred Seedless and Muscat Supreme	879 mm with micro-sprinklers	Myburgh & Howell (2007)

and is much lower than the industry average for table grape production in the country, which ranges between 22.5 and 27 t/ha, depending on cultivar and cultivation conditions. They also reported that the blue WF exceeded blue water availability in several basins for several months of the year. Avenant *et al*. (2017) conducted a WUE and blue WF analysis of table grape production in SA over three seasons (2013/2014 to 2015/2016), in a study comprising two components, namely: (i) a field trial including four mature production blocks in the Hex River Valley; and (ii) a survey including 18 commercial table grape blocks, representing the five SA table grape production regions, to determine irrigation and other water uses (water used for spray applications in the vineyard and water used in the pack store); these were included in the WUE and WF analyses. For this study, WUE was defined as the total harvested yield per unit of water use through ET (kg/m^3), whereas water productivity (WP) was defined as the total harvested yield per unit of irrigated volume (kg/m^3). Only seasonal ET, irrigation and transpiration volumes were considered for calculating the blue WF, WUE and WP in this study. This was deemed sufficient, since ET was reported to account for more than 90% of the blue WF (Gush & Taylor, 2014).

The regional average blue WF and WP based on irrigation water use of blocks in the field trial and the survey are presented in Table 3. Due to the relatively low annual rainfall in all five table grape production regions in SA (Table 3), water used for vineyard irrigation makes a major contribution to the blue WF. The blue WF, based on irrigation volume, varied from 202 m^3/kg (Hex River Valley) to 2 705 m^3/kg (Orange River region), and the WP from 0.59 kg/m^3 (Orange River region) to 4.94 kg/m^3 (Hex River Valley). The higher water volumes used for irrigation, resulting in the highest blue WF and lowest WP in the Orange River region, were ascribed to high evaporative demand due to higher temperatures, lower relative humidity and higher vapour pressure deficit; the longer growing season compared to most other regions; as well as the use of micro-sprinkler irrigation systems instead of drip.

Total blue water use for spray applications varied from 10.4 m^3/ha (Olifants River region) to 31.1 m^3/ha (Northern provinces). The highest volumes used in the Northern provinces were ascribed to: (i) the longer growing season and long summer rainfall period, necessitating more spray applications for plant protection; and (ii) insufficient chill unit accumulation in winter, causing uneven budbreak and flowering and further development of phenological stages, resulting in more plant bioregulator applications needed for rest breaking, thinning and berry sizing (Avenant & Avenant, 2020). Regarding "Pack store water use", there were large variations (< 1 to 11.8 m^3/ha), due, amongst others, to no pre-cooling done in the Western Cape sites included in the study, while pre-cooling was applied in the Orange River and Northern provinces (Avenant & Avenant, 2020).

The blue WF based on irrigation water, ET and transpiration (T), as well as the WP and WUE of Crimson Seedless blocks in the Hex River Valley, are presented in Table 4. Blue WF values ranged from 203 to 501 m^3/t (Blue WF Irr), 330 to 580 m^3/t (Blue WF ET) and 207 to 208 m^3/t (Blue water T); WP ranged from 2.00 to 4.93 kg/m^3; and WUE ranged from 1.72 to 3.03 kg/m^3. For both field trial blocks in which T was measured using sap flow, the WUE based

TABLE 2
Approaches and methods used for WF assessment.

Approaches and methods	Description	Reference
GWFS	Aims to assess the degree of sustainability with which freshwater is used to produce a particular product.	Mekonnen & Hoekstra (2010)
WFA through LCA	Focuses on the effect of certain processes on scarce freshwater resources.	Ridoutt & Pfister (2010)
WFN	Aims to use the WF concept to promote the transition to sustainable, fair and efficient use of freshwater resources worldwide.	Hoekstra et al. (2011)
Hydrological-based approach	Considers all the components of the water balance, rather than water consumption only.	Van der Laan (2017)

TABLE 3
Blue WF and WP of Crimson Seedless in SA (adapted from Avenant *et al*., 2017; Avenant & Avenant, 2020).

Region	Annual rainfall	Irrigation applied	Blue WF irr.	WP
	mm	m^3/ha	m^3/t	kg/m^3
Berg River	300-700	7 358-7 414	273-275	3.64-3.67
Hex River	300	4 590-10 560	202-501	2.00-4.93
Northern provinces	700	4 710-8 402	282-478	2.09-3.55
Olifants River	200	11 100-13 200	437-643	1.56-2.29
Orange River	80-150	12 760-18 358	815-1 705	0.59-1.23

TABLE 4
Blue WF, WP and WUE of four Crimson Seedless field trial blocks in the Hex River Valley of SA (adapted from Avenant & Avenant, 2020).

Farm no.	**Season**	**Rainfall**	**Irrigation applied**	**ET**	**T**	**Yield**		**Blue WF Irr**	**Blue WF ET**	**Blue WF T**	**WP**	**WUE ET**	**WUE T**
		mm	m^3/ha	m^3/ha	m^3/ha	Number of export cartons/ha	t/ha	m^3/ton	m^3/ton	m^3/ton	kg/m^3	kg/m^3	kg/m^3
1	2013/2014	1 018	4 598	8 837	-	4 000	18.0	255	491	-	3.91	2.04	-
	2014/2015	883	7 524	7 618	-	4 000	18.0	418	423	-	2.39	2.36	-
	2015/2016	232	5 698	8 591	-	4 200	18.9	301	455	-	3.32	2.20	-
2	2013/2014	1 018	8 565	8 463	-	4 000	18.0	476	470	-	2.10	2.13	-
	2014/2015	883	8 448	8 016	-	4 800	21.6	391	371	-	2.56	2.69	-
	2015/2016	232	10 560	8 959	5 039	5 400	24.3	435	369	207	2.30	2.71	4.82
3	2013/2014	1 018	9 344	10 174	-	5 200	23.4	399	435	-	2.50	2.30	-
	2014/2015	883	9 216	9 034	-	5 000	22.5	410	402	-	2.44	2.49	-
	2015/2016	232	9 248	10 709	-	4 100	18.5	501	580	-	2.00	1.72	-
4	2013/2014	1 018	6 501	10 489	-	5 500	24.8	263	424	-	3.81	2.36	-
	2014/2015	883	6 171	9 398	-	6 000	27.0	229	348	-	4.38	2.87	-
	2015/2016	232	6 201	10 084	6 374	6 800	30.6	203	330	208	4.93	3.03	4.80

DOI: https://doi.org/10.21548/43-2-5120

on T was similar (4.8 kg/m^3). The WUE of table and raisin grape vineyards on horizontal trellis systems reported from other studies include 5.5 kg/m^3 for Sultanina in California (Araujo *et al*., 1995), 4.05 kg/m^3 for Sultanina in Australia (Yunusa *et al*., 1997b), and 1.9 to 3.3 kg/m^3 for Sultanina in the Orange River region of SA (Myburgh, 2003).

Jarmain (2020) conducted a study to assess the WF of table grapes as an indicator of sustainability. The study, which included 236 commercial table grape blocks (representing 35 cultivars) and access to large production databases, together with spatial estimates of crop water use (ET) for a significant number of the blocks, allowed the estimation of WF for a wide spectrum of production conditions in three production regions of SA (Hex River Valley, Berg River region and Olifants River region) for the 2018/2019 season. A WF assessment as per the GWFS approach was applied in this project, and the WF calculations for table grapes included all direct water uses – from grape production in the vineyard up to the packing of grapes in the packhouse – but prior to final cold storage. It included the blue, green and grey WFs at field level and the blue WF at packhouse level, but not the grey WF at packhouse level. Considering the total WF (WF_{total}) for table grapes, the main findings of Jarmain (2020) were:

The WF_{total} for table grapes ranged between 500 and 714 m^3/t with a median value of 619 m^3/t, and the highest WF_{total} calculated for grapes produced in the Berg River region.

- The WF_{total} for table grapes showed a small or negligible contribution of the WF_{blue} from the packhouse (< 1% or 0.76 m^3/t) to the WF_{total}, with the field-level WF_{total} contributing to 99% of the estimates. It was noted that this was in the absence of WF_{grey} at packhouse level, which contributes to the WF_{total}.
- Variation in the WF_{total} was observed between cultivars, with the highest median WF_{total} calculated for Sugranineteen (Scarlotta Seedless®) and the lowest for Prime.
- For all areas studied, the WF_{blue} (field level plus packhouse) contributed most to the WF_{total} (more than 70%). The WF_{grey} contributed about 20% to the WF_{total}.
- The resultant WF_{total} for table grapes directly reflects the blocks included in the study, the conditions experienced during the 2018/2019 season, and the quality of the table grapes produced during the season, with a low annual rainfall (< 345 mm/year) and a median export fraction of 67%, representing a less than ideal production season.

WF OF GLOBAL GRAPE PRODUCTION SYSTEMS

Studies of both table and wine grape WFs are included in this section because limited publications are available on the WF of table grapes and, in some studies on global WF data, the type of grape is not specified.

Mekonnen and Hoekstra (2010) reported a global blue WF of 97 m^3/ton for grapes. The blue WF reported in this study was lower than the blue WF calculated in the SA studies (Avenant *et al*., 2017; Kangueehi, 2018; Jarmain, 2020). One possible explanation for the lower global WF values could be that smaller production units were included, which could have affected the average global yield value. This might have resulted in lower values compared to a situation where most units included are commercial units with considerably higher yields.

Aldaya *et al*. (2010) conducted a study in Spain and reported a yield of 6 t/ha for wine grapes under dryland production in a "normal" (1 000 mm per year) rainfall year. Water requirements of these vineyards (ET of 128 mm) were entirely based on green water resources, resulting in a blue WF of 0 m^3/t and a green WF of 229 m^3/t. Zoumides *et al*. (2012) conducted a WF study in Cyprus and reported the following values for table grapes: blue WF ranging from 700 to 975 m^3/t, and green WF ranging from 625 to 700 m^3/t. No field measurements or producer records were used in their study, and water-use values were obtained from an agricultural census for the period 1995 to 2009. Providing context to the high WF values reported, Cyprus is described as a semi-arid island situated in the north-east of the Mediterranean Sea, with water scarcity due to a high water demand compared to supply, limited and highly variable precipitation, high agricultural water use and overexploitation of groundwater resources.

Ene *et al*. (2012) conducted a study in Romania, estimating total crop water requirement, effective rainfall and irrigation requirements per region using the "CROPWAT" model. They reported values for "grapes" (average for the period 2005 to 2008) as follows: blue WF of 7 m^3/t, grey WF of 580 m^3/t, green WF of 1 226 m^3/t and total WF of 1 813 m^3/t. In the region where the study was conducted, irrigation infrastructure was underdeveloped, and all crop production was dependent on rainwater. There were fluctuations between "normal" and "dry" years, and the evaluation of monthly green and blue water availability indicated that total water availability, and the contributions of the green and blue components, differed between months within a year, as well as between years.

Multsch *et al*. (2013) conducted a study in Saudi Arabia using a special decision-support system (SPARE:WATER) and reported calculated water requirements for perennials crops, such as for dates, citrus and grapes, of 1 132, 1 745 and 1 139 mm respectively, as well as "high irrigation requirement" grapes, which exceeded 2 000 mm. They calculated the following values for grapes (not specifying the type of grapes): a blue WF of 1 448 m^3/t, a grey WF of 341 m^3/t and a green WF of 72 m^3/t. Similar to production regions in South Africa, the total WF was dominated by the blue component (86%), with the grey WF and green WF contributing 11% and 4% respectively. The small contribution of the green WF reflects the very low annual rainfall.

Herath (2013) conducted WF assessments of 36 wineries in two regions in New Zealand over a three-year period and reported a blue WF of -81 L/750 ml bottle of wine for irrigated wine grape vineyards, and -415 L/750 ml bottle of wine for rainfed (dryland vineyards) – the negative values indicating that the water resources were recharged to field capacity during winter through rainfall. Herath (2013) reported a grey WF of 40L/750 ml bottle of wine for irrigated vineyards and 188L/750 ml bottle of wine for rainfed vineyards. Similar to the study of Jarmain (2020) regarding the WF of table grape production systems, Herath (2013) also reported large variation in the WF of wine grapes at field level due to the large variability in regional rainfall and vast differences in local soil properties. Similar to the small contribution of packhouse water use to the WF of table grape production systems, Herath (2013) also found that the effect of cellar water use on the total WF was very small compared to the contribution of vineyard water use in the field.

Vazquez-Rowe *et al*. (2017) assessed the WF of grapes for pisco production in five regions of Peru, using a life-cycle approach. Irrigation water-use volumes were modelled using the FAO 56 approach Allen *et al*. (1998), and the high WF values obtained were ascribed to the inefficient flood irrigation systems used. The annual irrigation volumes reported ranged from 3 227 to 4 745 m^3, which seems to be very low for flood irrigation under the very low rainfall conditions of the regions studied. It could be that the assumptions made, and the standard crop factor used in the model, resulted in an underestimation.

Lovarelli *et al*. (2016) reviewed 96 scientific studies on the WF of agricultural crops, including studies conducted from 1960 to 2015. In this review, which included studies on cereal crops (33%), fruit (13%), vegetables (16%), sugar cane and beet (16%), cocoa, coffee and tea (14%), cotton (6%) and other crops (10%), no paper on the WF of table grapes was included or referenced, while only one study on the WF of wine was included. This indicates the limited published research results available on the WF of grapes, and specifically table grape production systems.

IDENTIFIED LIMITS IN WF ASSESSMENTS

Most of the studies conducted on grape WF and WUE were desktop studies and did not include actual field records and measurements from production units. In several of the existing WF studies, water-use components were quantified through modelling, for example by using the CROPWAT model (FAO, 2009) with general crop data and assumptions. This does not reflect or detail the variability of vineyards and important factors related to water management, such as vine density, canopy size and volume, and the timing of irrigation water.

Most of the global WF and WUE data available do not distinguish between the different grape types (table, raisin and wine grapes). While some studies have determined the WUE of table grapes (Araujo *et al*., 1995; Yunusa *et al*., 1997a, 1997b; Myburgh, 2003), limited research results are available regarding the total volume of water required throughout the entire production chain, from field to packhouse. In several on the WF studies on grapes, not all three components of the WF were included, with most studies quantifying only the blue and green WFs, similar to what Lovarelli *et al*. (2016) reported for 96 WF studies on a range of agricultural crops.

Quantifying the grey WF depends strongly on assumptions made about elements included in the quantification (nitrogen, phosphorous, metals and pesticides) (Lovarelli *et al*., 2016).

Jarmain (2020) states that, in collating the data required for a WFA of table grapes and wine, the main challenge faced was the lack of easily accessible data required for the WF calculations. This challenge is likely the reason why there have been so few studies of this nature in South Africa, and for the table grape industries, and why most of the existing studies have focused on single blocks or a few blocks. Jarmain (2020) also reported that no single table grape data management system is used in South Africa; therefore, easy access to production data is limited, which complicates data integration for multiple farms or packhouses, and linking the production data to remote-sensing data involves numerous steps and checks.

Despite increasing pressure on the available water in SA, water use on the block, farm and packhouse level are still not widely measured and, where WU data are available, they often include all uses for multiple blocks or the entire farm (Jarmain, 2020). Therefore, in Jarmain's (2020) project, the use of spatial ET data and regional specific lookup tables derived as part of the project outcomes were explored, with the latter providing a summary of valuable WU data.

The WF assessment results reflect the blocks and seasons studied. Variability in the results of WF assessments of the same crop are ascribed to different assessment/calculation methods used, crop vigour/production characteristics, and the cultivation practices applied. Therefore, WF values must always be interpreted in context, specifically regarding the water used versus production, quality and income, as well as the region, climatic conditions, soil characteristics, irrigation and other, and cultivation practices applied.

CONCLUSIONS

This review has shown that only a limited number of detailed WF and WUE studies have been undertaken in SA and globally, and that only a few of them were done specifically on table grapes. Existing region-specific lookup tables for quantifying blue, green and grey water use in table grape production systems are available for three table grape production regions of SA, and could be used for future WF assessments. In future WF studies, the existing lookup tables could be expanded, and similar lookup tables could also be compiled for other SA production regions.

Most of the studies conducted on table grape WF and WUE were desktop studies and did not include actual plant-based and/or physiological measurements. Most of the global WF and WUE data available do not distinguish between the different grape types (table grapes, raisin grapes and wine grapes). For future WF and WU assessments, it is recommended that a more detailed breakdown of water use in the production process and pack store are obtained, and that, where possible, measured values are obtained.

LITERATURE CITED

Aldaya, M.M., Martínez-Santos, P. & Llamas, M.R., 2010. Incorporating the water footprint and virtual water into policy: Reflections from the Mancha occidental region, Spain. Water Resour. Manag. 24, 941-958.

Allen, R.G., Pereira, L.S., Raes, D. & Smith,m., 1998. Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.

Araujo, F., Williams, L.E. & Matthews, M.A., 1995. A comparative study of young 'Thompson Seedless' grapevines (*Vitis vinifera* L.) under drip and furrow irrigation. II. Growth, water use efficiency and nitrogen partitioning. Sci. Hortic. 60, 251-265.

Araujo, J.A., Abiodun, B.J. & Crespo, O., 2016. Impacts of drought on grape yields in Western Cape, South Africa. Theor. Appl. Clim. 123, 117-130.

Avenant, E., 2019. Determining the water footprint of table grapes to improve water resource management of the South African table grape industry. SU Project S0037660. South African Table Grape Industry, P.O. Box 2932, Paarl 7620, South Africa.

Avenant, E. & Avenant, J.H., 2020. Water use and water use efficiency of table grapes in South Africa. SA Fruit J. Oct-Nov, 66-68.

Avenant, E., Kangueehi, G.N. & Avenant, J.H., 2017. Assessing the blue water footprint and water use efficiency of *Vitis vinifera* cv. Crimson Seedless in South Africa. In: Novello, V. & De Palma, L. (eds). Book of Extended Abstracts: 8th Int. Table Grape Symp., 1-7 October, Apulia and Sicily, Italy.

Avenant, J.H., 2018. Tafeldruifonderstokke in Suid-Afrika. South African Table Grape Industry. P.O. Box 2932, Paarl 7620, South Africa.

Brand South Africa, 2019. South Africa tackles water issues. Available from https://www.brandsouthafrica.com/south-africa-fast-facts/news-facts/south-africa-tackles-water-issues [accessed 26 January 2019).

Chaves, M.M., Santos, T.P., Souza, C.D., Ortuño, M.F., Rodrigues, M.L., Lopes, C.M., Maroco, J.P. & Pereira, J.S., 2007. Deficit irrigation in grapevine improves water-use efficiency while controlling vigour and production quality. Ann. Appl. Biol. 150, 237-252.

Department of Water Affairs and Forestry (DWAF), 2004. Department of Water Affairs and Forestry Annual Report 2003/2004. Report No. 131/2004. Pretoria: DWAF.

Egan, M., 2011. The water footprint assessment manual. Setting the global standard. Soc. Environ. Account. J. 31, 181-182.

Ene, S.A., Hoekstra, A.Y., Mekonnen, M.M. & Teodosiu, C., 2012. Water footprint assessment in north-eastern region of Romania. A case study for the Iasi County, Romania. J. Environ. Prot. Ecol. 13, 506-516.

FAO - Food and Agriculture Organization of the United Nations, Rome, 1998.

FAO, 2009. CROPWAT 8.0 Model. Rome: FAO.

Fourie, A., 1989. The effect of four soil water regimes on the performance of Barlinka table grapes in the Hex River Valley. MSc. Thesis, Stellenbosch University, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa.

Gush, M.B. & Taylor, N.J., 2014. The water use of selected fruit tree orchards (Volume 2): Technical report on measurements and modelling. *Water Research Commission report*, (1770/2), 14. WRC Report No 303/1/00. Water Research Commission, Private Bag X103, Gezina, Pretoria, 0031, South Africa.

Herath, I., Green, S., Singh, R., Horne, D., Van der Zijpp, S. & Clothier, B., 2013. Water footprinting of agricultural products: A hydrological assessment for the water footprint of New Zealand's wines. J. Clean. Prod. 41, 232-243.

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M. & Mekonnen, M.M., 2011. The water footprint assessment manual: Setting the global standard. London: Earthscan.

Jarmain, C., 2020. Water footprint as an indicator of sustainable table and wine grape production. WRC Report No. 2710/1/20, Private Bag X103, Gezina, Pretoria, 0031, South Africa.

Kangueehi, G.N., 2018. Water footprint analysis to improve water use efficiency in table grape (*Vitis vinifera* L. cv. Crimson seedless) production. A South African case study. PhD dissertation, Stellenbosch University, Private Bag X1, 7602 Matieland (Stellenbosch), South Africa.

Lovarelli, D., Bacenetti, J. & Fiala, M., 2016. Water footprint of crop productions: A review. Sci. Total Environ. 548, 236-251.

Mekonnen, M.M. & Hoekstra, A.Y., 2010. A global and high-resolution assessment of the green, blue and grey water footprint of wheat. Hydrology and Earth System Sciences, 14, 1259-1276.

Multsch, S., Al-Rumaikhani, Y.A., Frede, H.-G. & Breuer, L., 2013. A Site-sPecific agricultural water requirement and footprint estimator (SPARE:WATER 1.0). Geosci. Model Dev. Discuss. 6(1), 645-684.

Myburgh, P.A., 1996. Response of *Vitis vinifera* L. cv. Barlinka/Ramsey to soil water depletion levels with particular reference to trunk growth parameters. S. Afr. J. Enol. Vitic.17, 3-14.

Myburgh, P.A., 2003. Possible flood irrigation technologies to reduce water use of Sultanina grapevines in a hot, arid climate. S. Afr. J. Plant Soil 20, 180-187.

Myburgh, P.A., 2011a. Response of *Vitis vinifera* L. cv. Merlot to low frequency drip irrigation and partial root zone drying in the Western Cape Coastal Region – Part I. Soil and plant water status. S. Afr. J. Enol. Vitic. 32(1), 89-103.

Myburgh, P.A., 2011b. Effect of different drip irrigation strategies on vineyards in sandy soil in the Lower Olifants River region (Part 1): Irrigation and soil water status. Wynboer Technical Yearbook 2011, 24-27.

Myburgh, P.A. & Howell, C.L., 2007. Evapotranspiration of *Vitis vinifera* L. cvs Sunred Seedless and Muscat Supreme in response to soil water depletion and irrigation cut-off during berry ripening. S. Afr. J. Plant Soil 24, 209-213.

Myburgh, P.A. & Howell, C.L., 2012. Comparison of three different fertigation strategies for drip irrigated table grapes – Part I. Soil water status, root system characteristics and plant water status. S. Afr. J. Enol. Vitic. 33, 264-274.

Pahlow, M., Snowball, J. & Fraser, G., 2015. Water footprint assessment to inform water management and policy making in South Africa. Water SA 41, 300-313.

Pegasus, 2010. Water footprint analysis for the Breede catchment, South Africa. Pretoria: Pegasus Strategy and Development. 142 Loop Street, Vlaeberg 8018, Cape Town, South Africa..

Permanhani, M., Costa, J.M., Conceicao, M.A.F., De Souza, R.T., Vasconcellos, M.A.S. & Chaves, M.M., 2016. Deficit irrigation in table grape: Eco-physiological basis and potential use to save water and improve quality. Theor. Exp. Plant Physiol. 28, 85-108.

Ridoutt, B.G. & Pfister, S., 2010. A revised approach to water footprinting to make transparent the impacts of consumption and production on global freshwater scarcity. Glob. Environ. Change 20, 113-120.

Saayman, D. & Lambrechts, J.J.N., 1995. The effect of irrigation system and crop load on the vigour of Barlinka table grapes on a sandy soil, Hex River Valley. S. Afr. J. Enol. Vitic. 16, 26-34.

South African Table Grape Industry (SATI), 2019. Joint general marketing forum postseason analysis for the 2018/2019 season. South African Table Grape Industry. P.O. Box 2932, Paarl 7620, South Africa.

South African Table Grape Industry (SATI), 2021. South African table grape industry statistics booklet 2021. South African Table Grape Industry. P.O. Box 2932, Paarl 7620, South Africa.

Van der Laan, M., 2017. Application of water footprint accounting for selected fruit and vegetable crops in South Africa. WRC Report No. TT 722/17. Private Bag X103, Gezina, Pretoria, 0031, South Africa.

Vazquez-Rowe, I., Torres-García, J.R., Cáceres, A.L., Larrea-Gallegos, G., Quispe, I. & Kahhat, R., 2017. Assessing the magnitude of potential environmental impacts related to water and toxicity in the Peruvian hyper-arid coast: A case study for the cultivation of grapes for pisco production. Sci. Total Environ. 601-602, 532-542.

Yunusa, I.A.M., Walker, R.R. & Blackmore, D.H., 1997a. Characterisation of water use by Sultana grapevines (*Vitis vinifera* L.) on their own roots or on Ramsey rootstock drip-irrigated with water of different salinities. Irr. Sci. 17, 77-86.

Yunusa, I.A.M., Walker, R.R. & Guy, J.R., 1997b. Partitioning of seasonal evapotranspiration from a commercial furrow-irrigated Sultana vineyard. Irr. Sci.18, 45-54.

Zoumides, C., Bruggeman, A. & Zachariadis, T., 2012. Global versus local water footprint assessment: The agricultural production and consumption water footprint of Cyprus. In: Planet under pressure, new knowledge towards solutions, 26-29 March, London.