

# The impact of overhead netting on water use and the blue water footprint of *Vitis vinifera* L. 'Sultanina H5' in a semi-arid summer rainfall region

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# Introduction

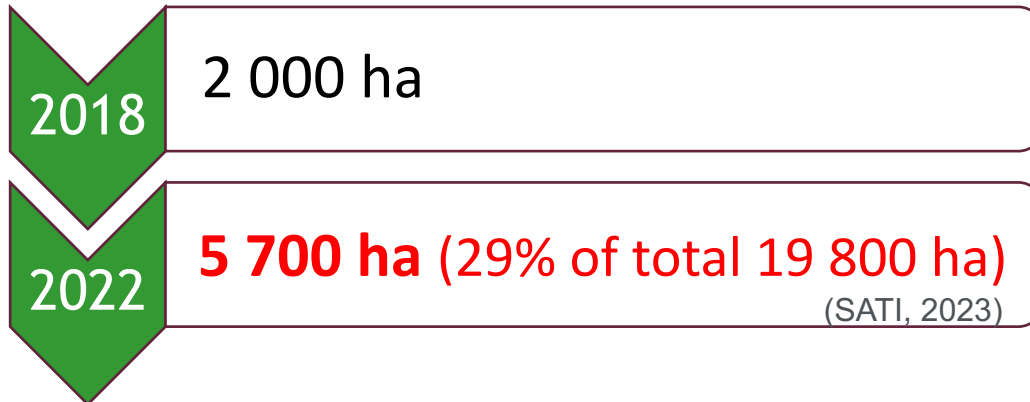
## Main reasons for using overhead nets

- **Protection against:**

- Hail damage
- Wind damage
- Bird damage

- **Microclimate modification**

- *Increased use of nets  
in all five SA table grape regions*



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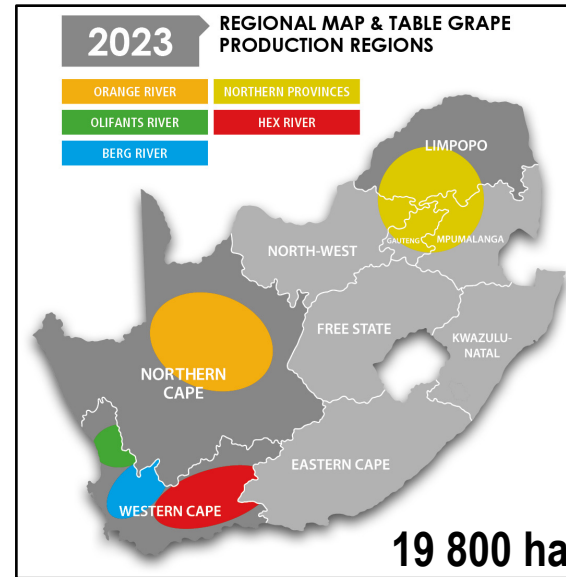
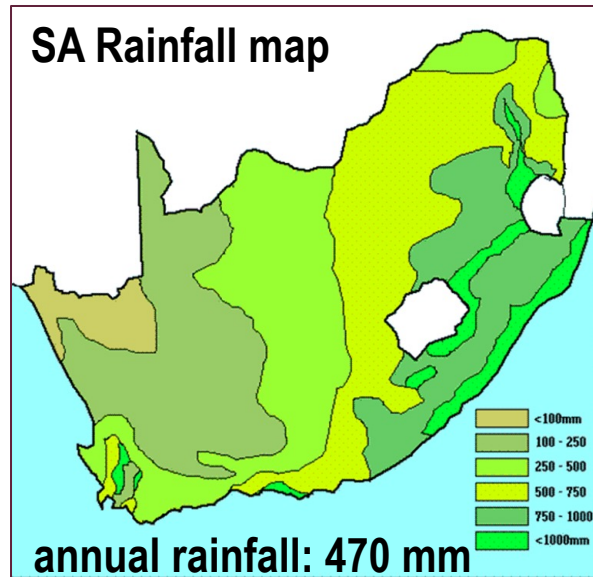
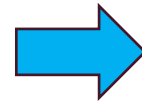
E. Avenant<sup>1,2\*</sup> and J.H. Avenant<sup>3,4</sup>

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## Introduction and Project Aim

- SA annual rainfall too low for table grape production without supplementary irrigation
- All commercial table grape production in SA under irrigation



## Annual table grape irrigation requirement in SA

Region	Irrigation requirement	Reference
Berg River	256 mm (low frequency drip) 492 mm (daily pulse drip) 740 mm (micro sprinkler)	Myburgh & Howell (2012) Myburgh & Howell (2012) Avenant et al. (2017)
Hex River	411 mm (drip) 569 mm (micro sprinkler) 663 mm (micro sprinkler) 741 mm (micro sprinkler) 879 mm (micro sprinkler) 460 mm (drip) – 1 060 (micro sprinkler)	Saayman & Lambrechts (1995) Saayman & Lambrechts (1995) Myburgh (1996) Fourie (1989) Myburgh & Howell (2007) Avenant et al. (2017)
Northern Provinces	520 mm (drip) – 900 mm (micro sprinkler)	Avenant et al. (2017)
Olifants River	1 110 mm ("double" drip) 1 320 mm (micro sprinkler)	Avenant et al. (2017)
Orange River	655 – 1 348 mm (micro sprinkler) 1 200 – 1 840 mm (micro sprinkler)	Myburgh (2003) Avenant et al. (2017)

Irrigation water use varies between regions (climate), irrigation practices, canopy characteristics, vineyard vigour.

- Increase in cultivation of table grapes under netting in SA
- Limited research results available regarding vineyard water use under netting
- Project aim: to determine the effect of overhead netting on water use of table grapes (semi-arid summer rainfall region)**

# Material and Methods: Experimental site



- Newgro farm, Kanoneiland, Lower Orange River region
- *Vitis vinifera* L. cv. Sultanina/Ramsey (10 ha), planted 2015
  - Augrabies soil form
  - 3.0 m x 2.5 m spacing
  - Pergola trellis system
  - Micro sprinkler irrigation
  - Rainfall at site during trial: 19 mm (2018/19); 80 mm (2019/20)



Open



Netted

- 2 sub-plots of 5 ha each (Open and Netted)
  - Netted: covered overhead and on sides (**WHITE NET; 20% shade**)
  - in central row of each sub-plot:
    - ❖ AWS, 3 vines instrumented for sap flow measurements, SWC probes
  - in central 5 rows of each sub-plot:
    - ❖ 10 panels (2 data vines each)  
randomly selected for plant-based measurements  
(*only midday stem water potential and yield included in this presentation*)
- macroclimate data obtained from Newgro AWS, 100 m from site

# Material and Methods:

## Water use measurements/ calculations



Sapflow monitoring (3 vines/sub-plot,  
probe depths 10, 15, 20, 25 mm)

- **Water use:**
  - **Irrigation volume** (water meters in irrigation system)
    - standard irrigation practices applied by farm, aimed at optimal supply of water during each phenological stage
    - Irrigation volumes based on 100% of estimated evapotranspiration
  - **Transpiration (T):** sap flow measurements  
(Heat Pulse Velocity method - Burgess et al., 2001)
  - **Estimated Evapotranspiration (ET):** AWS data , crop coefficients)

• **Irrigation Water Productivity** (Fernandez *et al.*, 2020)

$$(WP_i) = \frac{\text{Yield (kg)}}{\text{Irrigation water use (m}^3\text{)}}$$

- **Water use efficiency based on Transpiration Water Use**

$$(WUE_T) = \frac{\text{Yield(kg)}}{\text{Transpiration water use (m}^3\text{)}}$$

# Material and Methods: Blue water footprint

- **Irrigation Water Use**

$$\text{Blue WF Irr (m}^3\text{/t)} = \frac{\text{Irrigation water use (m}^3\text{/ha)}}{\text{Yield (t/ha)}}$$

- **Transpiration Water Use**

$$\text{Blue WF Irr (m}^3\text{/t)} = \frac{\text{Irrigation water use (m}^3\text{/ha)}}{\text{Yield (t/ha)}}$$

- **Irrigation Water Use for Production of 1 x 4.5 kg carton of grapes**

$$\text{Blue WF Irr (m}^3\text{/carton)} = \frac{\text{Irrigation water use (m}^3\text{/ha)}}{\text{Yield (cartons/ha)}}$$

# Material and Methods:

## Measurements: Midday Stem Water Potential ( $\Psi_s$ )

### $\Psi_s$ measurements with pressure chamber

- 5 mature, fully expanded sun-exposed leaves per data vine
- **Compare:**
  - sun-exposed leaves of data vines in OPEN (exposed to full sun)
  - sun-exposed leaves under NET (exposed to sun, but under the 20% shade net)
- **Leaves enclosed in aluminum bags for at least 30 minutes before measurement**

# Material and Methods:

## Statistical procedures

### Plant-based measurements

- Analysis of variance with Genstat for Windows 22<sup>nd</sup> Edition (VSM International, Hempstead, UK. Webpage: [Genstat.co.uk](http://Genstat.co.uk)3).
- Shapiro & Wilk test to test normality (Shapiro & Wilk, 1965)
- Student's t-test of least significant difference (5% level) to compare treatment means.

### Physiological measurements (midday stem water potential)

- Standard deviations (XLSTAT 2016)

**Limited replication of sap flow measurements precluded statistical comparison**

# Results: Water use

## Estimated evapotranspiration (ET)

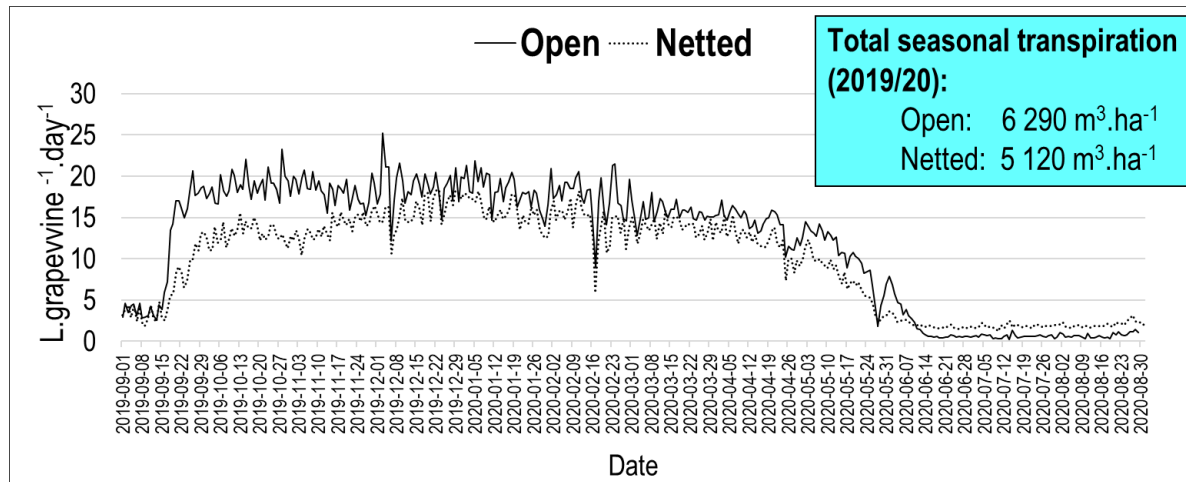
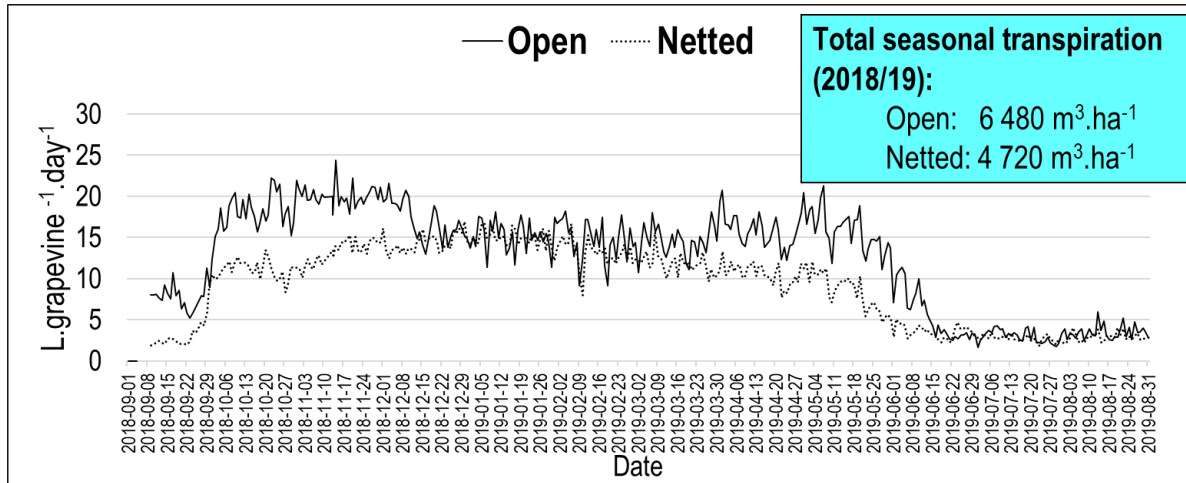
### Average monthly and total annual reference evapotranspiration (ET<sub>o</sub>) and estimated evapotranspiration (ET)

Season	ET <sub>o</sub> (mm.month <sup>-1</sup> ) from ISWC Newgro AWS												TOTAL
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2018/19	121	183	207	230	241	189	191	134	119	93	97	118	1923
2019/20	157	182	212	224	239	182	169	121	102	86	95	107	1876
Season	Estimated ET (mm.month <sup>-1</sup> ) = K <sub>c</sub> x ET <sub>o</sub>												TOTAL
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2018/19	93	156	188	216	231	180	172	114	95	55	34	72	1606
2019/20	121	155	193	211	229	173	152	103	82	51	33	65	1567

### Average daily reference evapotranspiration (ET<sub>o</sub>) and estimated daily evapotranspiration (ET)

Season	ET <sub>o</sub> (mm.day <sup>-1</sup> ) from ISWC Newgro AWS												Ave
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2018/19	4.0	5.9	6.9	7.4	7.8	6.8	6.2	4.5	3.8	3.1	3.1	3.8	5.3
2019/20	5.2	5.9	7.0	7.2	7.7	6.3	5.5	4.0	3.3	2.9	3.1	3.5	5.1
Season	Estimated ET (mm.day <sup>-1</sup> )												Ave
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	
2018/19	3.1	5.0	6.3	7.0	7.7	5.8	5.7	3.7	3.2	1.8	1.1	2.3	4.4
2019/20	4.0	5.0	6.4	6.8	7.6	5.6	5.1	3.3	2.7	1.6	1.1	2.1	4.3

# Results: Water use Sap flow/ Transpiration



Season	T (mm.month <sup>-1</sup> )												TOTAL (mm)	% dif-ference
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug		
Open 2018/19	34	86	87	76	72	64	70	70	67	22	0	0	648	
Netted 2018/19	12	57	61	67	68	56	56	45	35	15	0	0	472	▼ -27%
Open 2019/20	46	87	80	87	80	70	69	60	44	6	0	0	629	
Netted 2019/20	29	60	62	72	71	62	62	51	31	9	0	9	518	▼ -18%
Open ave	40	87	84	82	76	67	70	65	56	14	0	0	639	
Netted ave	21	59	62	70	70	59	59	48	33	12	0	5	495	▼ -23%

Except for OPEN at harvest 2019/20  
**Midday  $\Psi_s$  indicated low to moderate water stress**  
 18/19: Open -0.590 to -0.869 MPa; Netted -0.519 to -0.821 MPa  
 19/20: Open -1.062 to -1.200 MPa; Netted -0.918 to -1.056 Mpa

$$K_{cb} = \frac{T}{E T_o}$$

	Basal crop coefficient ( $K_{cb}$ )												
	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Ave
Open	0.32	0.46	0.40	0.35	0.31	0.34	0.36	0.48	0.47	0.15	0.00	0.10	0.32
Netted	0.14	0.31	0.29	0.30	0.28	0.31	0.32	0.38	0.30	0.13	0.00	0.10	0.14

# Results: Water use

## Midday stem water potential

Treatment Phenological stage	2018/19					2019/20				
	Date	OPEN		NETTED		Date	OPEN		NETTED	
		$\psi_s$ (MPa)	StDev	$\psi_s$ (MPa)	StDev		$\psi_s$ (MPa)	StDev	$\psi_s$ (MPa)	StDev
1 month before harvest	2018-12-11	0.869	0.338	0.821	0.273	2019-12-12	1.062	0.134	0.918	0.107
Harvest (1st week of harvest)	2019-01-09	0.590	0.112	0.519	0.142	2020-01-15	1.200	0.159	1.035	0.123
1 month after end of harvest	2019-03-28	0.766	0.114	0.794	0.070	2020-03-05	1.079	0.154	1.056	0.090

StDev = standard deviation

Except for OPEN at harvest 2019/20

**Midday  $\Psi_s$  indicated low to moderate water stress**

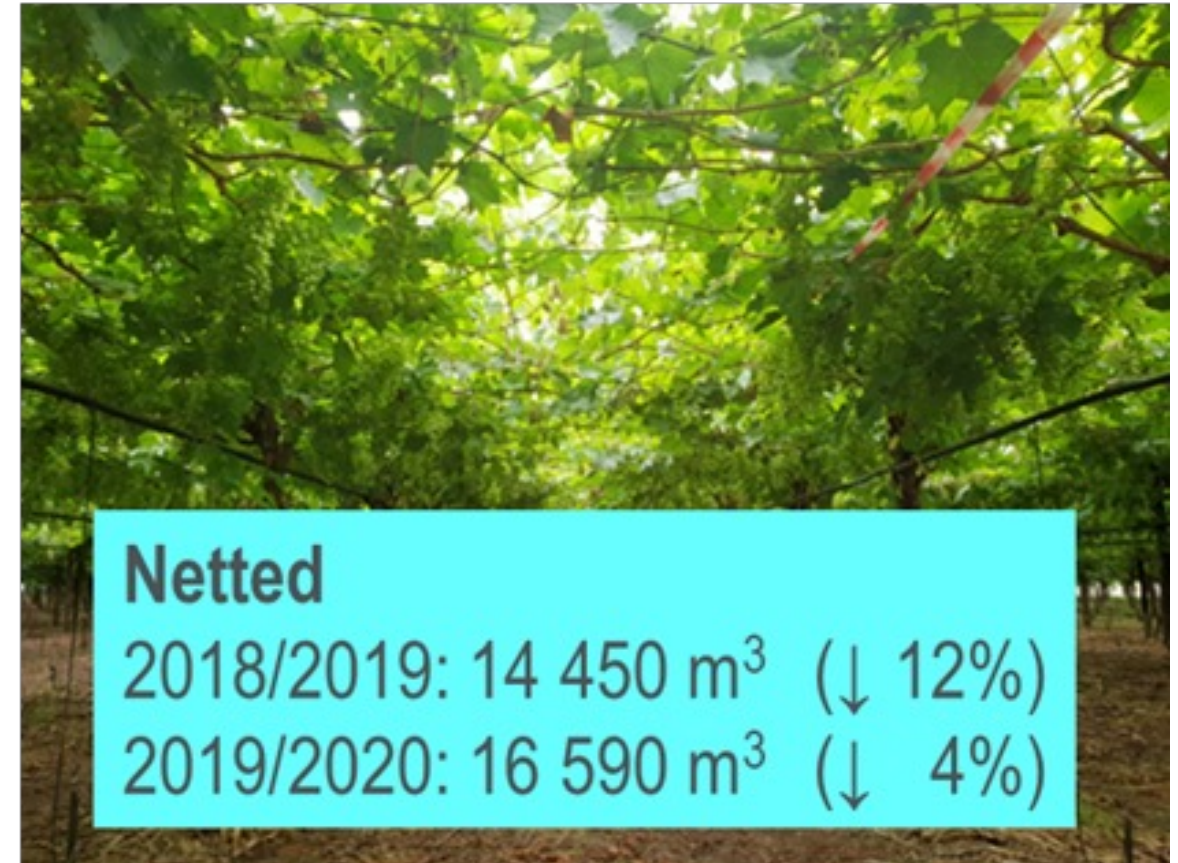
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**Water constraint classification according to midday  $\Psi_s$  for table grape production** (Myburgh & Howell (2022):

none ( $\Psi_s > -0.6$  MPa), weak ( $-0.6 \geq \Psi_s > -0.8$  MPa), moderate ( $-0.8 \geq \Psi_s > -1.0$  MPa), strong ( $-1.0 \geq \Psi_s > -1.2$  MPa) and severe ( $\Psi_s \leq -1.2$  MPa).

# Results: Water use Irrigation applied



# Results: Water use

## Water used vs. water applied

Season	ET total (mm.year <sup>-1</sup> )		ET daily (mm.day <sup>-1</sup> )		T total (mm.year <sup>-1</sup> )			Irrigation total (mm.year <sup>-1</sup> )		
	OPEN		OPEN		OPEN	NET	% diffe- rence	OPEN	NET	% diffe- rence
			min	max						
2018/19	1606		1.1	7.7	648	472	-27%	1640	1445	-12%
2019/20	1567		1.1	7.6	629	512	-18%	1727	1659	-4%
Gem	1587		4.3		639	492	-23%	1684	1552	-8%

↓ Irrigation under NET

↓ Transpiration  
under NET

Irrigation applied ≥ ET

- OPEN – both seasons
- NET – 2019/20

# Results: Water productivity, water use efficiency and blue water footprint

Treatment	Season	Irrigation	T	Total production		WP <sub>I</sub>	WUE <sub>T</sub>	Blue WF Irr	Blue WF T	Blue WF Irr
		m <sup>3</sup> /ha	m <sup>3</sup> /ha	cartons/ha	t/ha	kg/m <sup>3</sup>	kg/m <sup>3</sup>	m <sup>3</sup> /t	m <sup>3</sup> /t	m <sup>3</sup> /carton
Open	2018/19	16400	6480	6073	27.3	1.66	4.21	601	237	2.70
Netted	2018/19	14450	4720	7198	32.4	2.24	6.86	446	146	2.01
Open	2019/20	17270	6290	5836	26.3	1.52	4.18	657	239	2.96
Netted	2019/20	16590	5120	5036	22.7	1.37	4.43	731	226	3.29

T= transpiration; WP<sub>I</sub> = Irrigation Water Productivity; WUE<sub>T</sub> = WUE based on transpiration volume; Blue WF Irr = Blue WF based on irrigation water use; Blue WF T = Blue WF based on transpiration volume; Blue WF Irr m<sup>3</sup>/carton = Irrigation water used to produce a 4.5 kg carton of grapes.

# Results: Water productivity, water use efficiency and blue water footprint

Treatment	Season	Irrigation	T	Total production		WP <sub>I</sub>	WUE <sub>T</sub>	Blue WF Irr	Blue WF T	Blue WF Irr
		m <sup>3</sup> /ha	m <sup>3</sup> /ha	cartons/ha	t/ha	kg/m <sup>3</sup>	kg/m <sup>3</sup>	m <sup>3</sup> /t	m <sup>3</sup> /t	m <sup>3</sup> /carton
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## WP<sub>I</sub> of table/ raisin grapes (other studies):

Sultanina, Orange River region, SA (Myburgh, 2003a):	1.90 - 3.30 kg/m <sup>3</sup>
Sultanina, Australia (Yunusa <i>et al.</i> , 1997):	4.05 kg/m <sup>3</sup>
Sultanina, California (Araujo <i>et al.</i> , 1995):	5.50 kg/m <sup>3</sup>
Sultanina, Chile (Galvez <i>et al.</i> , 2014):	2.90 – 3.10 kg/m <sup>3</sup>
Redglobe, Chile (Galvez <i>et al.</i> , 2014):	4.40 – 9.80 kg/m <sup>3</sup>
Superior Seedless, Brazil (Teixeira <i>et al.</i> , 2007):	3.18 kg/m <sup>3</sup>
Crimson Seedless, SA (Avenant <i>et al.</i> , 2017):	0.59 - 4.94 kg/m <sup>3</sup>

# Conclusion and recommendations

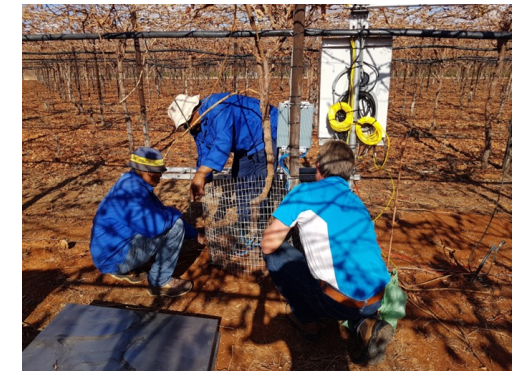
- **Seasonal total T values** → vines under NET used 19 - 27% less water
- **Midday  $\Psi_s$  for OPEN and NET** → low to moderate levels of water stress (adequate water supply)
- **Seasonal volume of water used for transpiration**
  - indication of the minimum water requirement for table grape vines under micro irrigation under conditions of the study
  - 4 720 m<sup>3</sup> (NET) to 6 480 m<sup>3</sup> (OPEN)
- **Estimated ET of the OPEN subplot (1 567 to 1 606 mm)**
  - considered as a maximum threshold value for water allocation per hectare for uncovered table grape vines under micro irrigation in this region, irrigated at 100% of estimated ET
- **Peak daily estimated ET of 7.7 mm.day<sup>-1</sup>**
  - could be used in irrigation system design for this region
  - to ensure that the delivery capacity of the system meets the peak demand

# Conclusion and recommendations

- Irrigation water applied equaled or exceeded the estimated ET (indicating over-irrigation)
- Producers should be aware of the possible negative impact net (shading) of nets on fertility
  - Adapt irrigation, nutrition and canopy management
- Water use under sufficient irrigation supply conditions has been quantified.
- Midday  $\Psi_s$  threshold values determined in recent study (Myburgh Howell, 2022) could be used to establish irrigation refill points
- Further research conducted: Establish to what extent irrigation applied can be decreased, without negatively impacting production and quality.

# Acknowledgements

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  - SATI
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  - SU and UP Viticulture Table grape students
- **Other research team members**
  - Dr Nicolette Taylor (UP)
  - Dr Carlos Poblete (SU)
  - Post-graduate students (SU DVO & SAGWRI, UP)



Thank you  
Enkosi  
Dankie

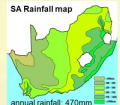
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## Introduction and Project aims

South Africa is a water scarce country, receiving about 470 mm of rainfall per annum. Table grapes are exclusively produced under irrigation in South Africa. Few publications on water use (WU) and water use efficiency (WUE) of table grapes in South Africa exist. Main project aims were:

- Quantifying WU and WUE of table grapes on farm level.
- Establishing a range of WUE and blue WF values for table grape production in all five SA production regions.



**Water use case studies: all 5 SA production regions**

- questionnaires, producer records, interviews
- 18 mature commercial Crimson Seedless blocks

**Field trial: Hex River Valley, Crimson Seedless**

- 2013/14, 2014/15, 2015/16
- different soil texture and irrigation system scenarios

Table 1: Crimson Seedless' in field trial

Descriptor	Block 1	Block 2	Block 3	Block 4
Year established	2001	2002	2000	2004
Rootstock	Rainier			
Rise orientation	NE-SW	NE-SW	NW-SE	NE-SW
Block size (ha)	1.7	1.8	1.9	1.4
Vine spacing (m)	3 x 1.8	3 x 1.8	2.75 x 1.8	3 x 1.8
Soil system	Ferrals			
Soil texture class	Sandy clay loam with high stone fraction (20.4% clay)	Sandy clay loam with high stone fraction (10.4% clay)	Loomy fine sand (21.4% clay)	Sandy clay loam with high stone fraction (21.4% clay)
Irrigation system	Drip	Micro-sprinkler	Micro-sprinkler	Drip

Water use and blue WF were calculated based on water used for irrigation (Irr), evapotranspiration (ET), transpiration (T)

Water use measurements/calculations:

- Irrigation (water meters, producer records)
- T (sapflow measurements, using the Heat Pulse Velocity (HPV) method)
- ET (FruitLook Actual ET www.fruitlook.co.za, AWS data, crop factors)



## Results and Discussion

Table 2: Blue WF and WUEy of Crimson Seedless in SA

Region	Irrigation applied m <sup>3</sup> /ha	Blue WF Irr m <sup>3</sup> /ton	WUE <sub>y</sub> Irr kg/m <sup>3</sup>
Hex River	4 590 - 10 560	202 - 501	2.00 - 4.94
Beit River	7 358 - 7 414	273 - 275	3.64 - 3.67
Olifants River	11 100 - 13 200	437 - 643	1.56 - 2.29
Orange River	12 760 - 18 358	816 - 1 705	0.59 - 1.23
Northern Provinces	4 710 - 8 402	282 - 478	2.09 - 3.55

WUE<sub>y</sub> Irr of Crimson Seedless in this study: 0.59 - 4.94 kg/m<sup>3</sup>

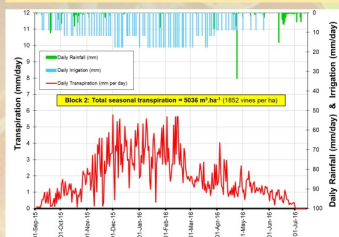
WUE<sub>y</sub> Irr of table/raisin grapes (other studies):

- Suttanina, Orange River region, SA (Myburgh, 2003): 1.9 - 3.3 kg/m<sup>3</sup>
- Suttanina, Australia (Yunusa et al., 1997): 4.05 kg/m<sup>3</sup>
- Suttanina, California (Araujo et al., 1995): 5.5 kg/m<sup>3</sup>

Table 3: Production blue water footprint (WF) and crop water use efficiency (WUE y) of field trial Crimson Seedless

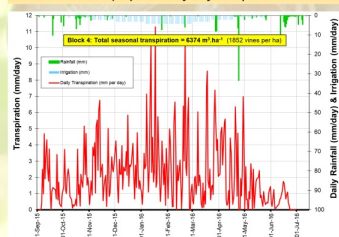
Farm nr	Season	Rainfall (mm)	Irrigation applied m <sup>3</sup> /ha	ET m <sup>3</sup> /ha	T m <sup>3</sup> /ha	Yield		Blue WF Irr m <sup>3</sup> /ton	Blue WF ET m <sup>3</sup> /ton	Blue WF T m <sup>3</sup> /ton	WUE <sub>y</sub> Irr kg/m <sup>3</sup>	WUE <sub>y</sub> ET kg/m <sup>3</sup>	WUE <sub>y</sub> T kg/m <sup>3</sup>
						export cartons/ha	t/ha						
1	2013/14	1018	4598	8837	-	4000	18.0	295	491	-	3.91	2.04	-
	2014/15	883	7524	7681	-	4000	18.0	418	423	-	2.39	2.36	-
	2015/16	232	5698	8591	-	4200	18.0	301	455	-	3.32	2.20	-
2	2013/14	1018	8565	8463	-	4000	18.0	476	470	-	2.10	2.13	-
	2014/15	883	8448	8016	-	4800	21.6	391	371	-	2.56	2.69	-
	2015/16	232	10560	9150	5039	5000	24.3	435	389	207	2.30	2.71	4.82
3	2013/14	1018	9344	10174	-	5200	23.4	399	435	-	2.50	2.30	-
	2014/15	883	9216	9034	-	5000	22.5	410	402	-	2.44	2.49	-
	2015/16	232	9248	10709	-	4100	18.5	501	580	-	2.00	1.72	-
4	2013/14	1018	6501	10489	-	5500	24.8	263	424	-	3.81	2.36	-
	2014/15	883	6174	5350	-	6000	27.0	229	348	-	4.38	2.87	-
	2015/16	232	6201	10084	6374	6800	30.6	203	330	208	4.93	3.03	4.80

Water applied vs. water used: Field trial Block 2 (Micro sprinkler on sandy clay loam)



Phenological stage	Bud break - bud set	Fruit set - Veraison	Veraison - Begin harvest - end harvest	End harvest - leaf fall complete	Demersal - before leaf fall	TOTAL
Period	7/6-28/10	28/10-27/12	27/12-1/12	1/12-7/4	7/4-30/6	30/6-31/8
Transpiration (t/ha)	823	1346	1153	880	634	0
Transpiration (% of total)	16	27	23	17	17	0
Evapotranspiration (t/ha)	1460	2180	1863	1878	1230	350
Evapotranspiration (% of total)	16	24	21	21	14	4
Irrigation (t/ha)	1643	2933	2200	2728	1056	0
Irrigation (% of total)	16	28	21	26	10	0
Midday SWP (kPa)	- 950-1100	-	800-1200	700-900	-	-
Stress category (based on SWP)	moderate	-	moderate	mild	-	-

Water applied vs. water used: Field trial Block 4 (Drip on sandy clay loam)



Phenological stage	Bud break - bud set	Fruit set - Veraison	Veraison - Begin harvest - end harvest	End harvest - leaf fall complete	Demersal - before leaf fall	TOTAL
Period	11/6-20/10	20/10-15/12	15/12-25/1	25/1-1/3	1/3-30/6	30/6-31/8
Transpiration (t/ha)	702	1463	1238	1146	1626	0
Transpiration (% of total)	11	23	19	18	29	0
Evapotranspiration (t/ha)	1240	1890	2230	2570	1800	350
Evapotranspiration (% of total)	12	19	22	25	18	3
Irrigation (t/ha)	208	1152	1624	2128	1089	0
Irrigation (% of total)	3	19	26	34	18	0
Midday SWP (kPa)	- 1100-1300	-	1100-1200	500-800	-	-
Stress category (based on SWP)	moderate	-	moderate	mild	-	-

## Conclusions and recommendations

- The seasonal volume of water used for transpiration can be considered as an indication of the minimum water requirement for a table grape vineyard under the conditions of the trial and ranged from 5 036 to 6 374 m<sup>3</sup> for the two blocks where sap flow measurements were conducted. Calculated ET values for these two blocks were 8 960 and 10 080 m<sup>3</sup> respectively.
- Comparing irrigation applied with water use through evapotranspiration and transpiration, results of the field trial indicated that water applied exceeded the water consumed during all phenological stages. It is recommended that stem water potential measurements should be used to establish "refill lines" for the degree of plant available water depletion allowed before irrigation is applied, maintaining SWP values within the "moderate" stress category.

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