ALTERNATIVE CROPS FUND (ACF)

FINAL REPORT

IRRIGATION AND POMEGRANATE TREE PERFORMANCE – A SURVEY

2019

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PROJECT INFORMATION

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SUMMARY OF FINAL REPORT
September 2019

EXECUTIVE SUMMARY:

Objectives & Rationale

A survey on the effect of current irrigation management practices in the pomegranate industry on tree performance is - as a first approach - needed to provide baseline information to direct more detailed irrigation research envisaged for the industry. The latter can in future potentially be co-funded by the Water Research Commission if a clear-cut need for irrigation research and potential spin-offs for the industry and South Africa as a whole can be illustrated.

Methods

Select a range of nine existing full bearing pomegranate orchards of the cultivar Wonderful on commercial farms in production areas in the Western Cape province with sandy and heavier soil, respectively. Characterise soil profiles, install research infrastructure and monitor irrigation applied, soil water dynamics and plant response (physiology, growth, yield, fruit quality).

Key Results

Water restrictions due to the Western Cape drought prevented pomegranate producers from supplying irrigation according the tree water requirements. Despite this, valuable information was obtained regarding the local production areas and the effect of irrigation application on yield and fruit quality. The evaporative demand that drives water use and irrigation water requirements ranged for the 2017/18 and 2018/19 seasons in the Wellington, Bonnievale, Gouda and Wolseley production areas between c. 942 mm and 1184 mm. With regard to irrigation management, soil water dynamics indicated instances of under- and overirrigation during the two seasons. The amount of irrigation water ranged in 2017/18 between 237 mm and 834 mm, and in 2018/19 between 272 mm and 867 mm. If effective rainfall is also taken into account, the total amount of effective rainfall and irrigation ranged for 2017/18 between 409 mm and 1001 mm, and for 2018/19 between 381 mm and 1161 mm. Tree water status indicated that Gouda and Wellington orchards were subjected to either moderate or severe water stress levels during the fruit growth and ripening stages, impacting negatively on fruit growth rate. Relative fruit growth rate tended to increase with an increased amount of effective rainfall and irrigation water applied during the fruit set and ripening phases. Final fruit size (fruit weight, length and diameter), yield and average fruit weight also related positively with increased irrigation rate until harvest/ for the total season. Total yield for the two seasons varied between 14.2 t ha^{-1} and 67.7 t ha^{-1}. Fruit skin moisture content and firmness, aril weight and moisture content and the percentage of fruit with dark red arils also tended to increase with increased irrigation rate until harvest, but the trends were not significant for all variables in both seasons. Fruit skin red colouration tended to decrease with increased rate of irrigation until harvest. Fruit of all orchards conformed to the ripeness standards expected for export. Pomegranate juice TA tended to increase, whereas the TSS, pH and MI decreased with increased rate of irrigation until harvest in the first season, but not in the second. The percentage sunburnt fruit at harvest tended to decrease with improved tree water status during fruit growth stage and increased rate of irrigation between fruit growth stage and harvest. Income of pomegranate orchards increased with more effective rainfall and irrigation applied in both seasons. Water use efficiency based on effective rainfall and irrigation applied ranged between 22.4 kg ha^{-1} mm^{-1} and 85.9 kg ha^{-1} mm^{-1}.

Conclusion and Discussion / Recommendation

Pomegranate tree performance can be bettered through improved irrigation scheduling. Research is though needed on water use of pomegranate orchards to develop a model for estimation of individual orchard water use. Irrigation strategies to save water, optimise yield and to manipulate fruit quality (e.g. colour, sunburn) should be researched, in some cases in combination with production practices. Irrigation practices with saline water for pomegranate should be researched under local conditions. Funding from the industry, agricultural and water sectors should be combined to enable the abovementioned research.

FINAL REPORT

1. Problem identification and objectives

Limited water resource availability and projected climate change impacts in the Western Cape requires improved water use efficiency and productivity from the agricultural sector. There is a lack of local research information on the effect of plant available soil water on pomegranate tree performance under local conditions. Such information is needed to compile guidelines for irrigation of pomegranate trees to promote efficient water use and to retain export market related fruit quality. A survey on the effect of current irrigation management practices in the pomegranate industry on tree performance is - as a first approach - needed to provide baseline information to direct more detailed irrigation research envisaged for the industry. The latter can in future potentially be co-funded by the Water Research Commission if a clear-cut need for irrigation research and potential spin-offs for the industry and South Africa as a whole can be illustrated.

Objectives:

- To compare the effect of various irrigation management practices and soil type on pomegranate tree performance.
- To provide baseline information to direct more detailed irrigation research for the pomegranate industry.
- To identify irrigation research needs for the pomegranate industry.

2. Workplan (materials & methods) and SOP

- *1. Literature survey*
  Conduct an extensive literature survey on the irrigation management of pomegranate trees. It is planned to publish the review in Water SA or in another relevant journal.
- *2. Plot selection*
  A range of nine existing orchards on commercial farms in pomegranate production areas in the Western Cape province in sandy and heavier soil, respectively, was selected. The cultivar selected, i.e. Wonderful, is an important role player in the export market (Pomosa, 2013). A water and soil sample for chemical status analyses was taken to assess suitability of the site for the experiment. Soil samples were taken at the 0-300 mm and 300-600 mm depths in the tree row.
- *3. Soil profile description*
  A profile pit was made per orchard to describe soil properties and to determine the extent of the root zone. This information was used to determine the depths and positions for the installation of soil water content monitoring equipment. Soil samples was taken for soil particle size analyses (five fraction) at three representative depth increments and soil texture determined.
- *4. Install research infrastructure*
  Manual water meters were installed in-line for each orchard to monitor the amount of water applied by irrigation for a section of five trees. Decagon 5TM and/ or ECH_2O soil water content sensors were installed in the irrigated area of two trees at at least two depths each - representing the middle and bottom end of the root zone. Meteorological data obtained from the nearest weather station of each orchard were used for characterisation of atmospheric conditions.
- *5. Monitoring of irrigation applied and soil water dynamics*
  The manual water meters were read at the end of each of four phenological phases (Flowering to fruit set, Fruit growth, Ripening, Post harvest). Soil water dynamics were measured hourly at two trees per orchard, except in one orchard where IRRICON monitored soil water content (one tree). Standard orchard practices were applied by the producers.
- *6. Monitor plant response*

- *Plant physiology*
  Tree water status was determined at three selected fruit growth stages (i.e. Flowering to fruit set, Fruit growth, Ripening) by using the pressure chamber technique. Midday stem water potential was measured on one short shoot per tree for each of five trees per orchard. Individual leaf petioles were too short to fit the available equipment.
- *Asses tree vegetative, reproductive growth and yield*
  Shoot length (10 shoots per tree of 5 trees per orchard) were measured as an indication of vegetative growth. Leaves were sampled end January for nutrient analysis at a commercial laboratory (Bemlab). Fruit size (10 fruit per tree of 5 trees per orchard) was measured at the beginning and/or end of the three selected fruit growth stages. Yield was quantified at harvest (fruits per tree of 5 trees per orchard counted and weighed).
- *Determine fruit quality at harvest*
  Fruit of five trees per orchard were evaluated for sunburn, cracking, blemishes, crown rot, external decay and false codling moth. More detailed fruit quality evaluation at harvest (four fruits per tree of five trees per orchard) included fruit length and diameter, fruit skin colour, colour of the arils and the total soluble solids (TSS), pH, and titratable acidity (TA) of the pomegranate juice. Susceptibility of fruit to external (e.g. decay, cracking) and internal (e.g. browning, pitting of arils and internal teguments and surfaces, paleness of arils, decay) physiological disorders was done. Physiological disorders that develop only during cold storage are not reported. Fruit mineral nutrient content was determined on a sample of two fruit per tree of five trees per orchard by a commercial laboratory (Bemlab). In addition, all fruit harvested was classified according to the norms below to compare fruit marketability (Table 1) and to determine gross farm income. Gross farm income per orchard was determined per marketing class based on the average amounts paid out by a local export company for exported fruit during 2017 and 2018. Extra class and class 1 fruit were - based on specific count groups - paid per 3.8 kg carton, whereas fruit for processing was paid out per kilogram. It was assumed that fruit classed as waste did not contribute to income.

Table 1. Pomegranate fruit marketing classification norms

Quality variable	**Subdivision**	**MARKETING CLASS**			
		EXTRA CLASS	**CLASS 1**	**PROCESSING**	**WASTE**
Weight (kg)		≥0.18	≥0.18	≥0.18	<0.180
Skin colour (Colour chart)		1 to 2	3 to 6	7 to 9	Not applicable
Sunburn	Colour	N = none	LB = light brown	LDB = light & dark brown	BL = black
	Degree	N = none	L10 = ≤10% surface	M10 = >10% surface	L10 or M10
Cracking		N = none	N = none	INT = up to integument	ARIL = up to arils
Blemishes		N = none	EL10 = 10% surface	EL25 = 25% surface	M25 = >25% surface
False codling moth		N = none	N = none	N = none	FCM

- *7.* Data processing and write annual progress report.
- *8.* Deliver papers upon request at field days, seminars and symposia provided funding is available to attend.
- *9.* Write final report
- *10.* Popular publication in SA Fruit Journal. Scientific publication if an article is accepted by a credible journal

3. Accumulated outputs

Results from the POMASA Annual progress report 2017, POMASA Annual progress report 2018 and ACF Preliminary progress report 2019 are included in the results and discussion section of the final report.

3. RESULTS AND DISCUSSION

3.1 Plot selection

POMASA identified 28 farm owners/ managers who were potentially interested in participating in the research. The selection of farms was further refined according to basic information supplied by consultants and/or farm managers to POMASA regarding climate, crop, soil, irrigation water source, irrigation system, irrigation scheduling method and crop management. Ten farms were visited and 14 potential orchards having full bearing Wonderful pomegranate blocks on sandy or heavier soil, were considered. The nine orchards selected for the purpose of this survey are located on six farms (Fig. 1) - three farms (five orchards) in the Berg Water Management Area (WMA) and three in the Breede WMA (four orchards) (Fig. 2).

Three orchards are in the Bonnievale production area, two in Gouda, one in Wolseley and three in Wellington (Table 1). Producer soil and water analysis records were used at first to assess suitability of the sites for the experiment. Orchards on sandy soil outnumbered those on heavier soils. However, sandy orchards included different irrigation management scenarios (Table 2). One orchard irrigated with poor quality water (data not shown) has been included to record the effects thereof on tree performance.

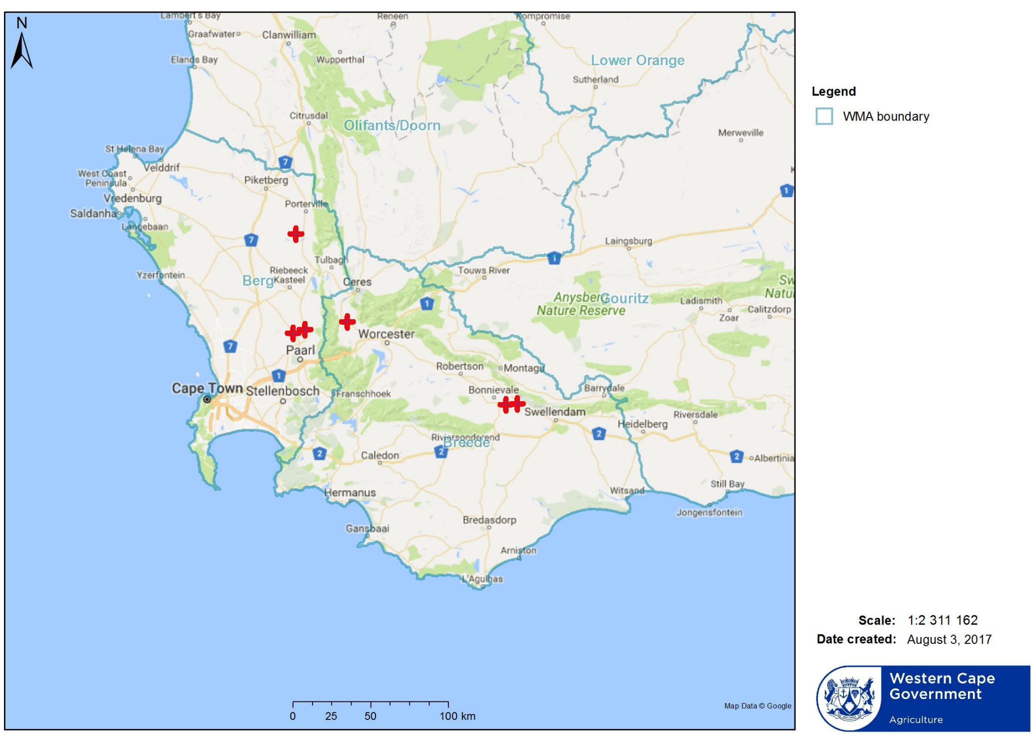

Fig. 1. Location of farms selected for a survey on irrigation and pomegranate tree performance in the Western Cape.

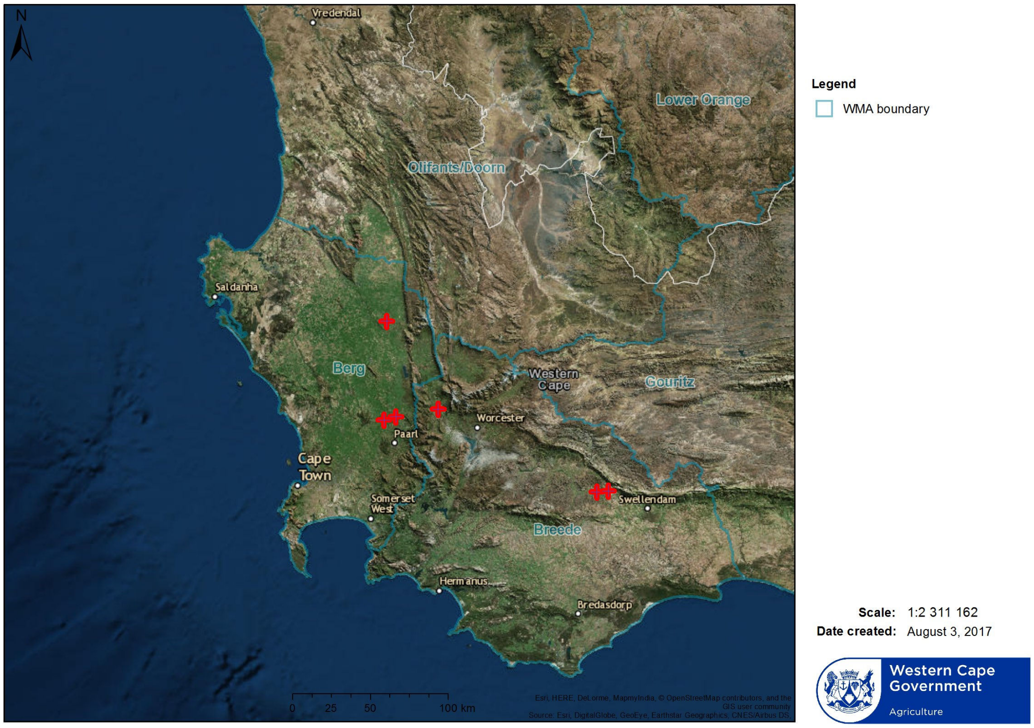

Fig. 2. Location of farms selected for a survey on irrigation and pomegranate tree performance within boundaries of the Berg and Breede Water Management Areas in the Western Cape.

3.2 Orchard characteristics

Orchard characteristics and an indication of tree size are summarized in Tables 2 and 3. Orchards included three with single, and six with multitrunk trees (Table 3). The single tree perimeter varied between 24 and 73 cm, and the multitrunk between 49 and 86 cm. Tree height ranged between 2.1 and 3.5 m. The percentage orchard area covered by the trees (estimated as solid area per full surface area) ranged between 32% and 72%. The solid area estimate of trees was based on mid-canopy diameter measurements at linear fruit growth stage.

3.3 Water and soil resources

3.3.1 Irrigation water quality

An irrigation water quality decision support system (Du Plessis et al., 2017) and chemical analysis data of irrigation water and soils sampled in August 2017 were used to determine the fitness of water for use. This was done by assessing the potential effect of the water quality on root zone salinity (Table 4), soil infiltrability (Table 5), hydraulic conductivity (Table 6), relative crop yield of sensitive crops (Table 7) and irrigation equipment (Table 8). As a first approach the assessment is conservative and is done for soils sensitive to a reduction in infiltration rate and hydraulic conductivity. The estimated impact may be less on sandy soils which are considered relatively tolerant to physical deterioration due to SAR and electrical conductivity interactions.

3.3.1.1 Effects on soil quality

According to the predicted equalibrium root zone salinity, water quality for all orchards was ideal for irrigation with mostly neglible effects of salinity on crop yield expected (Table 4). The exception was the borehole at Wellington, of which water quality was in the tolerable range that can potentially salinize the root zone to levels that restrict yield of many crops. The infiltration of water into soil depend amongst other factors on the interaction between the EC_{iw} (Table 4) and SAR of the top soil (Table 5). The degree of reduced surface infiltrability for the different orchards ranged between none and moderate.

Table 2. Details of orchards selected for the irrigation and pomegranate tree performance survey

Production area	Year planted	Orchard spacing	Open/ Net	Level/ Ridged	Ridge height (m)	Soil type*	Irrigation system	Microsprinkler/ emitter spacing (m)	Double line drip - emitter position
Bonnievale	2006	4 m x 6 m	Open	Ridged	c. 0.3 m	Clay	Microsprinklers	2	n.a.
	2007	4 m x 6 m	Open	Ridged	c. 0.3 m	Loam	Microsprinklers	2	n.a.
	2011	2 m x 4 m	Open	Ridged	c. 0.23 m** c. 0.43 m***	Clay	Double line drip	0.6	Staggered
Gouda/Porterville	2008	2.5 m x 5 m	Open	Level	n.a.	Sand	Double line drip	0.75	Even
	2008	2.5 m x 5 m	Net	Level	n.a.	Sand	Double line drip	0.75 & 0.5	Staggered
Wolseley/ Worcester	2009	2.4 m x 4.5 m	Net	Level	n.a.	Sandy loam on clay loam	Single line drip	0.6	n.a.
Wellington	2012	3.5 m x 5 m	Open	Ridged	Ripped	Sand on clay	Single line drip	0.6	n.a.
	2010	2 m x 4.5 m	Open	Level	n.a.	Sand	Double line drip	0.75	Staggered
	2008	2 m x 4.5 m	Open	Ridged	c. 0.62 m	Sand	Double line drip	0.75	Even

*According to producer records/ experience
** Upslope
***Downslope

Table 3. Orchard characteristics in the Bonnievale, Gouda, Wolseley and Wellington production areas. The soil texture class, irrigation system, year of plant, planting density, trunk nature and mean (±standard deviation) trunk base perimeter, tree height and estimated solid area (A) per full surface area (FSA) at linear fruit growth stage are indicated. Soil texture classes include clay (Cl), loam (Lm) and sand (Sa). Irrigation systems include microsprinkler (MS) or single (1LD) or double line drip (2LD). Presence of a ridge (R), ripped ridge (RR) or net is also indicated.

Production area	Soil texture class	Irrigation	Year planted	Planting density (Trees/ha)	Trunk nature	Base[1] (cm)	Height (m)		A/FSA (%)	
							2018	2019	2018	2019
Bonnievale	SaClLm	MS R	2006	416	Single	73±16	3.2±0.7	3.2±0.3	63.0±6.9	59.2±3.4
	LmSa/SaLm	MS R	2007	416	Single	58±7	3.1±0.4	3.2±0.4	42.5±4.9	49.2±4.2
	SaLm	2LD R	2011	1000	Multi	49±7	2.9±0.4	3.0±0.1	32.1±3.4	51.9±3.3
Gouda	Sa	2LD Net	2008	800	Multi	58±10	3.1±0.3	3.4±0.1	58.9±8	54.3±6.7
	Sa	2LD	2008	800	Multi	54±4	2.6±0.2	3.0±0.1	46.9±6.7	53.0±5.8
Wolseley	Sa	1LD Net	2009	571	Multi	86±17	2.9±0.5	3.5±0.2	58.4±5.4	62.7±2.6
Wellington	SaLm/SaClLm/Cl	1LD RR	2012	571	Multi	60±12	2.3±0.2	2.1±0.2	45.3±4.3	32.0±3.4
	LmSa	2LD	2010	1111	Single	24±2	2.4±0.1	2.5±0.2	47.1±4.7	46.1±5.6
	LmSa	2LD R	2008	1111	Multi	63±10	3.3±0.2	2.6±0.2	72.2±3.2	66.3±8.6

1 Trunk base perimeter measured beginning of October 2017.

Table 4. Irrigation water salinity (EC_{iw}), predicted equilibrium root zone salinity and fitness for use of irrigation water available in the different pomegranate production areas.

Production area	Irrigation water source	Irrigation system	EC_{iw} (mS m^{-1})	Predicted equilibrium root zone salinity (mS m^{-1})	Fitness for use	Root zone salinity range (mS m^{-1})
Bonnievale	Canal	Microsprinkler	71	133	Ideal	0-200
	Borehole	Double line drip	15	28	Ideal	0-200
Gouda	Borehole	Double line drip	46	9	Ideal	0-200
Wolseley	River	Single line drip	5	9	Ideal	0-200
Wellington	Borehole	Single line drip	224	421	Tolerable	400-800
	River/Dam	Double line drip	58	109	Ideal	0-200

Table 5. Sodium adsorption ratio (SAR) of the top 300 mm soil and potential degree of reduced surface infiltrability to irrigation water in the different pomegranate production areas. Soil texture classes include clay (Cl), loam (Lm) and sand (Sa).

Production area	Irrigation system	Soil texture	Surface SAR $(mmol/L)^{0.5}$	Degree of reduced surface infiltrability
Bonnievale	Microsprinkler	SaClLm	1.7	None
	Microsprinkler	LmSa/SaLm	1.9	None
	Double line drip	SaLm R	5.9	Severe
Gouda	Double line drip	Sa+Net	1.9	None
	Double line drip	Sa	3.5	Moderate
Wolseley	Single line drip	Sa+Net	0.3	Slight
Wellington	Single line drip	SaLm/SaClLm/Cl	19.2	Slight
	Double line drip	LmSa	3.7	Moderate
	Double line drip	LmSa	5.4	Moderate

Table 6. Sodium adsorption ratio (SAR), electrical conductivity of the soil water (EC_e) and the estimated degree of reduced hydraulic conductivity in the 0-300 mm and 300-600 mm soil layers in different pomegranate production areas. Soil texture classes include clay (Cl), loam (Lm) and sand (Sa). 1LD and 2LD, respectively refers to single and double line drip.

Production area	Irrigation system	Soil texture	Depth increment (mm)	SAR of soil layer $(mmol/L)^{0.5}$	ECe (mS m^{-1})	Degree of reduced hydraulic conductivity
Bonnievale	Microsprinkler	SaClLm R	0-300	1.7	21.4	Moderate
			300-600	2.0	23.5	Moderate
	Microsprinkler	LmSa/SaLm R	0-300	1.9	33.0	Moderate
			300-600	2.2	33.6	Moderate
	2L Drip	SaLm R	0-300	5.9	57.6	Moderate
			300-600	8.3	52.1	Moderate
Gouda	2L Drip	Sa+Net	0-300	1.9	23.2	Moderate
			300-600	1.2	19.7	Severe
	2L Drip	Sa	0-300	3.5	36.8	Moderate
			300-600	3.2	10.1	Severe
Wolseley	1L Drip	Sa+Net	0-300	0.3	12.0	Severe
			300-600	0.4	9.7	Severe
Wellington	1L Drip	SaLm/SaClLm/Cl RR	0-300	19.2	26.3	Severe
			300-600	33.8	153.4	Moderate
	2L Drip	LmSa	0-300	3.7	26.0	Severe
			300-600	2.8	10.2	Severe
	2L Drip	LmSa R	0-300	5.4	114.9	Slight
			300-600	11.8	93.7	Moderate

Hydraulic conductivity refers to the movement of water through the bulk soil. The SAR in the soil water was in most cases less than 3 and associated with low soil water salinity of between 20 and 40 mS m^{-1} (Table 4), which may result in moderately reduced hydraulic conductivity in sensitive soils (Table 6). In cases where SAR was less than 3 and salinity less than 20 mS m^{-1}, the hydraulic conductivity could decrease severely. In Wellington, in the single line drip irrigated orchard, soil water SAR values of more than 12 and EC_e values of less than 50 may result in severe reduction in hydraulic conductivity in the top soil, but deeper in the soil where the soil water salinity was c. 150 mS m^{-1}, hydraulic conductivity may decrease only moderately. In the 300-600 mm soil layer of the ridged double line drip irrigated orchard an SAR of c. 12 in combination with EC_e of c. 94 mS m^{-1} may also reduce the hydraulic conductivity moderately.

3.3.1.2 Effects on yield

Crop growth is affected by salinity (which reduces the ability of crops to absorb water from the soil) as well as accumulation of potentially toxic ions namely, sodium (Na), chloride (Cl) and boron (B) in the root zone. The potential effects of irrigation water salinity and ion concentrations on relative crop yield of a sensitive crop are summarized in Table 7. For the microsprinkler irrigated orchards in Bonnievale, a relative yield decrease of c. 18%, 36%, 8% and 1% is predicted due to salinity and high levels of sodium, chloride and boron, respectively. In the double line drip irrigated orchards in Wellington relative yield could decrease by 10% and 19% due to irrigation water salinity and sodium content. The effect of the high salinity, sodium and chloride in irrigation water used in the single line drip irrigated orchard in Wellington on relative yield of a sensitive crop is extreme. However, since pomegranate is considered to be moderately salinity tolerant (Allen et al., 1998), relative yield should be affected less.

Table 7. Predicted effect of irrigation water salinity (EC_{iw}), boron (B), chloride (Cl) and sodium (Na) content on relative crop yield of salt sensitive crops. MS, 1LD and 2LD, respectively refers to microsprinkler, single and double line drip.

Production area	Irrigation system	EC_{iw} (mS m^{-1})	Na mg/l	Cl mg/l	B mg/l	Predicted relative crop yield (%) as affected by Salinity	Na	Cl	B
Bonnievale	MS	71	91.0	197.4	0.16	82	64	92	99
	2L Drip	15	14.4	35.6	<0.08	100	100	100	100
Gouda	2L Drip	46	41.1	133.3	<0.08	100	100	100	100
Wolseley	1L Drip[3]	5	4.4	19.2	0.14	100	100	100	100
Wellington	1L Drip	224	420.9	779.7	0.40	0	0	0	90
Wellington	2L Drip	58	61.7	115.5	0.09	90	81	100	100

3.3.1.3 Effects on equipment

The potential for irrigation water according the Langelier index to result in irrigation equipment corrosion ranged between none (ideal) and unacceptable (Langelier index <-2) between orchards, whereas no problems with scaling is foreseen (Table 8). With regard to emitter clogging, pH appears to be too high at all orchards, while manganese and iron content did not pose a problem or was acceptable (data not shown).

Table 8. Irrigation water fitness-for-use classification for potential irrigation equipment corrosion/ scaling and clogging of drippers due to pH. MS, 1LD and 2LD, respectively refers to microsprinkler, single and double line drip.

Production area	Irrigation system	Irrigation equipment: Corrosion Fitness	Scaling Fitness	Emitter clogging: pH Units	Fitness
Bonnievale	MS	Acceptable	Ideal	7.9	Tolerable
	2L Drip	Tolerable	Ideal	8.6	Unacceptable
Gouda	2L Drip	Acceptable	Ideal	9.4	Unacceptable
Wolseley	1L Drip[3]	Unacceptable	Ideal	7.9	Tolerable
Wellington	1L Drip	Acceptable	Ideal	7.5	Tolerable
Wellington	2L Drip	Ideal	Ideal	9.1	Unacceptable

3.3.2 Available soil water

3.3.2.1 Soil water holding capacity according to texture

Soil particle size analyses (five fraction) were done for soils sampled at 0-300 mm, 300-600 mm and 600-900 mm depth increments to determine soil texture. The average clay, silt and sand contents up to 900 mm depth and soil texture classes for the nine orchards are indicated in Figure 3. The average for the sandy loam soil in Bonnievale is only to 600 mm depth as sampling was not possible deeper due to a restrictive layer.

Soil classification according to soil texture analysis indicated that the microsprinkler irrigated orchards in the Bonnievale production area had deep, heavier soils with no coarse fraction, i.e. a sandy clay loam and loamy sand to sandy loam soil. The drip irrigated orchard had sandy loam soil up to only c. 600 mm deep where soil depth was limited by shallow dorbank. The soil contained c. 24% (v/v) and c. 19% (v/v) stone in the 0-300 mm and 300-600 mm depth increments.

The sandy double line drip irrigated *Gouda* soils had similar particle size, but the coarse fraction in the orchard below net increased in the 0-300 mm, 300-600 mm and 600-900 mm depth increments, respectively, from c. 8% to c. 26% to c. 35%. In the orchard without net the very stony layer occurred a bit deeper as the coarse fraction increased from c. 6% to c. 9% and c. 31% for the respective layers mentioned above. In *Wolseley*, the sandy soil in the single line drip irrigated orchard contained no stones and had c. 20% less coarse sand and c. 5% and c. 15% more fine and medium sand, respectively, than the Gouda soils.

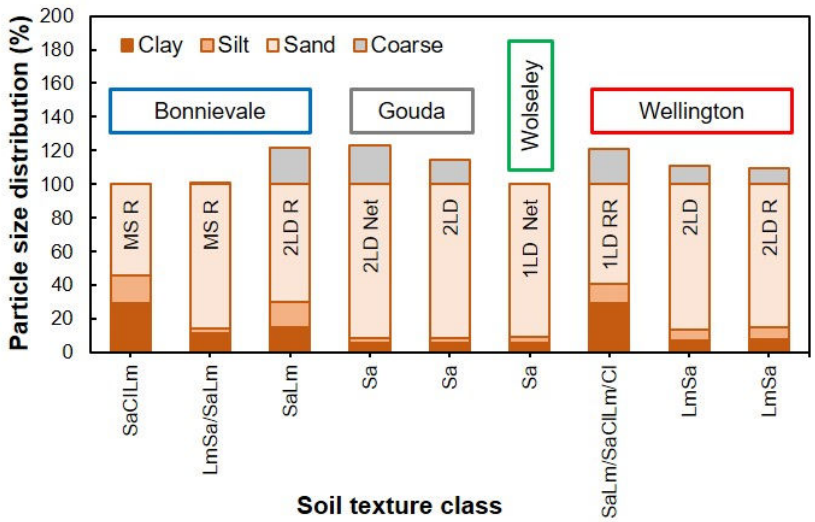

Fig. 3. Soil particle size distribution of open or netted (Net) microsprinkler (MS), single or double line drip irrigated (1LD or 2LD) orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas. Ridged (R) or ripped ridge (RR) is indicated where applicable. The 100% total of the finer fractions are used as baseline (x-axis) for the coarse fraction percentage (v/v). The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

In the *Wellington* production area, the single line drip irrigated orchard had sandy loam soil in the top 0-300 mm, which changed to sandy clay loam and clay in the 300-600 mm and 600-900 mm depth increments. The soil was considerably stony in the 0-300 mm (c. 27% v/v) and 300-600 mm (c. 37% v/v) depth increments. The double line drip irrigated orchards (level and ridged) had loamy sand with similar particle size distribution, c. 4% (v/v) stones in the top 300 mm and up to c. 13% (v/v) stones in the deeper soil layers.

According to the soil water holding capacity between -10 kPa and -100 kPa (estimated from soil texture analysis, Bemlab) the heavier soils in Bonnievale had the highest soil water holding capacity, i.e. between 144 and 165 mm m^{-1}, whereas it was slightly lower for the sandy loam with c. 21% stone (117 mm m^{-1}) (Fig. 4). The soil water holding capacity of the sandy Gouda soils were the lowest and on average c. 50% of that available in the microsprinkler irrigated orchards. The soil water holding capacity in the netted and open orchards, respectively, was c. 69 mm m^{-1} (profile average stone 23% v/v) and 84 mm m^{-1} (profile average stone c. 15% v/v). The water holding capacity of the sandy soil in Wolseley and the sandy loam and loamy sand in the Wellington area were 93, 88 and c. 100 mm m^{-1}, respectively.

The soil water holding capacity of the drip irrigated soils were on average 40% less than that of the micro-irrigated soils. With respect to soil water holding capacity in production regions, Gouda, Wolseley and Wellington, respectively, had on average 46%, 34% and 32% less water available between -10 kPa and -100 kPa than the Bonnievale soils.

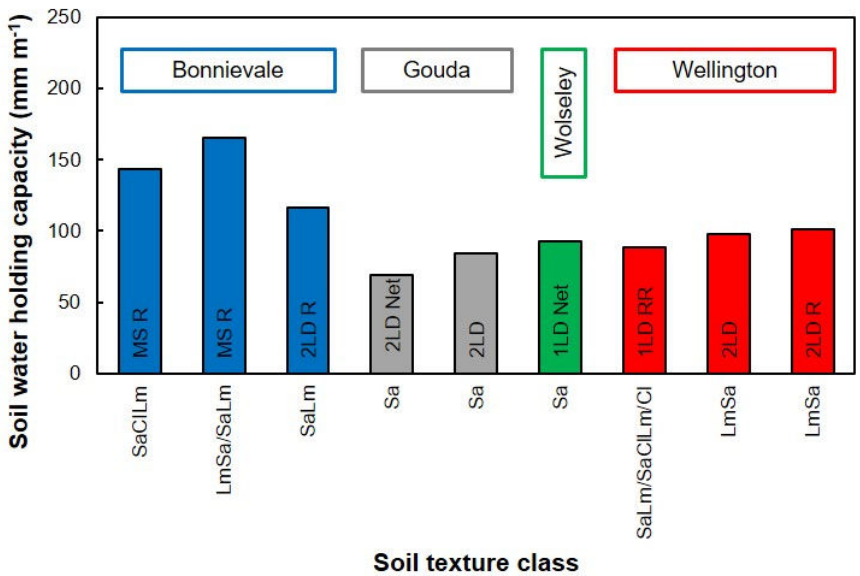

Fig. 4. Soil water holding capacity of soils in open or netted (Net) microsprinkler (MS), single or double line drip irrigated (1LD or 2LD) orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas. Ridged (R) or ripped ridge (RR) is indicated where applicable. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

3.3.2.2 Root zone distribution

One soil profile pit was made per orchard to determine the extent of the root zone and to determine the placement of soil water monitoring equipment. The root systems of seven of the nine orchards developed up to a depth of 1.2 m (Fig. 5). At Bonnievale, the root depth of the double line drip irrigated sandy loam orchard was limited to 600 mm by an impermeable layer (Fig. 5a), and at Wolseley in the single line drip irrigated sand below net, by a clay layer at 1 m depth (Fig. 5b). The root density to a 600 mm depth was on average c. 45% lower in the microsprinkler irrigated orchards compared to that in the drip irrigated orchards. The highest root density in the top 600 mm soil was found in Wellington in the ridged loamy sand orchard (429 roots m^{-2}) and the lowest in Wellington in the single line drip irrigated ripped ridge sandy loam/sandy clay loam on clay (125 roots m^{-2}). At Gouda in the double line drip irrigated sandy soils roots were prevalent deeper in the soil (Fig. 5b) despite stone content being more than 30% at the 600-900 mm depth increment. Root distribution perpendicular to the tree row (Fig. 6) indicated that for the drip irrigated orchards, most of the roots were concentrated in a c. 1 m radius from the tree, whereas for micro-irrigated orchards, roots were distributed in the whole area allotted to the tree.

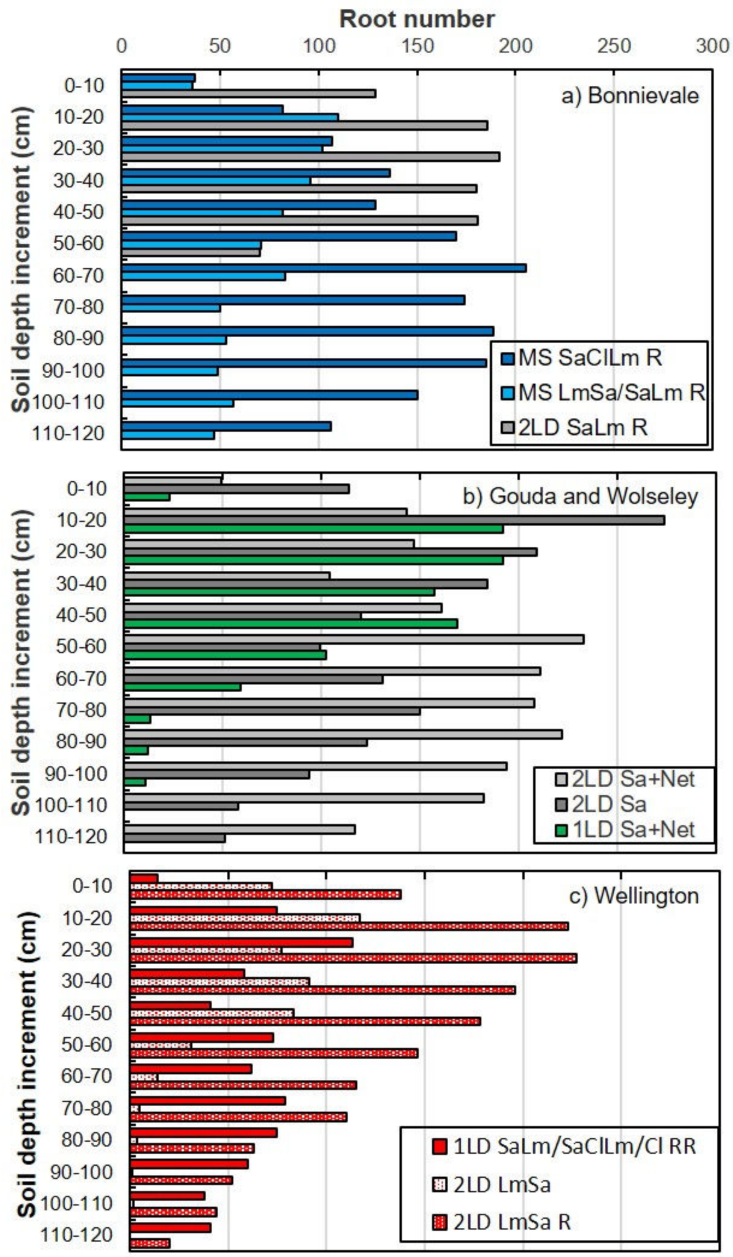

Fig. 5. Vertical root profile distribution of full bearing Wonderful pomegranate orchards in the Bonnievale (a), Gouda and Wolseley (green bars) (b) and Wellington (c) production areas during the 2017/18 season. MS, 1LD, 2LD, R and RR refers to microsprinkler, single and double line drip, ridged and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

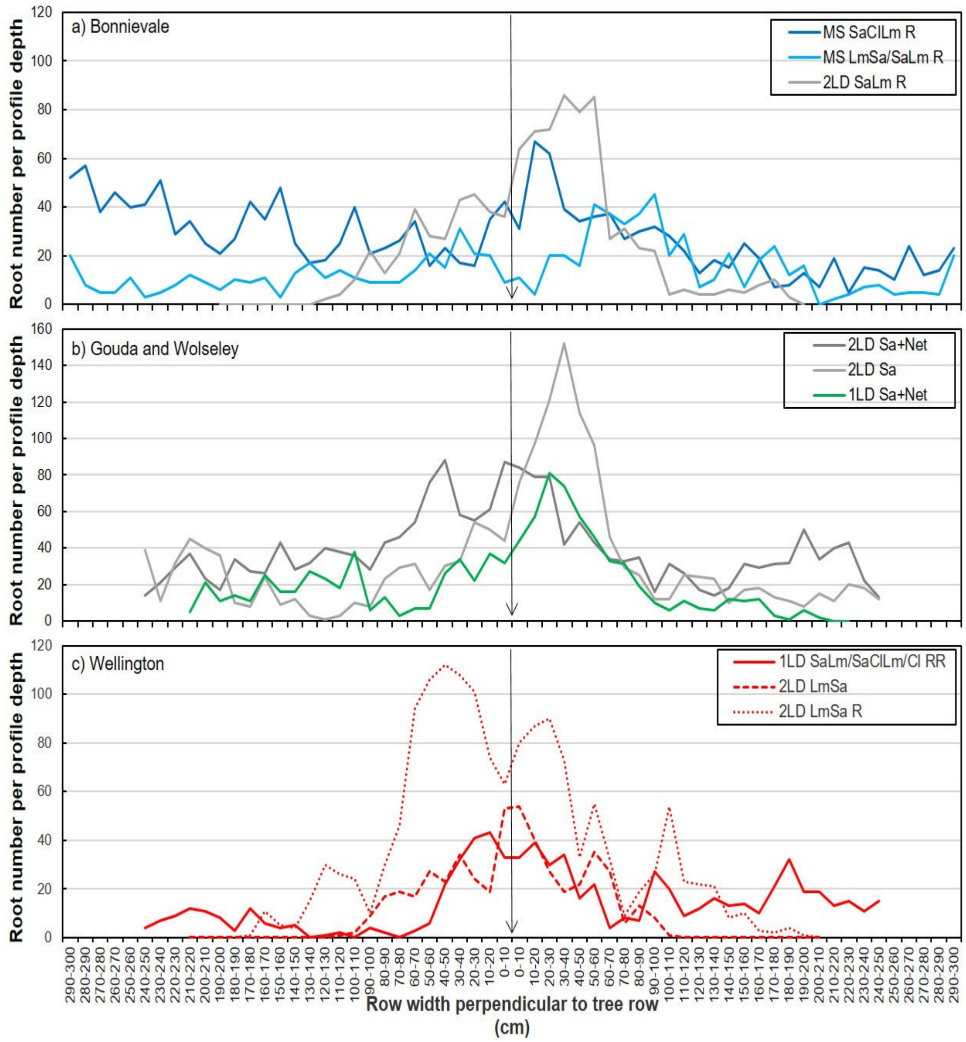

Fig. 6. Root distribution perpendicular to the tree row of full bearing pomegranate(cv. Wonderful) orchards in the Bonnievale (a), Gouda and Wolseley (green line) (b) and Wellington (c) production areas during the 2017/18 season. The tree row is indicated by the arrow. MS, 1LD, 2LD, R and RR refers to microsprinkler, single and double line drip, ridged and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

3.4 Evaporative demand of production areas

Water use of orchards are driven by the evaporative demand of the atmosphere, which can be quantified by the Penman-Monteith reference evapotranspiration or ET_o (Allen et al., 1998). Rainfall, in addition to irrigation, supplies in the water requirements of trees. Weather stations representative of the orchards in the different pomegranate production areas were selected (Table 9) to compare various climate variables (e.g. radiation, temperature, relative humidity, wind speed; data not shown), the evaporative demand and rainfall (Fig. 7)). In general, the daily ET_o increased from August until January, after which it started to decline gradually in all production regions towards June (Fig. 7a-c). During the two seasons the monthly averaged ET_o peaked in December and/ or January and ranged for Bonnievale between c. 5.4 and c. 5.7 mm d^{-1} for the micro-sprinkler irrigated orchards, and between c. 5.6 and c. 6 mm d^{-1} for the drip irrigated orchard (Fig. 7a). In Wellington the monthly averaged ET_o for these months reached values of between 6.5 and 6.8 mm d^{-1} for the single drip irrigated orchard, with lower values of 5.5 to 5.7 mm d^{-1} recorded for the double line drip irrigated orchards (Fig. 7c).

Table 9. Weather stations representative of orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Sa, Cl, Lm, R and RR, respectively refers to microsprinkler, single and double line drip, sand, clay, loam, ridged and ripped ridge.

Production area	Orchard	Station Name	Latitude	Longitude	Altitude
Bonnievale	MS SaClLm R	Merwespont	-33.9729	20.1552	117
	MS LmSa/SaLm R	Merwespont	-33.9729	20.1552	117
	2LD SaLm R	Boesmanspad	-33.9222	20.20251	191
Gouda/Porterville	2LD Sa+Net	Porterville: De Hoek	-33.1552	19.03216	126
	2LD Sa	Porterville: De Hoek	-33.1552	19.03216	126
Wolseley/Worcester	1LD Sa+Net	La Plaisant	-33.4527	19.2154	283
Wellington	1LD SaLm/SaClLm/Cl RR	Diemerskraal	-33.568	18.90825	113
	2LD LmSa	Landau	-33.5778	18.96795	126
	2LD LmSa R	Landau	-33.5778	18.96795	126

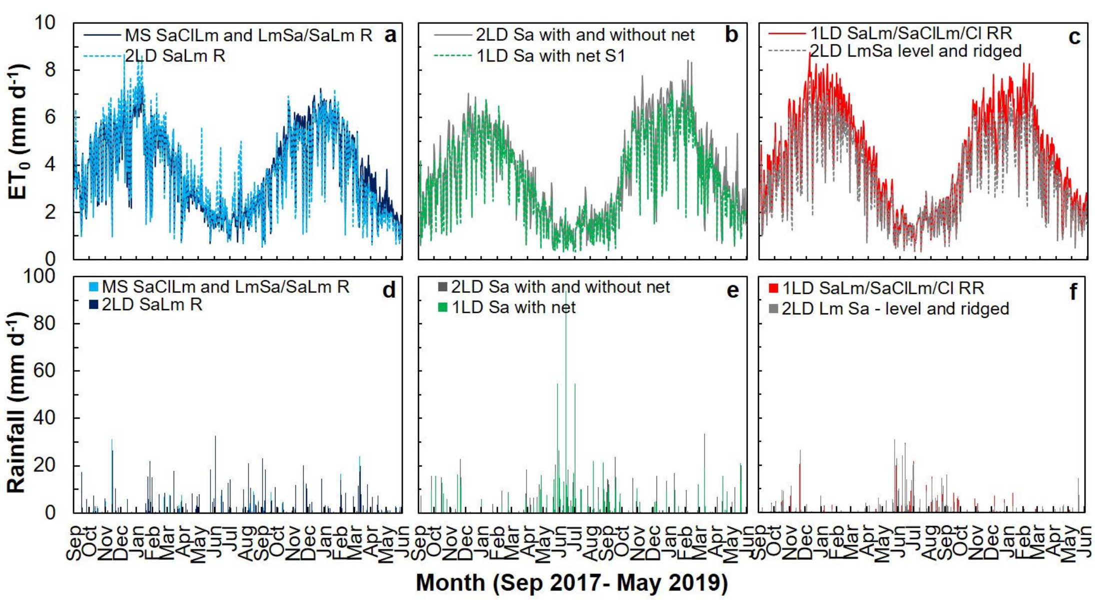

Fig. 7. Daily Penman-Monteith reference evapotranspiration (ET_o, a, b, c) and rainfall (d, e, f) during September 2017 to May 2019 for pomegranate (cv. Wonderful) orchards in the Bonnievale (a & d), Gouda (grey) and Wolseley (green) (b & e) and Wellington (c & f) production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

In Gouda the monthly averaged ET_o ranged between 5.3 and 6.2 mm d^{-1} with that in Wolseley reaching c. 5.9 and 6.1 mm d^{-1} (Fig. 7b). In all production areas, rainfall events during the period

September to May was - with few exceptions - less than 25 mm d^{-1}. Although all orchards received in 2017/18 limited rainfall during December (Fig. 7d-f), this trend extended until February for Gouda and Wolseley (Fig. 7e) and for Wellington until May in both seasons (Fig. 7f). The average daily ET_o per growth stage was the highest during linear fruit growth and ripening (Fig. 8). In 2017/18 the average ET_o tended to remain higher in the Wellington orchards during ripening compared to the other production areas, whereas in 2018/19 the ET_o decreased for all orchards relative to the linear fruit growth stage. However, during the second season the ET_o in the Gouda and Wolseley orchards was higher during ripening compared to the Bonnievale orchards, and higher than or comparable to that of Wellington towards the end of the season. Both the Gouda and Wolseley production areas had higher ET_o rates during 2018/19 compared to 2017/18.

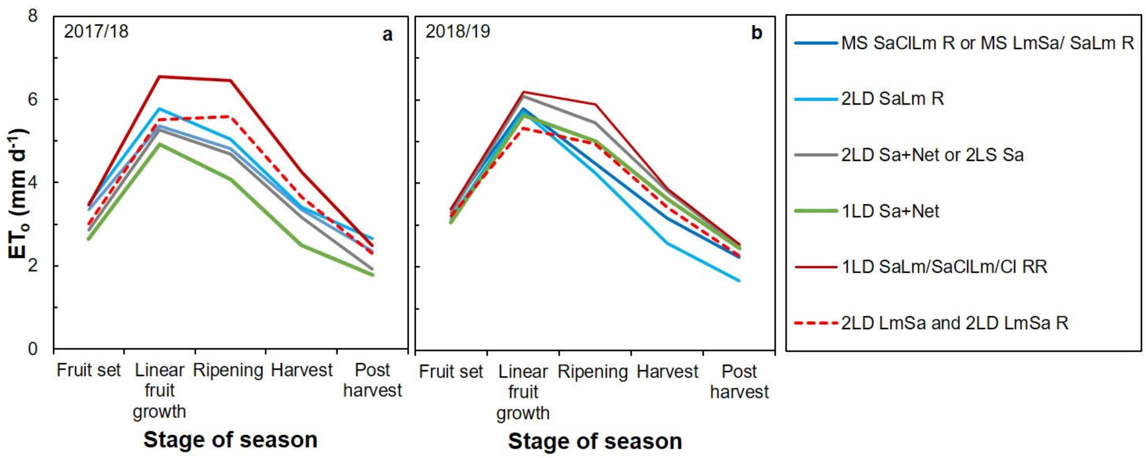

Fig. 8. Average daily Penman-Monteith reference evapotranspiration (ET_o) for the fruit set, linear fruit growth, ripening, harvest and post-harvest stages for pomegranate (cv. Wonderful) orchards during the 2017/18 and 2018/19 growing seasons in the Bonnievale (blue), Gouda (grey), Wolseley (green) and Wellington (red) production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

The total ET_o for the period from September to May was in 2017/18 on average for Wellington, Bonnievale, Gouda and Wolseley, respectively, c. 1168 mm, 1092 mm, 1003 mm and 942 mm (Fig. 9a). The evaporative demand in the Bonnievale, Gouda and Wolseley areas were therefore c. 7%, c. 14% and c. 19% less compared to Wellington. In 2018/19 though differences in total ET_o between production regions diminished with that for Bonnievale (1070 mm) and Wolseley (1095 mm) being 6% and 4% less, and that for Gouda (1184 mm) becoming c. 4% more than that for Wellington (1137 mm) (Fig. 9b). The total ET_o from 1 September to 31 May in 2018/19 compared to 2017/18 decreased by 3% and 2% for Wellington and Bonnievale, whereas it increased for Gouda and Wolseley by 18% and 16%, respectively. Evaporative demand was during the two seasons relatively similar for the different growth stages, being on average for production regions over seasons 416 mm, 288 mm, 186 mm, 84 mm and 134 mm from the beginning of September until fruit set, from fruit set until linear fruit growth, linear fruit growth to ripening, ripening to harvest and post-harvest until end May, respectively (Fig. 9). The evaporative demand for these respective stages relative to the seasonal total ET_o (1106 mm) was likewise comparable between seasons and on average 38%, 26%, 17%, 8% and 12% of the total ET_o (Fig. 10). The evaporative demand for the 2017/18 growing season was 86% of the annual ET_o from 1 September 2017 until end August 2018 for the Bonnievale area, and on average 89% for the other production regions.

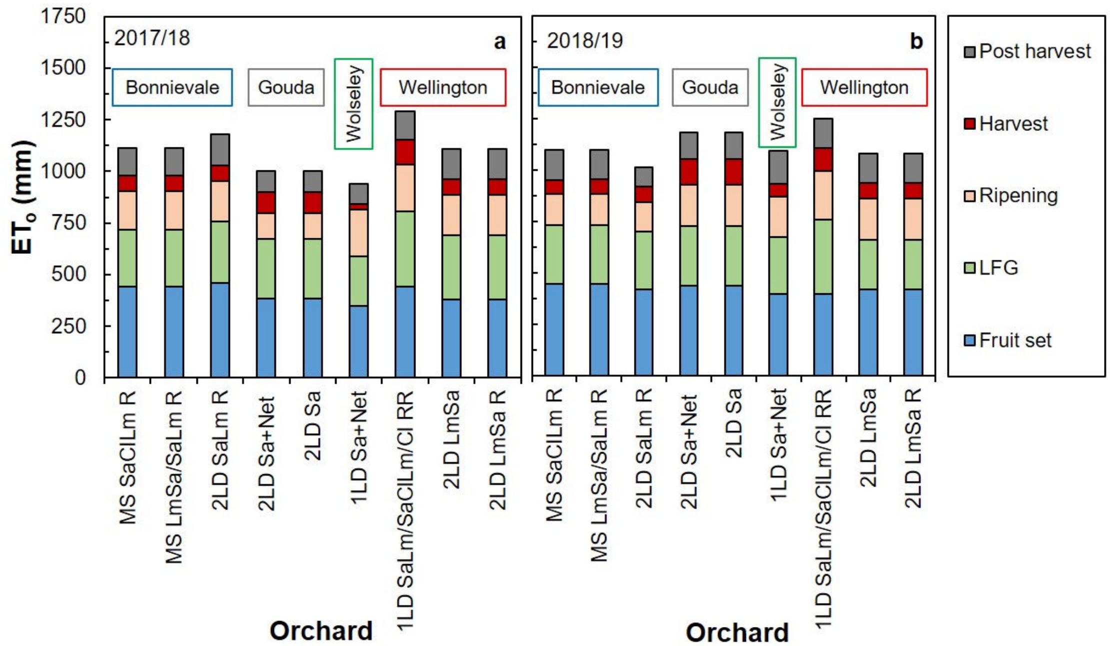

Fig. 9. Total Penman-Monteith reference evapotranspiration (ET_o) for the fruit set, linear fruit growth, ripening, harvest and post-harvest stages for pomegranate (cv. Wonderful) orchards during the 2017/18 and 2018/19 growing seasons in the Bonnievale, Gouda, Wolseley and Wellington production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

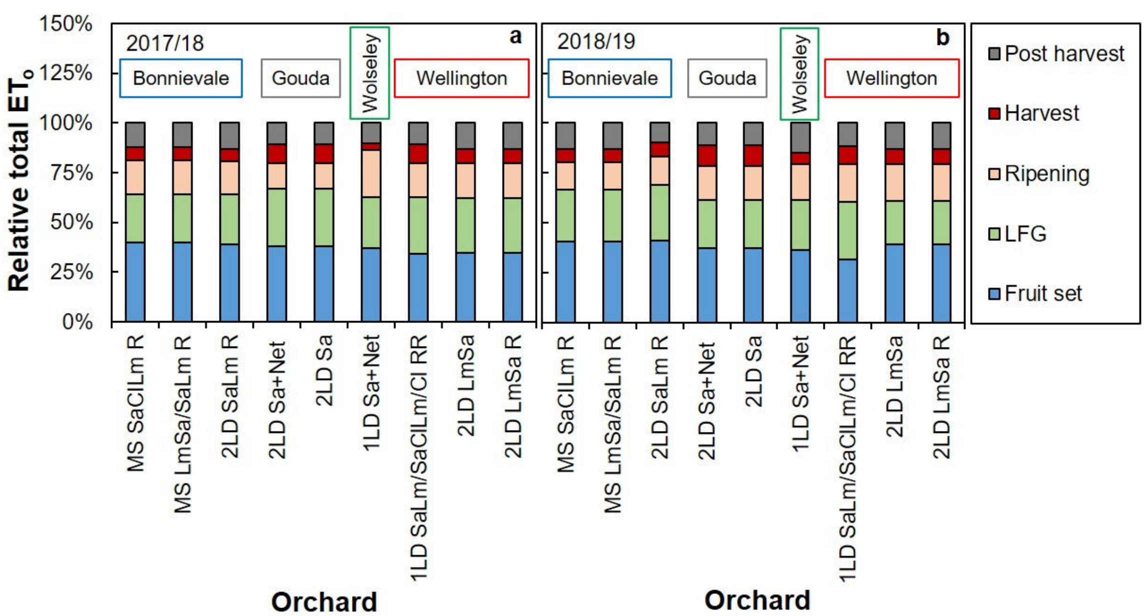

Fig. 10. Relative total Penman-Monteith reference evapotranspiration (ET_o) for the fruit set, linear fruit growth, ripening, harvest and post-harvest stages for pomegranate (cv. Wonderful) orchards during the 2017/18 and 2018/19 growing seasons in the Bonnievale, Gouda, Wolseley and Wellington production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

The total amount of rainfall received from 1 September 2017 to end May 2018 ranged between 202 mm (microsprinkler irrigated orchards) and 305 mm (double line drip irrigated orchard) for Bonnievale, 306 mm for Gouda, 244 mm for Wolseley and 174 mm (single line drip irrigated orchard) and 204 mm (double line drip irrigated orchards) for Wellington. During winter 2018 (June to August) the respective orchards received 114, 152, 252, 326, 242 and 256 mm of rainfall. The total amount of rainfall received from September 2018 to May 2019 ranged between 241 and 327 mm for the microsprinkler and drip irrigated Bonnievale orchards, respectively. Rainfall for the same period amounted to 314 mm for Gouda, 196 mm for Wolseley and 128 and 107 mm for the single and double line drip irrigated orchards in Wellington. During the 2018/19 season the microsprinkler and drip irrigated orchards in Bonnievale received c. 20% and 7%, respectively, more rainfall, and the Gouda orchards c. 3% more, compared to 2017/18. However, the orchard in Wolseley and the single and double line orchards in Wellington received c. 20%, c. 27% and c. 47% less rainfall, respectively, in the second season compared to the first.

3.5 Irrigation management

3.5.1 Irrigation water applied

The amount of irrigation water applied from the first week in September until end May to the nine full bearing Wonderful pomegranate orchards ranged in 2017/18 between 237 mm and 834 mm, and in 2018/19 between 272 mm and 867 mm (Fig. 11). In both the 2017/18 and 2018/19 seasons most water was applied in Bonnievale (688 mm and 775 mm), followed by Gouda (426 mm and 492 mm), Wolseley (385 mm and 456 mm) and Wellington (243 mm and 346 mm). On average over seasons Gouda, Wolseley and Wellington applied 63%, 57% and 40% of that applied to the Bonnievale area. Irrigation applied in the 2018/19 season was 13%, 15%, 19% and 42% more in the 2018/19 season compared to the 2017/18 season for Bonnievale, Gouda, Wolseley and Wellington, respectively. In addition to the irrigation applied during the growing season some orchards were also irrigated from June to August. In Bonnievale the microsprinkler irrigated ridged sandy clay loam and loam sand on sandy loam orchards received 29 mm and 50 mm of irrigation, respectively, whereas 7.6 mm was applied to the double line drip irrigated orchard. In Wellington the single line drip irrigated orchard received 2.6 mm irrigation water during this period.

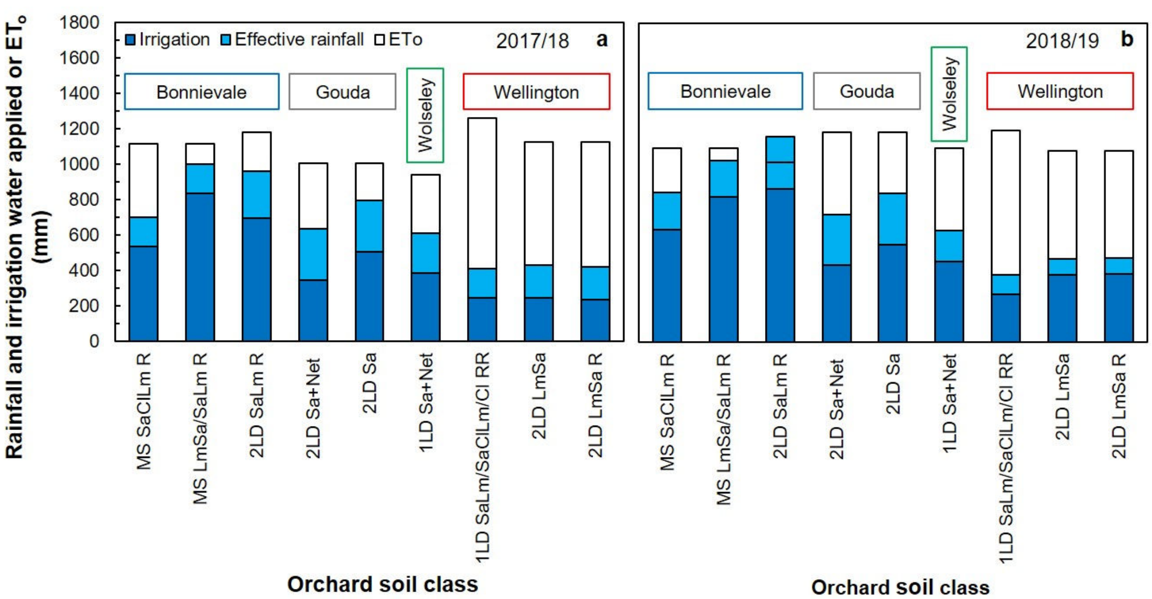

Fig. 11. Reference evapotranspiration, effective rainfall and irrigation water applied to full bearing Wonderful pomegranate orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas from September until May during the 2017/18 and 2018/19 seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

On average for soil type, 68% and 47% more water was applied from 1 September to end May in the 2017/18 and 2018/19 seasons, respectively, to clayey and sandy loam soils compared to the loamy sand and sandy soils. Microsprinkler irrigated orchards received 80% and 53% more water than drip irrigated orchards in the two respective seasons. In Gouda the drip irrigated orchard without net received 45% and 27% more water than the one below net. However, the lower amount of irrigation water applied below net cannot solely be contributed to effects of the net since the emitter spacing differed for the two orchards and the borehole supplying the netted orchard occasionally ran dry in the 2017/18 season. Orchards were irrigated according to producer practice and the amount of water applied therefore does not necessarily reflect water requirements of these orchards accurately.

3.5.2 Effective rainfall

Effective rainfall was obtained by correcting rainfall for estimated evaporation losses (Allen et al., 1998), but not by taking into account the effect of soil water content. Effective rainfall during the 2017/18 and 2018/19 growing seasons, respectively, amounted on average for Bonnievale, Gouda, Wolseley and Wellington to 201 mm and 236 mm; 289 mm and 288 mm; 226 mm and 177 mm; and 173 and 95 mm (Fig. 11). Effective rainfall that occurred from beginning of September until fruit set, from fruit set until linear fruit growth, linear fruit growth to ripening, ripening to harvest and post-harvest until end May was on average over production regions, 77 mm and 93 mm, 20 mm and 18 mm, 8 mm and 16 mm, 19 mm and 32 mm and 92 mm and 36 mm for the 2017/18 and 2018/19 seasons, respectively (Fig. 12).

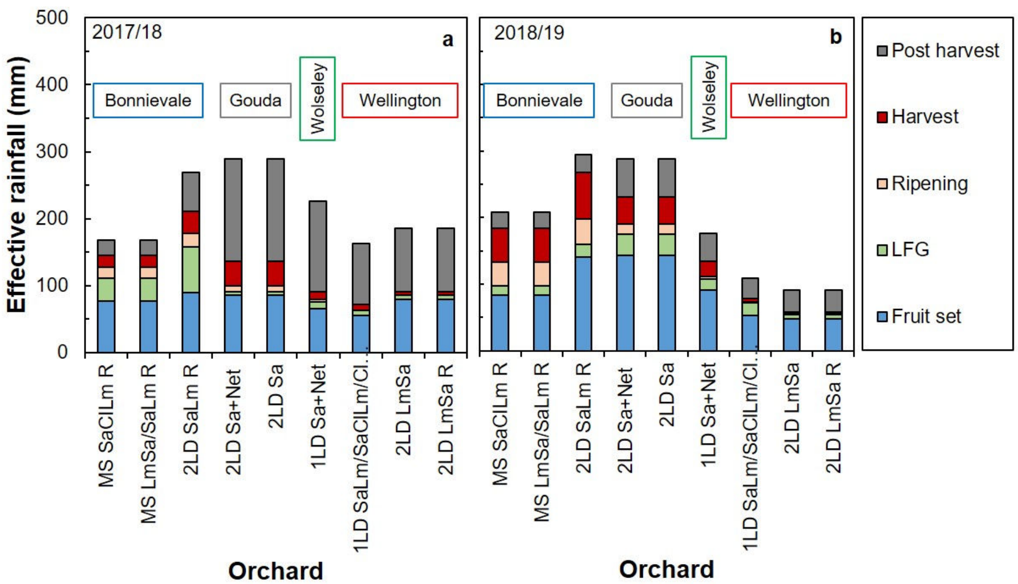

Fig. 12. Total effective rainfall for the fruit set, linear fruit growth, ripening, harvest and post-harvest stages for pomegranate (cv. Wonderful) orchards during the 2017/18 and 2018/19 growing seasons in the Bonnievale, Gouda, Wolseley and Wellington production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

Effective rainfall that occurred from beginning of September until fruit set, from fruit set until linear fruit growth, linear fruit growth to ripening, ripening to harvest and post-harvest until end May was on average over production regions for the 2017/18 and 2018/19 seasons, respectively, 37% and 48%, 10% and 9%, 4% and 7%, 8% and 14% and 41% and 22% of the total rainfall that fell during the growing season (Fig. 13). The effective rainfall on average for production regions increased in the second season during fruit set, ripening and harvest and decreased post-harvest compared to the first.

The Bonnievale area compared to the other production regions tended to receive a larger portion of the effective rainfall during linear fruit growth until harvest, although the difference between areas became somewhat smaller in the 2018/19 season. In 2017/18 and 2018/19, respectively, 42% and 47%; 18% and 30%; 11% and 24%; and 7% and 16% of the seasonal total effective rainfall occurred during linear fruit growth until harvest for the Bonnievale, Gouda, Wolseley and Wellington production areas. The risk for cracking/ splitting of fruit for Bonnievale increased in 2018/19 compared to the previous season as 25% of the seasonal effective rainfall occurred during harvest, compared to 11% the previous season. Effective rainfall post-harvest was in both seasons less in the Bonnievale area compared to the other production areas. Effective rainfall during the 2017/18 growing season was for Bonnievale, Gouda, Wolseley and Wellington, respectively, 63%, 54%, 41% and 42% of the annual effective rainfall that occurred from 1 September 2017 until end August 2018.

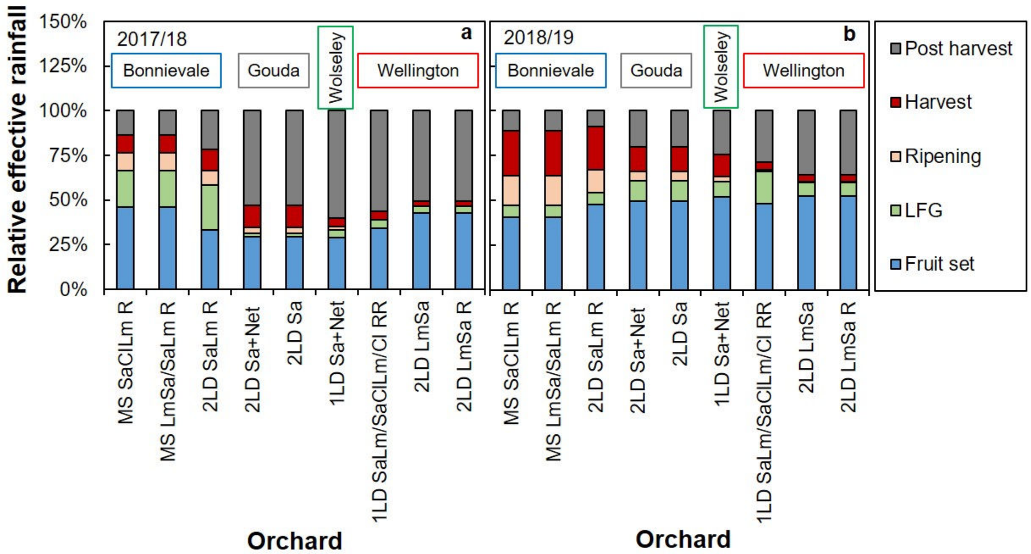

Fig. 13. Effective rainfall for the fruit set, linear fruit growth, ripening, harvest and post-harvest stages relative to the growing season total for pomegranate (cv. Wonderful) orchards during the 2017/18 and 2018/19 growing seasons in the Bonnievale, Gouda, Wolseley and Wellington production areas. Orchards are identified by their irrigation system and soil texture classification: MS, 1LD, 2LD, Cl, Lm, Sa, R and RR, respectively refers to microsprinkler, single and double line drip, clay, loam, sand, ridged and ripped ridge.

3.5.3 Total irrigation and effective rainfall

The total amount of effective rainfall and irrigation water applied from the first week in September until end May to the nine full bearing Wonderful pomegranate orchards ranged in 2017/18 between 409 mm and 1001 mm, and in 2018/19 between 381 mm and 1161 mm (Fig. 11). As in the case for irrigation (refer 9.5.1) the total of effective rainfall and irrigation was in both seasons the highest in Bonnievale (889 mm and 1011 mm), followed by Gouda (715 mm and 780 mm), Wolseley (611 mm and 633 mm) and Wellington (421 mm and 443 mm). On average over seasons the total effective rainfall and irrigation for Gouda, Wolseley and Wellington was 79%, 66% and 46% of that for the Bonnievale area. The total of effective rainfall and irrigation for Bonnievale, Gouda, Wolseley and Wellington, respectively, for the 2018/19 season was 14%, 9%, 4% and 5% more than for the 2017/18 season. The total effective rainfall and irrigation for the 2017/18 and 2018/19 seasons, respectively, equalled 78% and 94%; 71% and 66%; 65% and 58%; and 36% and 39% of the seasonal total ET_o for the Bonnievale, Gouda, Wolseley and Wellington production areas, respectively. The total effective rainfall and irrigation exceeding ET_o in 2018/19 at the drip irrigated orchard in Bonnievale can partially be attributed to higher rainfall during fruit set and harvest compared to at the microsprinkler irrigated orchards and application of slightly more irrigation. The effectivity of large rainfall events or significant amounts of rainfall occurring on subsequent days may have been overestimated.

3.5.4 Soil water dynamics

Data obtained from soil water content sensors were converted to volumetric soil water content using the factory calibration equation supplied or a calibration equation obtained from previous research for comparable soil types. No temperature corrections have been applied to data. Graphs in this report reflect general trends in volumetric soil water content.

In Bonnievale, the volumetric soil water content at the micro-irrigated ridged sandy clay loam orchard indicated from October 2017 to May 2018 the largest fluctuation at the 300 mm and 600 mm depths (Fig.14a). There was also oscillation in soil water content at the 900 mm and 1200 mm depths at the beginning of the season, which levelled off at the 900 mm depth from December as it became drier compared to initial soil water content. Soil water content at the 1200 mm depth had a less steep but definite downward trend towards the end of the season – pointing to drier subsoil conditions, compared to that in October. Rainfall and/ or irrigation replenished soil water content at all depths during winter 2018, and in the 2018/19 season soil water content fluctuated similarly at all depths until 23 March 2019 after which the soil gradually began drying at all depths. The soil water content increased a few times more at the 300, 600 and 900 mm depths, but was not refilled at the 1.2 m depth before measurements ended.

The soil water dynamics of the ridged loamy sand on sandy loam soil orchard was from October 2017 to May 2018 similar to that of the sandy clay loam orchard as the most soil water content fluctuation occurred at the 300 mm and 600 mm depths (Fig. 14b). It appears though as if oscillations were of more or less the same magnitude throughout the season until harvest, which was not always the case in Fig. 14a. Soil water content at 900 mm depth reflected irrigations/ rainfall but appeared to remain almost constant throughout the season, while that at the 1200 mm depth fluctuated, but started drying out from February onwards. Rainfall/ irrigation increased the soil water content in the two top soil layers during winter, but there was a gradual drying trend present at all depths. Data was not available for the 900 mm depth during this time due to equipment problems. There was a large increase in soil water content at the 300 mm depth on 17 October, and at the 600 mm depth at 11 November. Soil water content at the 1200 mm depth gradually increased from 11 November until 27 February, after which it started to decrease again towards the end of the season.

In the 2017/18 season the double line sandy loam drip irrigated orchard appeared to have fluctuation in soil water content at all levels up to 800 mm depth (Fig. 14c). Root studies indicated that roots of trees may be restricted to about 600 mm by an impermeable layer (Fig. 5a) and that the soil contains a large percentage of coarse material (Fig. 3). It is possible that roots penetrated the soil deeper at the soil water content measurement site where a drill was used to install the soil water measurement probe. Soil water content at all levels increased during February to March, and it levelled off at a maximum at the 800 mm depth. This may be an indication of overirrigation during this period. The soil water content at the 800 mm depth decreased from 8 April until 9 September 2018 after which it reached similar levels to the previous season. The soil water content though did not remain that high as frequently. There was overall a trend for soil water content at the 100, 200, 400 and 600 mm soil layers to increase from October 2017 until May 2019.

In Gouda in the orchard with net, the soil water content of the sandy soil in the root zone at 300 mm depth was very low, but fluctuated and reflected irrigation or rain throughout the 2017/18 season (Fig. 15a). The soil water content at the bottom of the root zone became very dry and levelled off as early as end November 2017. Roots in this orchard proliferated in the deeper gravelly part of the soil profile (Fig. 5b). The borehole supplying this orchard at times ran dry during the season due to the drought and near mid April soil water content at both the 300 mm and 1100 mm depths were levelled off at the low end. During winter in 2018 a water table was

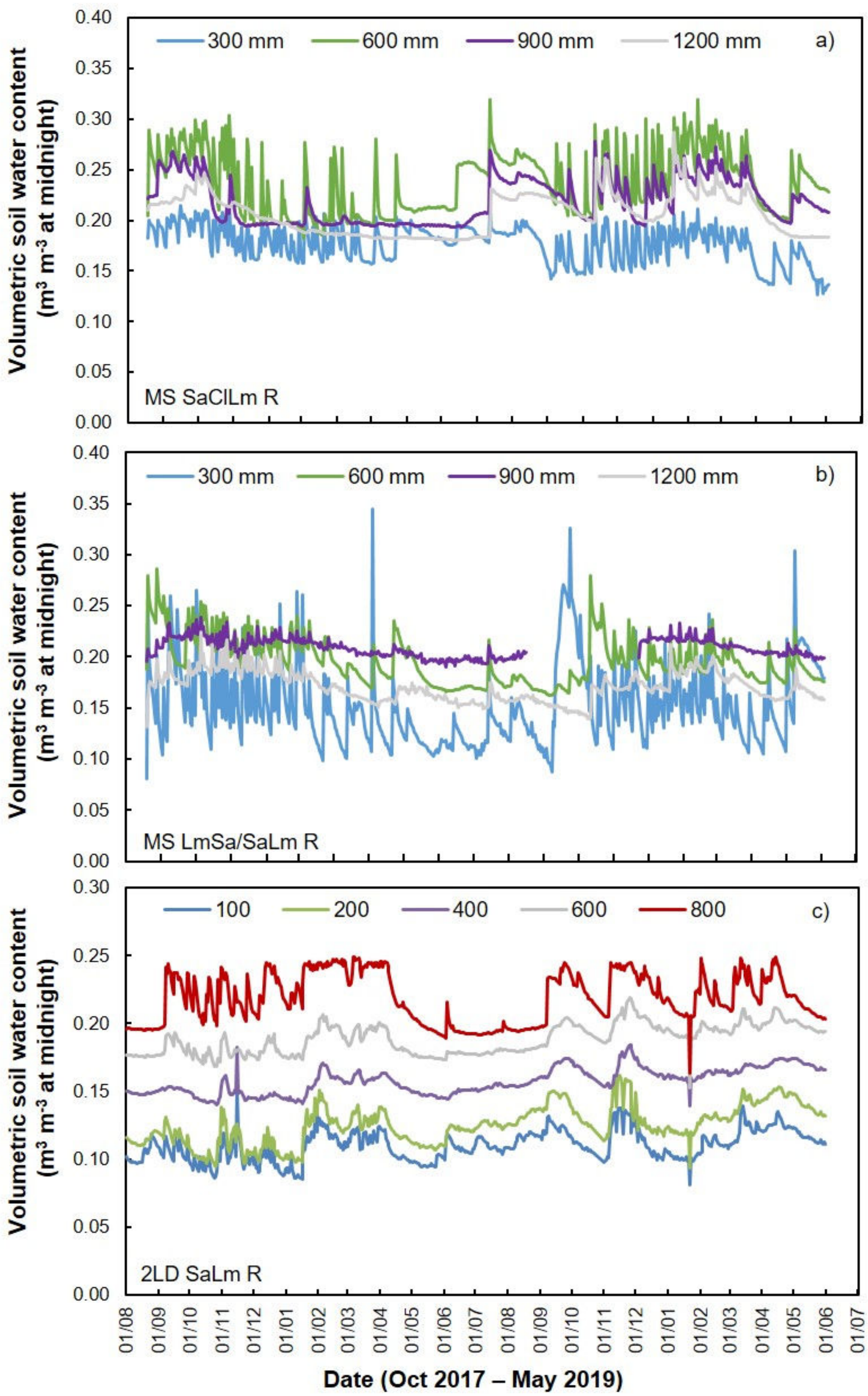

Fig.14. Soil water dynamics of the pomegranate (cv. Wonderful) orchards in the Bonnievale production area from October 2017 until May 2019. Soil water status at selected depths are indicated for the microsprinkler irrigated ridged sandy clay loam (a) and loamy sand/ sandy loam (b) orchards as well as for a double line drip irrigated ridged sandy loam orchard (c).

present at the 1100 mm depth, which gradually decreased from about 6 September until 4 October, with a drastic decrease until 15 November 2018 (Fig. 15a). Soil water content at the 300 mm depth decreased from about 19 September until 5 December after which it gradually increased toward Mid-March. It is possible that in addition to irrigation, 10.9 mm rainfall on the 8th of March combined with a total of 37.5 mm on the 19^{th} and 20^{th} of March increased the soil water content up to below the root zone. In the orchard without net in the 2017/18 season, the soil water content of the sandy soil in the root zone at 400 mm and 1200 mm fluctuated until mid-January after which soil water content at the 1200 depth levelled of until near end February, and again after the 25^{th} of March (Fig. 15b). It appears as if a temporary water table was present up to a depth of 400 mm during winter. Frequent fluctuation of soil water content at the 1200 mm depth most likely indicate preferential flow of irrigation water from the sandy top to the gravelly subsoil.

At Wolseley, the volumetric soil water content at 500 mm depth in the root zone reflected clear oscillations, becoming in general drier before irrigation or rainfall from February 2018 onwards (Fig. 10c). There was limited movement in soil water content at the 1000 mm depth below the root zone, except for a period in December 2017 and January 2018 when the soil water was probably replenished by over-irrigation, since no significant rainfall occurred shortly before this increase. During winter a water table developed up to the 500 mm depth. Fluctuation at the 1000 mm depth during the 2018/19 season indicate irrigation beyond the root zone from the end of December until 4 March 2019, after which the subsoil gradually dried out towards the end of the season.

In Wellington, in the single line drip irrigated sandy loam/ sandy clay loam/ clay irrigated orchard the volumetric soil water content at the 300 mm depth was relatively high until end November after which it dropped considerably as irrigation was not being applied due to a broken pump (Fig. 11a). Hereafter soil water content was increased gradually by limited rainfall and/or irrigation until it was finally restored to its initial levels by mid-March. The soil water in the clayey layer at the bottom of the root zone (1200 mm) gradually decreased from November and levelled off at a low by end January. The soil water at this level was restored by rainfall in May. Soil water content at the 300 mm depth remained after winter 2018 similar to that in the previous season until the beginning of March when it increased significantly, remained more or less similar to the end of April after which it decreased towards the end of the season. Soil water content at 1200 mm depth decreased from about 20 October 2018 until end April 2019, after which it gradually increased. The subsoil became less dry in the 2018/19 season compared to 2017/18.

In the level double line drip irrigated loamy sand orchard, the volumetric soil water content fluctuated at the 400 mm depth, the depletion level before irrigation remaining more or less similar throughout the season (Fig. 16b). The soil water content at the 800 mm depth started decreasing gradually from the beginning of November 2017 until it reached its driest point by 9 March 2018. During winter 2018 a water table appeared to develop at the 800 mm depth which gradually decreased from the 9^{th} of October towards the end of the season. Soil water dynamics at the 400 mm depth appeared to be similar in 2018/19 compared to that of the previous season.

In the ridged double line drip irrigated loamy sand orchard the volumetric soil water content at which irrigation refill occurred decreased from beginning of November 2017 until end of January 2018 and was only restored at end May 2018 (Fig. 16c). During the 2018/19 season the soil water content at 500 mm depth clearly fluctuated in response to irrigation. The soil water content at the 900 mm depth decreased gradually from the beginning of November 2017 and levelled off at a low near the beginning of January 2018. It only increased significantly by 16 June 2018. During the 2018/19 season the soil water content at 900 mm depth decreased from about 25 September until end November, after which it remained low until the end of the season.

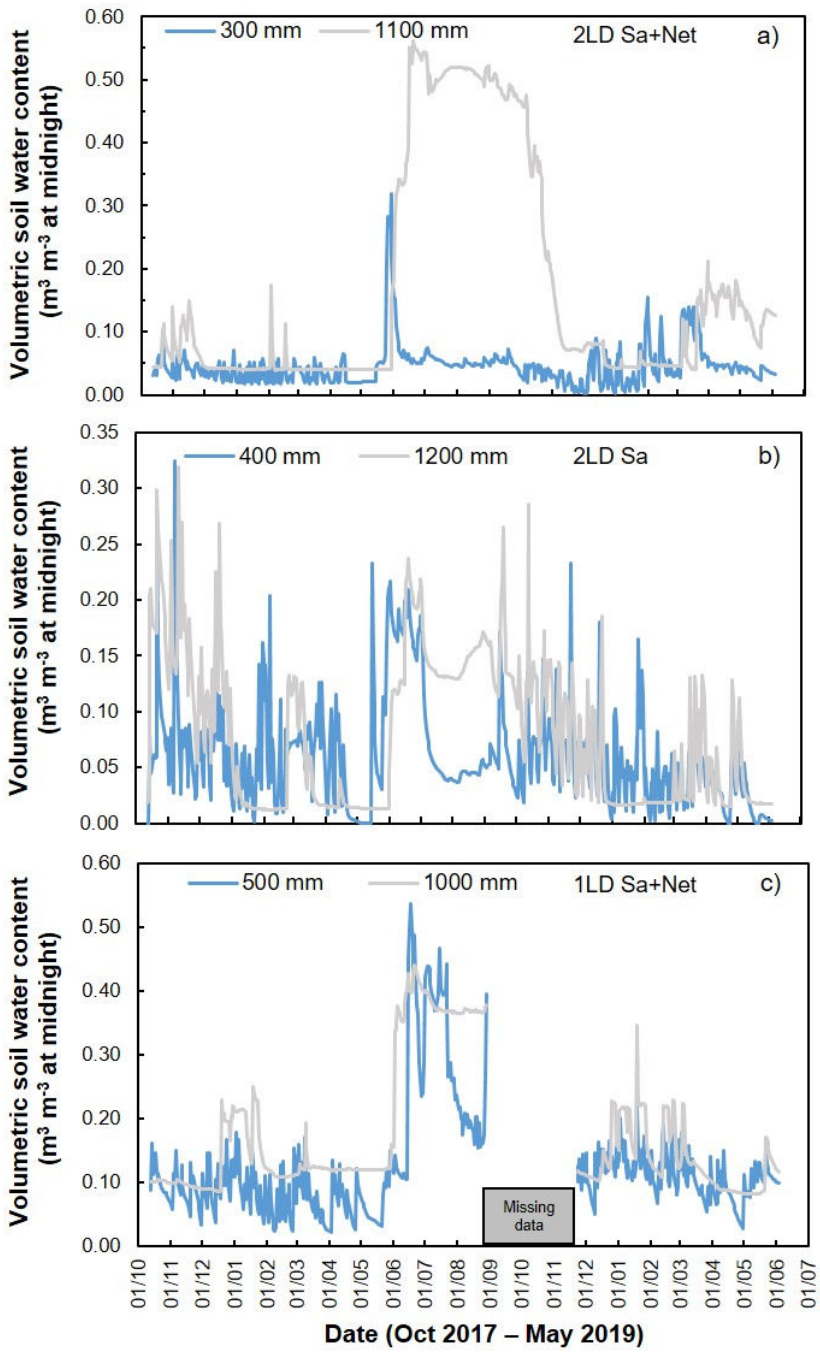

Fig.15. Soil water dynamics of the pomegranate (cv. Wonderful) orchards in the Gouda and Wolseley production areas from October 2017 to June 2019. Soil water status in the main root zone (blue line) and bottom of/ below the root zone (grey line) are indicated fpr the Gouda sandy double line drip irrigated orchards with (a) and without net (b) and the Wolseley sandy single line drip irrigated orchard.

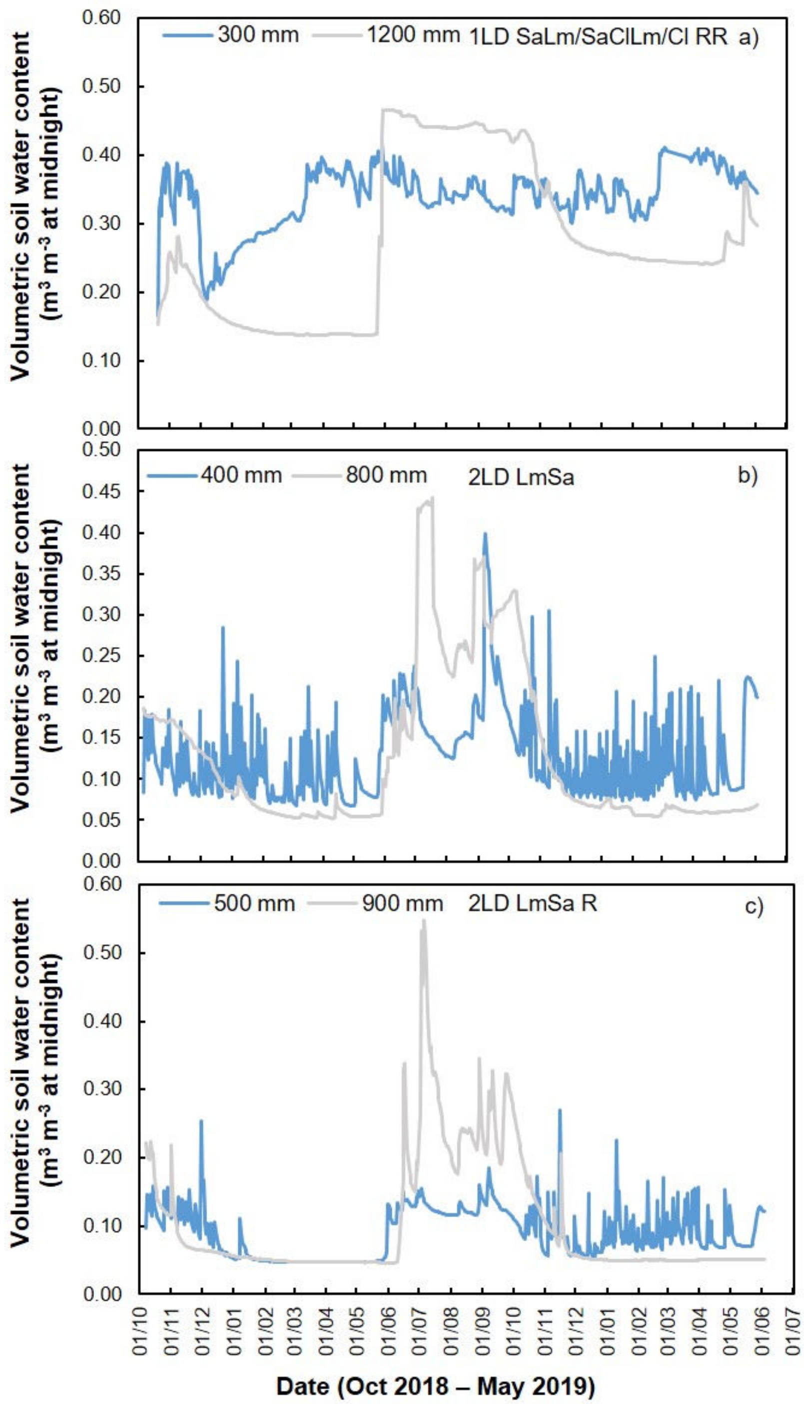

Fig.16. Soil water dynamics of pomegranate (cv. Wonderful) orchards in the Wellington production area from October 2017 until May 2019. Soil water status in the main root zone (blue line) and bottom of/ below the root zone (grey line) are indicated for the single line drip irrigated ripped ridge sandy loam/ sandy clay loam/ clay orchard (a), the level double line drip irrigated loamy sand (b) and ridged double line drip irrigated loamy sand (c) orchards.

3.6 Plant response

3.6.1 Growth stages

Tree shoot length, fruit diameter and canopy dimensions were measured near the end of the three phenological growth stages, namely fruit set, fruit growth and ripening in the 2017/18 and 2018/19 seasons (Table 10). In 2017/18, for the orchards on average, the duration of the stages from beginning to end for fruit set (relative to 1 September), fruit growth and ripening was 101±3, 53±2 and 36±6 days. From ripening until the first harvest 13±5 days elapsed, followed by the second harvest 12±2 days later. In 2018/19 the duration of the stages was similar to that in the first season i.e. for fruit set, fruit growth and ripening was 100±5, 49±4 and 37±3 days. From ripening until the first harvest 14±4 days elapsed, followed by a second harvest 12±4 days later, and in some cases a third after another 9±2 days.

3.6.2 Tree water status

Tree water status in the different production areas was determined during 2017/18 and 2018/19 at flowering to fruit set, fruit growth and ripening and orchards in each production area was measured on the same day per growth stage, with one exception (i.e. fruit set in Wellington in 2018/19, Table 11). Current season shoots were enclosed in stem water potential bags up to the fourth node two hours before measurements were done. Xylem (stem) water potential of shoots selected at a height of between 0.7 m and 1.22 m was determined between 12h00 and 14h30. Weather conditions and time elapsed after irrigation application varied between stages, production areas and between orchards within production areas, which make direct comparison between orchards difficult or invalid (Table 12). The xylem water potential values therefore only indicate whether the trees were experiencing water stress at the time of measurement, and is not necessarily indicative of conditions directly foregoing irrigation. In 2017/18 weather conditions during fruit set stage included c. 80%-100% cloud in the Bonnievale area, no cloud cover in Gouda and c. 10% cloud cover in Wolseley and Wellington. Conditions during fruit growth stage for both seasons were ideal, i.e. full sun. In 2017/18 during ripening there was light high level cloud in Bonnievale and Gouda, and none in Wolseley and Wellington. In 2018/19 weather conditions during fruit set stage was sunny with high cloud cover in the Bonnievale area, with no cloud cover in Gouda, Wolseley and Wellington. During ripening there was cloudy conditions in Gouda and Wolseley, and full sun conditions in Bonnievale and Wellington.

In Spain, midday stem water potential values of ‘Mollar de Elche’ pomegranate trees without water stress in several experiments ranged between -0.6 to -1.6 MPa, but could become as low as -1.8 MPa (Intrigliolo et al. 2011, Intrigliolo et al., 2013, Mena et al. 2013). Trees subjected to moderate and severe sustained water deficits have been reported to reach minimum stem water potential values of −1.78 and −2.62 MPa, respectively (Mena et al. 2013). Due to a lack of stem water potential norms for Wonderful pomegranate, the ‘Mollar de Elche’ indicator values are used to interpret the shoot xylem water potential measurements. It must also be taken into account that weather conditions also affect stem water potential values. In 2017/18 during fruit set, the xylem water potential of all the orchards were equal to or below -1 MPa except for the microsprinkler irrigated sandy clay loam in Bonnievale, which had a xylem water potential of c. -1.4 MPa (Table 13). It appears as if water supply in all orchards was adequate during this stage. During the fruit growth stage, xylem water potential ranged between -1.035 MPa and -2.28 MPa. Moderate water deficits may have occurred in Gouda, with the ridged double line drip irrigated loamy sand orchard in Wellington being subjected to severe water stress before irrigation. The xylem water potential in the other two Wellington orchards were approaching the moderate water deficit range. There was no difference in the xylem water potential of the orchard below net and without net at Gouda during this stage. During ripening the xylem water potential ranged between -1.06 MPa and -2.723 MPa. The Bonnievale orchards, the Gouda orchard without net and Wolseley orchard were irrigated the morning before/ during measurement, which explains the higher xylem water potential values compared to the orchards which were not irrigated. The exception was the Wellington single line drip orchard which still displayed a moderate degree of water deficit after twenty minutes of irrigation before tree water status was determined.

Table 10. Dates at fruit set, linear fruit growth and ripening during which shoot length, fruit diameter and canopy dimensions* were measured as well as dates of sequential harvests in different pomegranate (cv. Wonderful) production areas in the 2017/18 and 2018/19 seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Season	Production area	Orchard	Stage				
			Fruit set	Fruit growth	Ripening	Harvest 1	Harvest 2&3
2017/18	Bonnievale	MS SaClLm R	2017/12/12	2018/02/01	2018/03/12	2018/03/20	2018/04/03
		MS LmSa/SaLm R	2017/12/12	2018/02/01	2018/03/12	2018/03/21	2018/04/03
		2LD SaLm R	2017/12/12	2018/02/01	2018/03/12	2018/03/22	2018/04/04
	Gouda	2LD Sa+Net	2017/12/14	2018/02/07	2018/03/06	2018/03/27	2018/04/06
		2LD Sa	2017/12/14	2018/02/07	2018/03/06	2018/03/27	2018/04/06
	Wolseley	1LD Sa+Net	2017/12/11	2018/01/29	2018/03/26	2018/04/05	-
	Wellington	1LD SaLm/SaClLm/Cl RR	2017/12/07	2018/01/30	2018/03/08	2018/03/23	2018/04/05
		2LD LmSa	2017/12/07	2018/01/30	2018/03/08	2018/03/19	n.a.
		2LD LmSa R	2017/12/07	2018/01/30	2018/03/08	2018/03/19	2018/03/29
2018/19	Bonnievale	MS SaClLm R	2018/12/12	2019/01/30	2019/03/05	2019/03/13	2019/03/27
		MS LmSa/SaLm R	2018/12/12	2019/01/30	2019/03/05	2019/03/19	2019/03/28
		2LD SaLm R	2018/12/12	2019/01/30	2019/03/05	2019/03/26	2019/04/03
	Gouda	2LD Sa+Net	2018/12/13	2019/01/29	2019/03/07	2019/03/20	2019/04/09
		2LD Sa	2018/12/13	2019/01/29	2019/03/07	2019/03/20	2019/04/02 2019/04/09**
	Wolseley	1LD Sa+Net	2018/12/10	2019/01/28	2019/03/08	2019/03/25	-
	Wellington	1LD SaLm/SaClLm/Cl RR	2018/11/28	2019/01/25	2019/03/06	2019/03/18	2019/03/25 2019/04/04**
		2LD LmSa	2018/12/11	2019/01/25	2019/03/06	2019/03/18	2019/03/29
		2LD LmSa R	2018/12/11	2019/01/25	2018/03/06	2019/03/18	2019/03/29

*Only linear fruit growth stage
** Harvest 3

This specific orchard is irrigated with saline water (Table 4) and salinity may in addition to water deficits further decrease stem water potential. The trees in the Wellington orchards was according to their water status either on the brink of moderate water stress or experiencing moderate or severe water deficits. The Gouda orchard below net was also subjected to moderate water deficits. In 2018/19 during fruit set, the xylem water potential of all the orchards were equal to or below -1.1 MPa except for the double line drip irrigated sandy loam in Wellington, which had a xylem water potential of c. -1.3 MPa (Table 13). Orchards appeared to be watered adequately during this stage. During the fruit growth stage, xylem water potential ranged between -0.86 MPa and -1.74 MPa. The greatest water deficits occurred in Gouda, and in the double line drip irrigated loamy sand in Wellington, approaching the moderate water deficit range. During ripening the xylem water potential ranged between -0.666 MPa and -1.636 MPa, which is much higher compared to the minimum xylem water potential of -2.7 MPa (i.e. severe stress) reported during the critical drought of the previous season. Despite variability between sites, shoot xylem water potential at fruit growth stage tended in 2017/18 and in 2018/19 to increase (i.e. became less negative) non-linearly and linearly, respectively, with an increase in the average rate of effective rainfall and irrigation water applied per day from fruit set to end fruit growth stage (Fig. 17a & b). For data of both seasons combined the overall trend was for shoot xylem water potential at fruit growth stage to increase non-linearly with greater rates of effective rainfall and irrigation applied (Fig. 17c). Data of orchards omitted as outlying values in 2018/19 were excluded based on the impact of heavy winter pruning on trees or questionable tree health. Under the conditions of the research conducted application of microsprinkler irrigation of between 6.2 and 7 mm d^{-1} or drip irrigation of between 5.3 to 5.6 mm d^{-1} resulted in shoot stem water potential values of between -0.95 MPa and -1.1 MPa, which can be considered indicative of well-watered trees.

Table 11. Xylem water potential measurement dates during fruit set, fruit growth and ripening in different Wonderful pomegranate production areas in the Western Cape during 2017/18 and 2018/19.

Season	Growth stage	Production area			
		Bonnievale	***Gouda***	***Wolseley***	***Wellington***
2017/18	Fruit set	13/11/2017	10/11/2017	29/11/2017	9/11/2017
	Fruit growth	1/2/2018	7/2/2018	29/1/2018	31/1/2018
	Ripening	18/3/2018	6/3/2018	26/3/2018	8/3/2018
2018/19	Fruit set	12/12/2018	13/12/2018	10/12/2018	28*&30/11/2018
	Fruit growth	5/2/2019	29/1/2019	28/1/2019	24/1/2019
	Ripening	5/3/2019	7/3/2019	8/3/2019	6/3/2019

*1LD SaLm/SaClLm/Cl RR

Table 12. Weather conditions prevailing during xylem water potential measurements during fruit set, fruit growth and ripening in different Wonderful pomegranate production areas in the Western Cape during 2018/19.

Season	Growth stage	Production area			
		Bonnievale	***Gouda***	***Wolseley***	***Wellington***
2017/18	Fruit set	Cloudy	Clear	Cloudy	Cloudy
	Fruit growth	Clear	Clear	Clear	Clear
	Ripening	Cloudy	Cloudy	Clear	Clear
2018/19	Fruit set	Cloudy	Clear	Clear	Clear
	Fruit growth	Clear	Clear	Clear	Clear
	Ripening	Clear	Cloudy	Cloudy	Clear

Table 13. Pomegranate (cv. Wonderful) xylem water potential (± standard error) measured during fruit set, fruit growth and ripening in different Western Cape production areas in the 2017/18 and 2018/19 seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Season	Production area	Orchard	Shoot xylem water potential (MPa)					
			Fruit set		Fruit growth		Ripening	
			AVG	SE	AVG	SE	AVG	SE
2017/18	Bonnievale	MS SaClLm R	-1.390	0.033	-1.200	0.016	-1.210	0.062
		MS LmSa/SaLm R	-0.900	0.091	-1.040	0.043	-1.060	0.073
		2LD SaLm R	-0.950	0.032	-1.050	0.038	-1.260	0.062
	Gouda	2LD Sa+Net	-0.950	0.050	-1.915	0.024	-1.830	0.030
		2LD Sa	-0.800	0.032	-1.890	0.033	-1.230	0.058
	Wolseley	1LD Sa+Net	-0.830	0.020	-1.035	0.038	-1.180	0.124
	Wellington	1LD SaLm/SaClLm/Cl RR	-0.970	0.044	-1.665	0.050	-1.790	0.037
		2LD LmSa	-0.960	0.073	-1.540	0.116	-1.670	0.132
		2LD LmSa R	-1.000	0.042	-2.280	0.041	-2.730	0.090
2018/19	Bonnievale	MS SaClLm R	-1.050	0.187	-0.973	0.081	-0.983	0.080
		MS LmSa/SaLm R	-0.930	0.091	-0.860	0.107	-0.985	0.120
		2LD SaLm R	-1.050	0.117	-1.166	0.058	-0.965	0.070
	Gouda	2LD Sa+Net	-0.980	0.057	-1.724	0.099	-1.114	0.143
		2LD Sa	-0.910	0.074	-1.655	0.121	-1.178	0.150
	Wolseley	1LD Sa+Net	-0.670	0.076	-0.907	0.089	-0.666	0.049
	Wellington	1LD SaLm/SaClLm/Cl RR	-0.960	0.055	-1.180	0.182	-1.232	0.163
		2LD LmSa	-1.315	0.065	-1.740	0.173	-1.412	0.159
		2LD LmSa R	-1.144	0.072	-1.398	0.194	-1.636	0.123

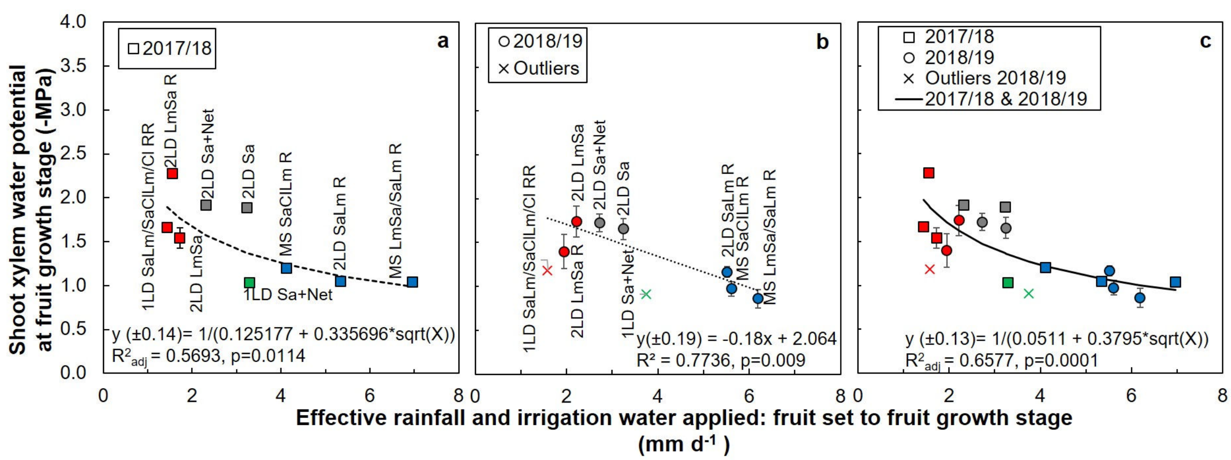

Fig. 17. The relationship between shoot xylem water potential (±standard error) and irrigation water applied to full bearing Wonderful pomegranate orchards in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas during the 2017/18 season. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

3.6.3 *Vegetative growth*

Shoot growth on current season shoots varied from bud break to linear fruit growth stage between 243 mm and 442 mm in 2017/18 and between 211 mm and 624 mm in 2018/19 (Fig. 18a & b). In 2017/18 more than 94% of the shoot growth was completed by end of fruit set. Exceptions were the double line drip irrigated clay soil in Bonnievale and sand in Gouda, for which 84% and 66%, respectively, of the total shoot growth was completed at fruit set stage. In 2018/19, 90% or more of the shoot growth was completed by end of fruit set for the majority of orchards. Exceptions were the microsprinkler irrigated ridged loamy sand/ sandy loam soil orchard in Bonnievale and the heavily winter-pruned sandy loam/ sand clay loam/clay orchard in Wellington, for which 78% of the total shoot growth was completed at fruit set stage. The latter, originally freestanding trees were trained onto a trellis system in the 2018/19 season.

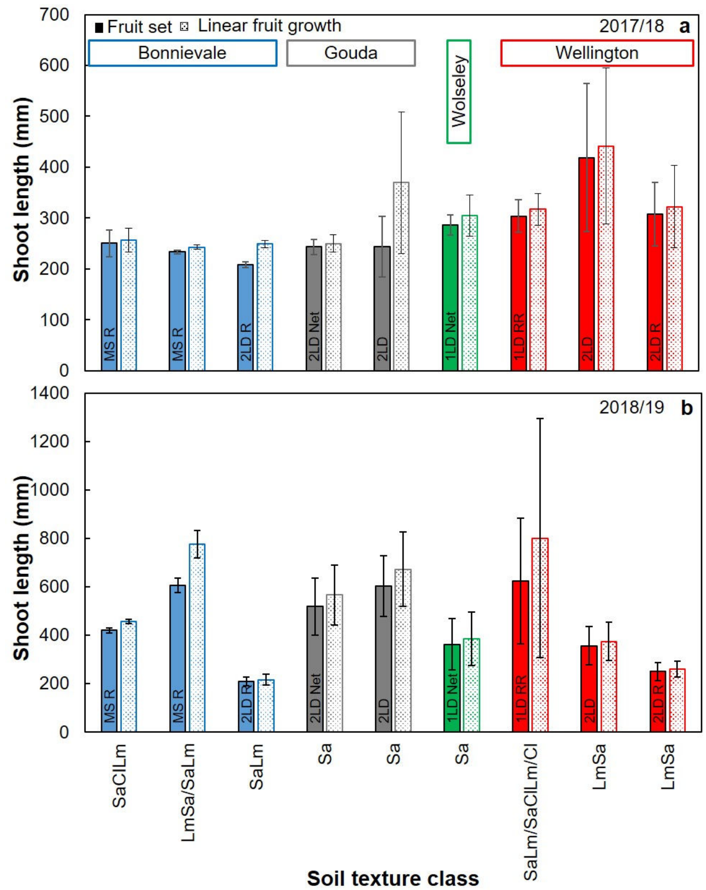

Fig. 18. Shoot growth from bud break until fruit set (solid bars) and linear fruit growth stage (patterned bars) of full bearing Wonderful pomegranate orchards in the Bonnievale (blue bars), Gouda (grey bars), Wolseley (green bars) and Wellington (red bars) production areas during the 2017/18 (a) and 2018/19 (b) seasons. MS, 1LD, 2LD, R and RR refers to microsprinkler, single and double line drip, ridged and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

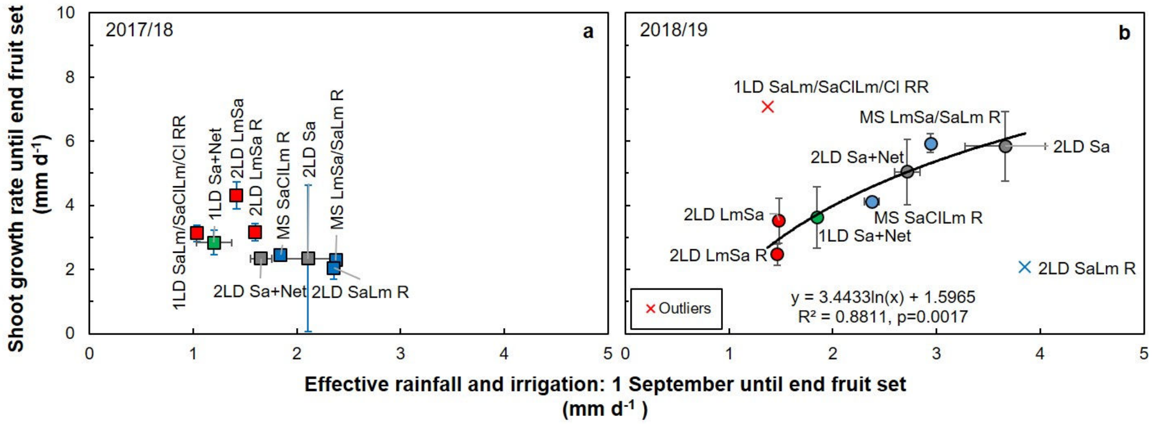

Fig. 19. Shoot growth rate from bud break until end fruit set vs daily irrigation applied from 1 September until fruit set stage for Wonderful pomegranate orchards in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red marker) production areas during the a) 2017/18 and b) 2018/19 seasons. MS, 1LD, 2LD, R and RR refers to microsprinkler, single and double line drip, ridged and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

In 2017/18 the rate of effective rainfall and irrigation applied from the beginning of September until the end of fruit set fruit growth stage amounted to less than 2.5 mm d^{-1}, whereas in 2018/19 the amount ranged from 1.5 mm d^{-1} to 3.7 mm d^{-1} (Fig. 19 a & b). In the first season there was no clear relationship between the effective rainfall and amount of water applied per day from 1 September until end fruit set stage and shoot growth rate (Fig. 19a). In 2018/19 though shoot growth rate increased logarithmically from 2.5 mm d^{-1} to 5.9 mm d^{-1} with more effective rainfall and irrigation applied, provided two outlying values were excluded (Fig. 19b). The excessive growth of the single drip irrigated orchard on sandy loam/ sandy clay loam/ clay in Wellington was considered as a response to heavy pruning. In the ridged double line drip irrigated orchard on sandy loam in Bonnievale vegetative growth of the trees was according to the farm manager adequate and tree height increased notably. The only explanation for the apparently poor growth was that the shoots selected for measurement at mid-canopy height did not represent the actual growth of the trees. Shoot growth rate for the period between 1 September and the end of linear fruit growth increased exponentially with increasing rates of effective rainfall and irrigation applied (data not shown, y (SE±0.19) = exp(0.176 + 0.35x), R^2=0.767, p= 0.0098).

For production regions on average in 2017/18, Wellington had the highest shoot growth rate from 1 September until linear fruit growth (3.5 mm d^{-1}), followed by Wolseley, Gouda and Bonnievale (20%, 34% and 36%, respectively, less than the Wellington average). In 2018/19 though Gouda had the highest shoot growth rate during this period (5.4 mm d^{-1}), followed by Wellington, Bonnievale and Wolseley (20%, 26% and 33%, respectively, less than the Gouda average). On average for soil type, shoot growth rate of trees on clayey and sandy loam soils was in the first season c. 18% less compared to those on sandy and loamy sand soils (2.7 mm d^{-1}). In the second season the shoot growth rate of trees on clayey and sandy loam soils was once again lower (7%) compared to those on sandy and loamy sand soils, where shoot growth rate averaged 4.4 mm d^{-1}.

Pruning mass as indicator to compare vegetative growth between orchards was discarded since one orchard was pruned severely to adapt a different training system, some orchards were not pruned at all, while others were pruned without notifying the research team.

3.6.4 Fruit growth

Fruit diameter was measured at the end of fruit set, during linear fruit growth and ripening. In 2017/18, at end fruit set, the fruit of the microsprinkler irrigated orchard on ridged loamy sand

and the double line drip irrigated ridged sandy loam orchard in Bonnievale had on average fruit of c. 57 mm in diameter, which were c. 15% larger than the fruit of all the other orchards on average (Fig. 20a). The microsprinkler irrigated orchards in Bonnievale had based on fruit diameter, c. 13% larger fruit compared to all other orchards at both linear fruit growth (average fruit diameter c. 78 mm) and ripening stage (average fruit diameter c. 93 mm) (Fig. 17). The smallest fruit were from Wolseley (Fig. 20b) and the orchards in Wellington (Fig. 20c). At Gouda, fruit below net was until the first harvest between 2% and 6% smaller (Fig. 20b), and at the second harvest 12% smaller compared to fruit produced without net (data not shown).

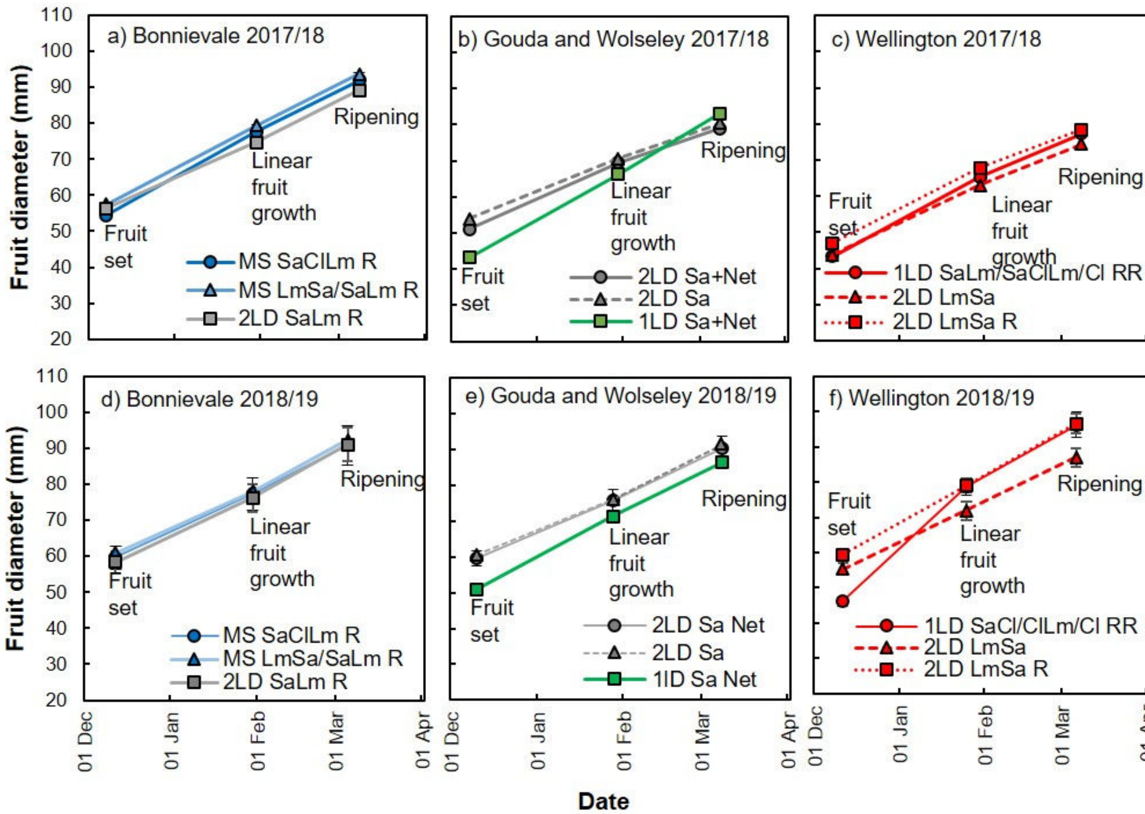

Fig. 20. Fruit diameter of full bearing Wonderful pomegranate orchards measured during fruit set, linear fruit growth and ripening in the Bonnievale (a, d), Gouda and Wolseley (green line) (b, e) and Wellington (c, f) production areas during the 2017/18 (a, b, c) and 2018/19 (d, e, f) seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridged and ripped ridge, respectively. Soil texture classes include clay (Cl), loam (Lm) and sand (Sa).

At end fruit set in 2018/19 the fruit of most orchards were comparable and on average c. 59 mm in diameter (Fig. 20d-f). Notably smaller fruit were present in the Wolseley orchard (51 mm, Fig. 20e) and in Wellington in the 2LD Lm Sa orchard (55 mm, Fig. 20f). Significantly smaller fruit at the 1LD SaCl/ClLm/Cl RR orchard (46 mm, Fig. 20f) could be due earlier onset of the end of fruit set in the 2018/19 season and/or a carry-over effect of severe winter pruning applied to train the previously free standing trees on a trellis system. By linear fruit growth stage though these fruit overcame the initial small size and the orchard had of the largest fruit (96 mm) at ripening stage (Fig. 20f). Fruit diameter at ripening was on average (±standard deviation) for all orchards 91±3.5 mm, with fruit from the single line drip irrigated orchard below net in Wolseley (Fig.20e, 86 mm) and the double line drip irrigated loamy sand orchard in Wellington (Fig. 20f, 87 mm) being the smallest.

With regard to production areas, in 2017/18 at fruit set fruit at Bonnievale had 6%, 23% and 20% larger fruit (diameter c. 54 mm) compared to fruit at Gouda, Wolseley and Wellington, respectively (Fig. 21). At linear fruit growth stage, fruit in the respective areas was 9%, 14% and 15% smaller compared to the Bonnievale fruit (c. 75 mm diameter) and during ripening (c. 92 mm diameter) 13%, 9% and 16%. Fruit diameter based on all fruit at the first harvest was comparable between Bonnievale (c. 90 mm), Gouda and Wolseley (c. 88 mm), but still 10% smaller at Wellington (c. 81 mm) compared to Bonnievale. Fruit from the second harvest was also smaller at Gouda (8%) and Wellington (13%) compared to that at Bonnievale (c. 86 mm). At Wolseley all fruit were removed during one harvest. Microsprinkler irrigated trees had c. 13% larger fruit diameter at fruit set, linear fruit growth and ripening stage compared to drip irrigated orchards. At both the first and second harvests, though, fruit diameter (based on all fruit harvested) was only 5% more compared to that of fruit from drip irrigated orchards.

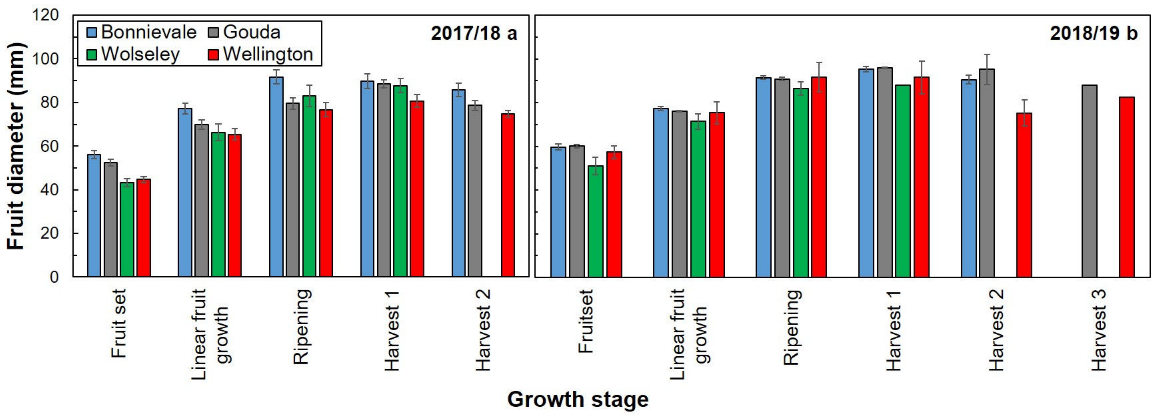

Fig. 21. Fruit diameter (±standard deviation) of full bearing Wonderful pomegranate orchards measured during fruit set, linear fruit growth, ripening and the first, second and third harvest in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 (a) and 2018/19 (b) seasons. The average fruit diameter (±standard deviation) at different fruit growth stages until ripening are for fifty fruit per orchard, and at harvest for all fruit excluding cracked or split fruit.

In 2018/19 at fruit set, linear fruit growth stage and ripening fruit at Bonnievale, Gouda and Wellington was comparable (diameter c. 59, 76 and 91 mm on average) and c. 14%, and 6.3% and 5.5% larger compared to fruit at Wolseley at these respective stages (Fig. 21). At the first harvest, fruit from Bonnievale and Gouda had comparable diameter (on average 96 mm), whereas fruit from Wellington was on average 92 mm and that of Wolseley 88 mm. There was large variability in fruit size for the Wellington area compared to that of the other areas. Fruit diameter at the second harvest was similar to that of the first for Bonnievale and Gouda on average, with that for Wellington being c. 26% smaller. Fruit from the third harvest at Gouda and Wellington was on average of 88 and 83 mm diameter, respectively. Fruit from microsprinkler irrigated orchards was at fruit set c. 8% larger than the drip irrigated fruit, but the size difference got smaller later in the season with fruit being of comparable size at the first harvest, and only 5% larger at the second. At Gouda there was only small differences (i.e. less than 3%) between fruit diameter below net compared to the open except for the second harvest, where fruit below net was 10% smaller compared to those from the open orchard. Fruit diameter of fruit from orchards having clay loam or sandy loam soils was between 5% and 7% more than those having loamy sand or sandy soils.

Fruit growth rate for fruit set phase was calculated relative to 1 September, since exact dates of flowering were not available for the different orchards. Fruit growth rate during 2017/18 and 2018/19 was on average 0.56 and 0.47; 0.38 and 0.39; and 0.35 and 0.41 mm d^{-1} during the fruit set, linear fruit growth and ripening phases, respectively. Fruit growth rate during fruit set phase tended to increase with more effective rainfall and irrigation applied in both seasons, but the relationship for the linear fruit growth and ripening phases were less clear (Fig. 22a-c).

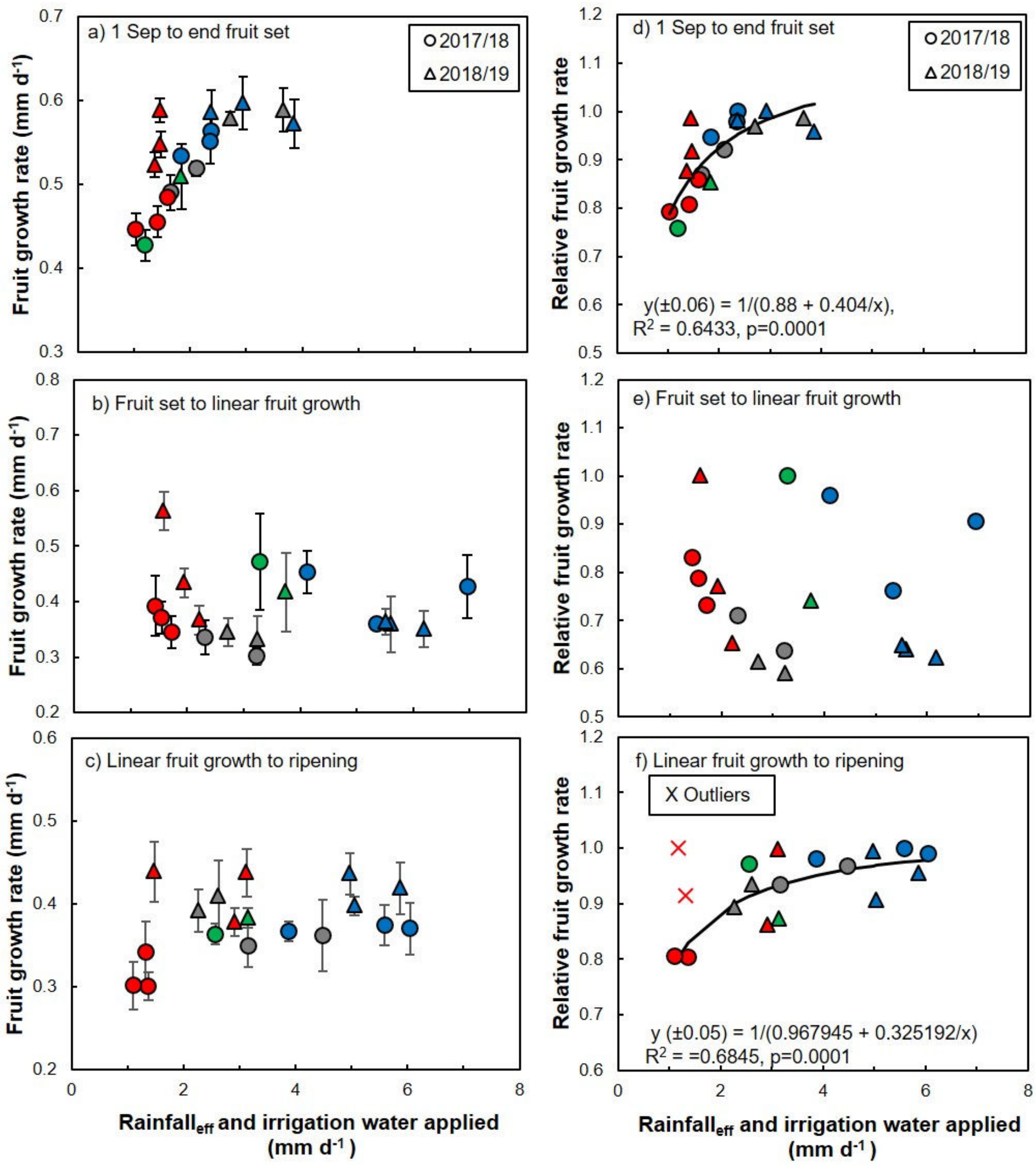

Fig. 22. Absolute (±standard deviation) (a - c) and relative (d - f) fruit growth rate of full bearing Wonderful pomegranate orchards measured during fruit set (a & c), linear fruit growth (b & e) and ripening (c & f) phases in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas during the 2017/18 and 2018/19 seasons.

Relative fruit growth rate during fruit set (Fig. 22d) and ripening (Fig. 22f) tended to increase non-linearly with an increased amount of effective rainfall and irrigation water applied daily. The relative fruit growth rate during ripening of the single line drip irrigated orchard in Wellington was identified as an outlier for both seasons, deviating by more than two standard deviations from the mathematical model (Fig. 22f). There was no simple relationship between the daily effective rainfall and amount of water applied and absolute or relative fruit growth rate during linear fruit growth (Fig. 22b & e). However, fruit growth rate during the linear fruit growth stage tended to improve with higher (i.e. less negative) shoot xylem water potential in 2017/18 (Fig. 23a). In 2018/19 though it was not possible to fit one mathematical relationship for all orchards (Fig. 23b). The fruit growth rate in Gouda and Wellington decreased non-linearly with stem water potential between -1.18 and -1.74 MPa. The lack of correlation between fruit growth rate and stem water potential for the Bonnievale area may be related to the effect of more than 20 mm of rainfall that occurred between two and five days before the measurements were made. The Wolseley stem water potential data point was previously identified as and outlying data point in comparison to effective rainfall and irrigation applied (refer Figure 17b).

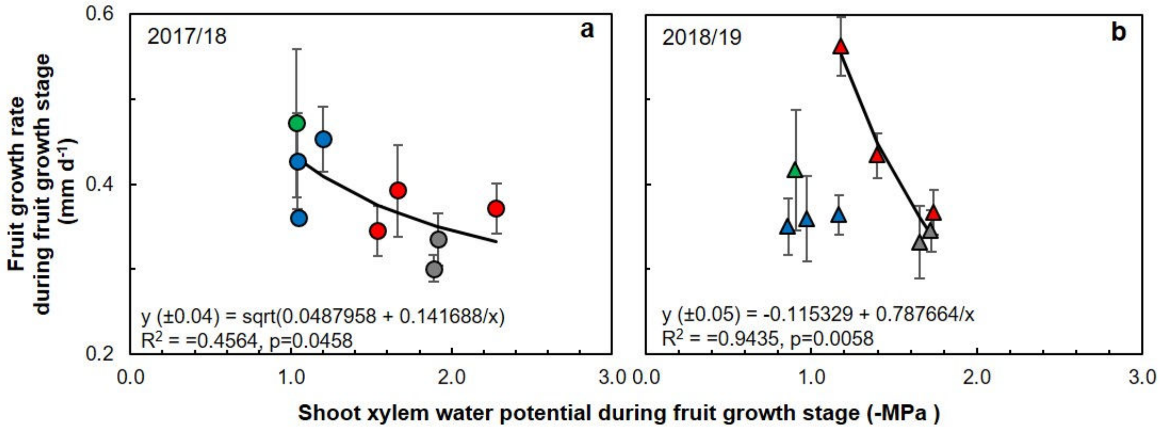

Fig. 23. The relationship between fruit growth rate (±standard deviation) and shoot xylem water potential during fruit growth stage of full bearing Wonderful pomegranate orchards in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas during the 2017/18 season. The mathematical relationship in 2018/19 applies only to Gouda and Wellington.

3.6.5. Leaf nutrient analysis

Leaf macro- and micronutrient contents are summarized in Tables 14 and 15. In 2017/18, according to norms for pomegranate trees (refer Bemlab, Tables 14), the leaf nitrogen (N) and phosphate (P) levels from the Bonnievale micro-irrigated orchards were very high, whereas the N was deficient in four of the drip irrigated orchards, especially the Wolseley orchard below net. The P levels was low in all the drip irrigated orchards in Wellington and in the drip irrigated Gouda orchard without net, but very high in the Wolseley orchard. In 2017/18, leaves from all orchards indicated potassium (K) deficiency, but calcium (Ca) levels were adequate. Leaf magnesium (Mg) levels were deficient in Wolseley and in the level double line drip irrigated loam sand orchard in Wellington. Magnesium levels were very high in leaves of the Gouda orchard without net, and in Bonnievale, in the microsprinkler irrigated loam sand/ sandy loam and the sandy loam drip irrigated orchard. In 2018/19, leaves from the Bonnievale and Gouda areas tended to have normal to high levels of N, P and Mg. The Wolseley orchard was deficient in N, but had very high levels of P and K. Leaves of all the Wellington orchards were nitrogen deficient, with the double line drip loamy sand orchards indicating a phosphate deficiency as well. Potassium levels in leaves of the Wellington orchards were adequate. Leaves of the ridged double line drip irrigated loamy sand orchard in Wellington contained very high levels of Mg. In both seasons the Ca levels in leaves of all orchards were adequate.

Leave surfaces were not washed before analysis and high levels of certain micronutrients may therefore be due to spray residues. Sodium was within norms for both seasons (Table 15). Manganese (Mn) and copper (Cu) reached toxic levels in leaves of most orchards, with the exception of Wolseley leaves, which were deficient in Cu in 2017/18 and had low levels in 2018/19 (Table 15). Iron (Fe) levels tended to be high in the Bonnievale orchards and in the Gouda orchard without net in 2017/18, but in 2018/19 Fe levels were exceeding the high norm in all orchards but one. In 2017/18 leaves of all orchards were deficient in boron (B) and zinc (Zn), except for the Gouda orchards, which had high Zn levels. In 2018/19 leaves of all orchards were once again boron deficient, except for Wolseley which had low levels of this micronutrient. All orchards also had either low or deficient levels of Zn, except for the double line drip irrigated orchard in Gouda without net, which contained high levels of Zn in leaves.

For most leaf macro- and micronutrients there was in both seasons no significant relationship between leaf nutrient content and effective rainfall and irrigation that occurred until end linear fruit growth when leaves were sampled. Leaf phosphate and magnesium content though increased either non-linearly or linearly with higher rates of effective rainfall and irrigation applied until end linear fruit growth, provided outlying values were omitted in some seasons (Fig. 24).

Table 14. Macronutrient content of leaves sampled end January/ beginning of February from the middle of current year shoots of full bearing Wonderful pomegranate trees in different Western Cape production areas. Nitrogen (N), phosphate (P), potassium (K), calsium (Ca) and magnesium (Mg) are indicated. Symbols in columns indicate whether nutrient concentrations are deficient (D), low (L), high (H), very high (V) or toxic (T).

Season	Production area	Orchard	N	P	K	Ca	Mg
					%		
2017/18	Bonnievale	MS SaClLm R	2.42V	0.20V	0.81D	1.85	0.37
		MS LmSa/SaLm R	2.27V	0.22V	0.74D	1.52	0.40V
		2LD SaLm R	1.68D	0.17	0.57D	1.22	0.53V
	Gouda/Porterville	2LD Sa+Net	1.08D	0.15	0.85D	1.31	0.38
		2LD Sa	1.74	0.13D	0.73D	1.31	0.57V
	Wolseley	1LD Sa+Net	0.44D	0.19V	0.84D	1.14	0.24D
	Wellington	1LD SaLm/SaClLm/Cl RR	1.87	0.12D	0.67D	1.25	0.32
		2LD LmSa	1.76	0.12D	0.85D	1.28	0.26D
		2LD LmSa R	1.69D	0.13D	0.84D	1.36	0.37
2018/19	Bonnievale	MS SaClLm R	2.19V	0.20V	1.07	2.38	0.41V
		MS LmSa/SaLm R	2.02V	0.19V	1.21V	1.63	0.43V
		2LD SaLm R	1.96V	0.22V	1.01	1.57	0.56V
	Gouda/Porterville	2LD Sa+Net	1.81	0.17	1.13	1.75	0.44V
		2LD Sa	2.01V	0.18V	1.24V	1.43	0.51V
	Wolseley	1LD Sa+Net	1.24D	0.29V	1.33V	1.81	0.35
	Wellington	1LD SaLm/SaClLm/Cl RR	1.64D	0.15	0.97	1.61	0.32
		2LD LmSa*	1.60D	0.12D	0.95	1.95	0.32
		2LD LmSa R	1.51D	0.13D	1.07	1.61	0.41V
		Norm: Low	***1.7***	***0.14***	***0.9***	***1***	***0.3***
		Norm: High	***1.9***	***0.18***	***1.2***	***2.5***	***0.4***

Table 15. Micronutrient content of leaves sampled end January/ beginning of February from the middle of current year shoots of full bearing Wonderful pomegranate trees in different Western Cape production areas. Sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and Boron (B) are indicated. Symbols in columns indicate whether nutrient concentrations are deficient (D), low (L), high (H), very high (V) or toxic (T).

Season	Production area	Orchard	Na	Mn	Fe	Cu	Zn	B
							mg kg^{-1}	
2017/18	Bonnievale	MS SaClLm R	111	40T	148	721T	16D	14D
		MS LmSa/SaLm R	106	32	162	625T	12D	13D
		2LD SaLm R	69	132T	149	487T	21D	12D
	Gouda/Porterville	2LD Sa+Net	89	72T	185	136T	71H	15D
		2LD Sa	66	58T	130	104T	74H	15D
	Wolseley/Worcester	1LD Sa+Net	57	47T	109	7D	11D	13D
	Wellington	1LD SaLm/SaClLm/Cl RR	108	43T	111	86H	13D	13D
		2LD LmSa	66	119T	130	12	18D	15D
		2LD LmSa R	84	37	119	102T	18D	16D
2018/19	Bonnievale	S SaClLm	52	43T	246	446T	16D	20D
		S LmSa/SaLm R	125	36	155	436T	11D	19D
		2LD SaLm R	139	117T	219	410T	34L	20D
	Gouda/Porterville	2LD Sa+Net	83	93T	190	95H	22D	21D
		2LD Sa	142	79T	173	90H	52H	23D
	Wolseley/Worcester	1LD Sa+Net	110	39	214	9L	24D	29L
	Wellington	1LD SaLm/SaClLm/Cl RR	164	50T	223	262T	13D	18D
		2LD LmSa*	58	35	136	79H	20D	18D
		2LD LmSa R	60	46T	161	60H	31L	20D
		Norm: Low	***0***	***20***	***45***	***9***	***30***	***25***
		Norm: High	***300***	***40***	***150***	***20***	***35***	***35***

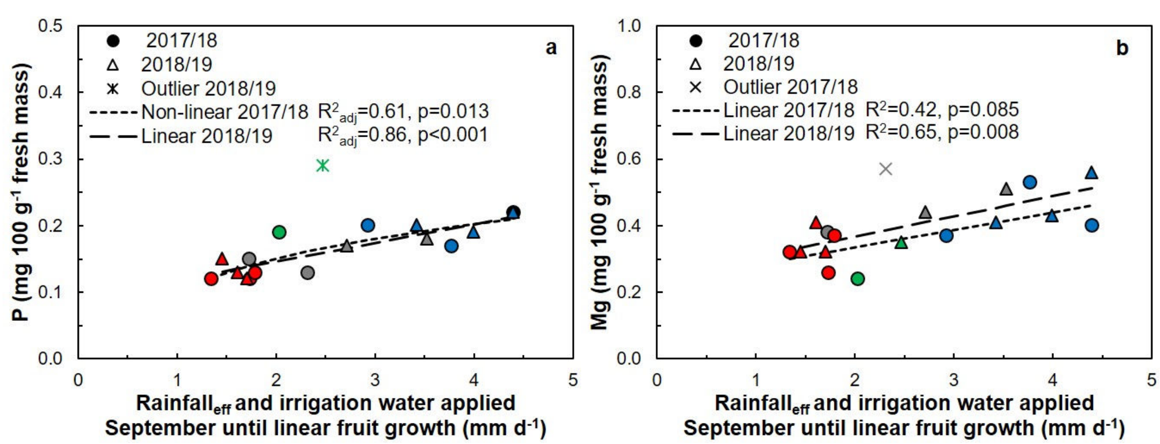

Fig. 24. The effect of effective rainfall and irrigation applied until linear fruit growth on the a) phosphate (P) and b) magnesium (Mg) content of Wonderful pomegranate leaves in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas during the 2017/18 and 2018/19 seasons.

3.6.6 Yield

In 2017/18, orchards were harvested from 19 March until 5 April 2018. Total yield for the 2017/18 season varied between 20 kg per tree (21.9 t ha^{-1}) and 145 kg per tree (60.3 t ha^{-1}) (Table 16). The highest yield (Bonnievale microsprinkler irrigated sandy clayloam ridged orchard) was c. 63% more than the lowest (Wellington double line drip irrigated ridged loamy sand orchard). Total yield for the level Wellington double line drip irrigated sandy loam orchard was not available since the second commercial harvest was completed without notification. Data of this orchard are omitted from comparisons between areas, soils and irrigation systems. The harvesting norms differed between farms and the mass of fruit harvested during the first harvest varied between 18% and 86% of the total, except for Wolseley which harvested once-off. The Bonnievale area on average had the highest yield (59.4 t ha^{-1}), with 35 t ha^{-1}, 26.4 t ha^{-1} and 22.9 t ha^{-1} for the Gouda, Wellington and Wolseley production areas, respectively. Yield for Bonnievale was therefore 41%, 56% and 62% higher than in Gouda, Wellington and Wolseley. Total yield on the heavier soils (sandy clay loam, sandy loam) was 52.3 t ha^{-1}, i.e. 45% higher compared to that from the lighter soils (sand and loamy sand). Yield of microsprinkler irrigated orchards was on average 59.7 t ha^{-1}, 43% higher than that of the drip irrigated orchards on average. In Gouda, the orchard below net realised 50% of the yield of the orchard without net. In 2018/19, orchards were harvested from 13 March until 9 April 2019. Between 1 and 3 harvests occurred, depending on orchard (Table 16). Total yield for the 2018/19 season varied between 15 kg per tree (14.2 t ha^{-1}) and 162 kg per tree (67.7 t ha^{-1}). The highest yield occurred once more in the Bonnievale microsprinkler irrigated sandy clayloam ridged orchard and was c. 79% more than the lowest (Wolseley single line drip irrigated sandy soil orchard below net).

Table 16. Yield (±standard deviation or SD) per tree and per hectare of full bearing pomegranate orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 and 2018/19 seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Production area	Orchard ID	Harvest	Yield (kg/tree)				Yield (t/ha)			
			2017/18		2018/19		2017/18		2018/19	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Bonnievale	MS SaClLm R	1	124	22.9	64.6	22.5	51.7	9.6	26.9	9.4
		2	21	14.8	97.7	21.8	8.6	6.2	40.7	9.1
		Total	**145**	**12.9**	**162.4**	**12.7**	**60.3**	**5.4**	**67.7**	**5.3**
	MS LmSa/SaLm R	1	70	29.5	56.5	10.7	29.1	12.3	23.6	4.5
		2	72	28.5	74.4	22.5	29.9	11.9	31.0	9.4
		Total	**142**	**33.2**	**131.0**	**30.6**	**59.0**	**13.8**	**54.6**	**12.8**
	2LD SaLm R	1	11	3.9	32.2	12.7	10.8	3.9	13.4	5.3
		2	48	4.8	27.1	8.4	48.1	4.8	11.3	3.5
		Total	**59**	**5.9**	**59.3**	**11.5**	**58.9**	**5.9**	**59.3**	**11.5**
Gouda	2LD Sa+Net	1	17	2.4	12.7	1.3	13.7	1.9	10.1	1.1
		2	12	4.3	21.4	7.7	9.6	3.4	17.1	6.1
		Total	**29**	**4.9**	**34.1**	**7.8**	**23.2**	**3.9**	**27.3**	**6.2**
	2LD Sa	1	26	5.4	14.6	5.0	20.6	4.3	11.7	4.0
		2	33	16.1	21.5	4.2	26.2	12.9	17.2	3.3
		3	-	-	25.6	19.7	-	-	20.5	15.8
		Total	**58**	**14.3**	**61.7**	**18.0**	**46.7**	**11.5**	**49.3**	**14.4**
Wolseley	1LD Sa+Net	**Total**	**25**	**7.0**	**15.3**	**5.2**	**22.9**	**6.5**	**14.2**	**4.8**
Wellington	1LD SaLm/SaClLm/Cl RR	1	19	12.3	14.2	7.1	11.0	7.0	8.1	4.1
		2	35	7.7	9.6	4.2	19.9	4.4	5.5	2.4
		3	-	-	4.6	3.1	-	-	2.6	1.8
		Total	**54**	**14.0**	**28.4**	**11.9**	**30.9**	**8.0**	**16.2**	**6.8**
	2LD LmSa	1	16	6.1	28.4	4.6	17.4	6.8	31.6	5.1
		2	n.a.	n.a.	2.7	1.4	n.a.	n.a.	3.0	1.5
		Total	**n.a.**	**n.a.**	**31.2**	**5.6**	**n.a.**	**n.a.**	**34.6**	**6.3**
	2LD LmSa R	1	14	4.3	17.1	8.1	15.5	4.8	19.1	9.0
		2	6	1.1	10.5	2.0	6.5	1.3	11.7	2.3
		Total	**20**	**5.0**	**27.7**	**7.3**	**21.9**	**5.6**	**30.8**	**8.1**

The Bonnievale area on average had also for the second season the highest yield (60.5 t ha^{-1}), followed by Gouda (38 t ha^{-1}), Wellington (27.2 t ha^{-1}) and Wolseley (14.2 t ha^{-1}). The yield in Bonnievale was therefore 37%, 55% and 77% higher compared to Gouda, Wellington and Wolseley. Total yield on the sandy clay loam and sandy loam soils was 49.5 t ha^{-1}, i.e. 28% higher compared to that from the loamy sand and sandy soils. Yield of microsprinkler irrigated orchards was on average 61.2 t ha^{-1}, 46% higher than that of the drip irrigated orchards on average. In Gouda, the orchard below net realised 55% of the yield of the orchard without net. The high total yield at the Bonnievale sandy clayloam orchard in both the 2017/18 and 2018/19 seasons was a combination of a high number of fruit per tree (444 and 423) with an average weight of c. 0.328 and 0.385 kg per fruit, respectively (Table 17).

Table 17. The average (±standard deviation) fruit number per tree and fruit weight of full bearing Wonderful pomegranate orchards in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 and 2018/19 seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Production area	Orchard ID	Harvest	Fruit number (n)				Fruit weight (kg)			
			2017/18		2018/19		2017/18		2018/19	
			Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Bonnievale	MS SaClLm R	1	371	89.0	164	58.4	0.338	0.017	0.394	0.019
		2	73	44.5	259	67.7	0.266	0.035	0.380	0.023
		Total	**444**	**62.8**	**423**	**47.5**	**0.328**	**0.015**	**0.385**	**0.021**
	MS LmSa/SaLm R	1	195	87.0	141	37.3	0.362	0.028	0.407	0.042
		2	220	94.2	213	81.6	0.332	0.031	0.362	0.043
		Total	**415**	**119.4**	**354**	**114.3**	**0.347**	**0.030**	**0.380**	**0.043**
	2LD SaLm R	1	33	16.6	81	40.6	0.351	0.050	0.419	0.050
		2	151	17.9	83	17.2	0.319	0.023	0.338	0.065
		Total	**184**	**28.3**	**164**	**50.5**	**0.323**	**0.026**	**0.378**	**0.049**
Gouda	2LD Sa+Net	1	58	4.4	32	6.2	0.294	0.021	0.391	0.048
		2	60	23.6	61	20.1	0.201	0.025	0.350	0.056
		Total	**118**	**29.1**	**93**	**22.4**	**0.249**	**0.027**	**0.365**	**0.050**
	2LD Sa	1	71	13.8	37	13.7	0.360	0.012	0.404	0.024
		2	113	51.3	47	11.5	0.285	0.015	0.458	0.039
		3	-	-	76	55.0	-	-	0.327	0.027
		Total	**185**	**46.0**	**160**	**53.6**	**0.316**	**0.004**	**0.393**	**0.033**
Wolseley	1LD Sa+Net	**Total**	**77**	**25.9**	**46**	**18.3**	**0.324**	**0.027**	**0.338**	**0.031**
Wellington	1LD SaLm/SaClLm/Cl RR	1	55	33.5	31	15.4	0.338	0.024	0.464	0.062
		2	149	33.8	25	9.1	0.235	0.005	0.390	0.058
		3	-	-	16	11.1	-	-	0.270	0.031
		Total	**204**	**45.5**	**68**	**30.4**	**0.265**	**0.021**	**0.404**	**0.047**
	2LD LmSa	1	71	29.8	97	13.2	0.225	0.022	0.295	0.030
		2	n.a.	n.a.	15	5.3	n.a.	n.a.	0.183	0.026
		Total	**n.a.**	**n.a.**	**112**	**17.1**	**n.a.**	**n.a.**	**0.281**	**0.025**
	2LD LmSa R	1	69	30.5	42	21.9	0.211	0.024	0.412	0.025
		2	33	6.8	43	9.7	0.177	0.015	0.251	0.031
		Total	**102**	**35.9**	**85**	**21.0**	**0.198**	**0.018**	**0.328**	**0.030**

In 2017/18 the poor yield of the Wellington double line drip irrigated ridged loamy sand orchard was due to less fruit per tree and smaller fruit (c. 0.2 kg), whereas in the case of Wolseley, low fruit number dictated total yield (Tables 16 & 17). In 2018/19 Wolseley had the lowest yield and

40% less fruit than in 2017/18, although the fruit was slightly larger compared to the previous season. The low yield for the single line drip irrigated orchard in Wellington in 2018/19 may be related to the heavy pruning the trees were subjected to during winter, and the first season of training on a trellis system.

In 2017/18 the Bonnievale orchards had 56% more fruit than Gouda and Wellington, and 78% more fruit than Wolseley (Table 17). Trees on heavier soils had 61% more fruit per tree compared to those on lighter soils, while micro-irrigated orchards bore 66% more fruit per tree than drip irrigated orchards (Fig. 25a). In Gouda, the orchard below net had c. 36% less fruit than the orchard without net. Fruit losses due to false codling moth (FCM) in the orchard were not quantified, but c. 64% of fruit of trees below net was infested with FCM compared to c. 27% in the orchard without net. Less severe FCM infestations occurred in the single line drip irrigated orchards in Wellington (6%) and Wolseley (2.9%). In 2018/19, the Bonnievale orchards had 60% more fruit than Gouda, 64% more fruit than Wolseley and 72% more than Wellington (Table 17). The orchards having clay and sandy loam soils had 61% more fruit compared to the orchards with loamy sand and sandy soils. The microirrigated orchards had 73% more fruit than the drip irrigated orchards (Fig. 25a). In Gouda, the orchard below net had c. 42% less fruit than the orchard without net with no fruit classed as FCM infested for the second season.

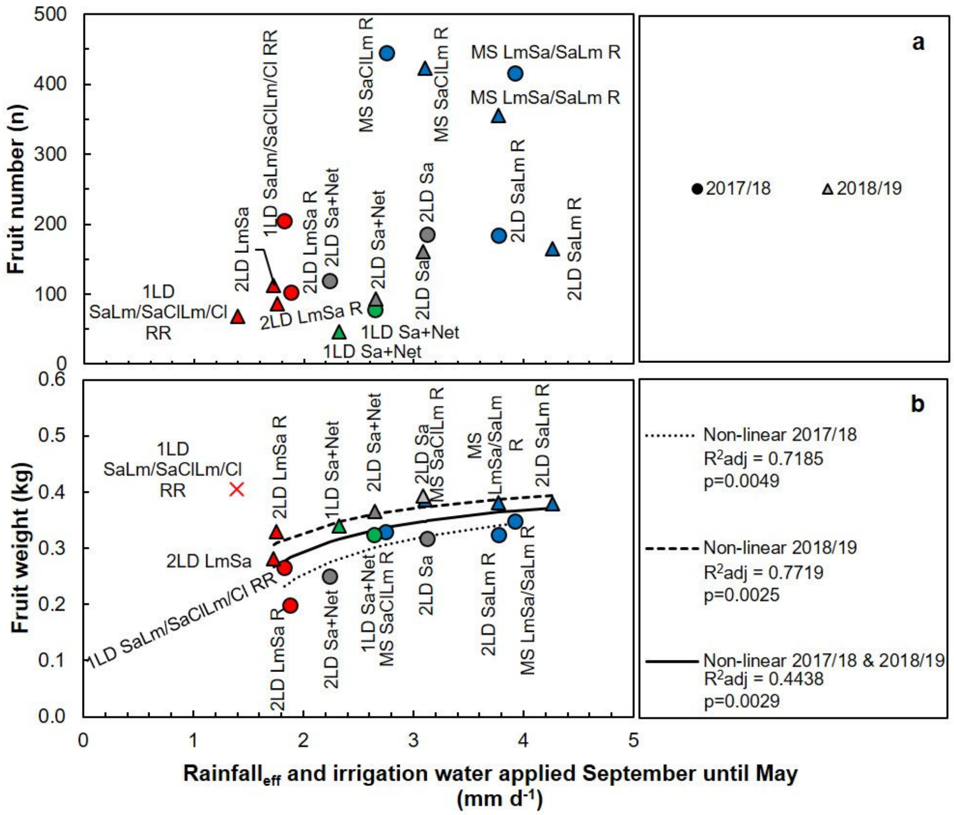

Fig. 25. The relationship between(a) fruit number per tree and (b) mean fruit weight of full bearing Wonderful pomegranate orchards in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green markers) and Wellington (red markers) production areas and the amount of effective rainfall (Rainfall$_{eff}$) and irrigation water applied from 1 September until end May during the 2017/18 and 2018/19 seasons. Data for 2018/19 for the single line drip irrigated orchard from Wellington was considered an outlier (X).

In 2017/18 the Bonnievale area had on average the heaviest fruit (c. 315 g), with that in Gouda, Wolseley and Wellington weighing 15%, 3% and 30% less (Table 17). Fruit weight from trees on heavier soils was c. 14% more than on the lighter soils, while fruit weight of micro-irrigated trees was c. 17% more than those of drip irrigated orchards. In Gouda, the fruit from below the net weighed on average 21% less than those from the orchard without net. In 2018/19, fruit from Bonnievale and Gouda was of similar weight (c. 380 g), whereas those from Wolseley and Wellington weighed c. 11% less. Fruit weight from trees on heavier soils was c. 12% more than on the lighter soils, while fruit weight of micro-irrigated trees was c. 7% more than those of drip irrigated orchards. In Gouda, the fruit from below the net weighed on average 7% less than those from the orchard without net.

Mean fruit weight and yield tended to increase with the amount effective rainfall and irrigation water applied from 1 September until end May during the both seasons (Figs. 25b & 26). Mean fruit weight was based on measured individual fruit weight. There was no clear trend with regard to fruit number and the amount of water applied from beginning of September until end May (Fig. 25a).

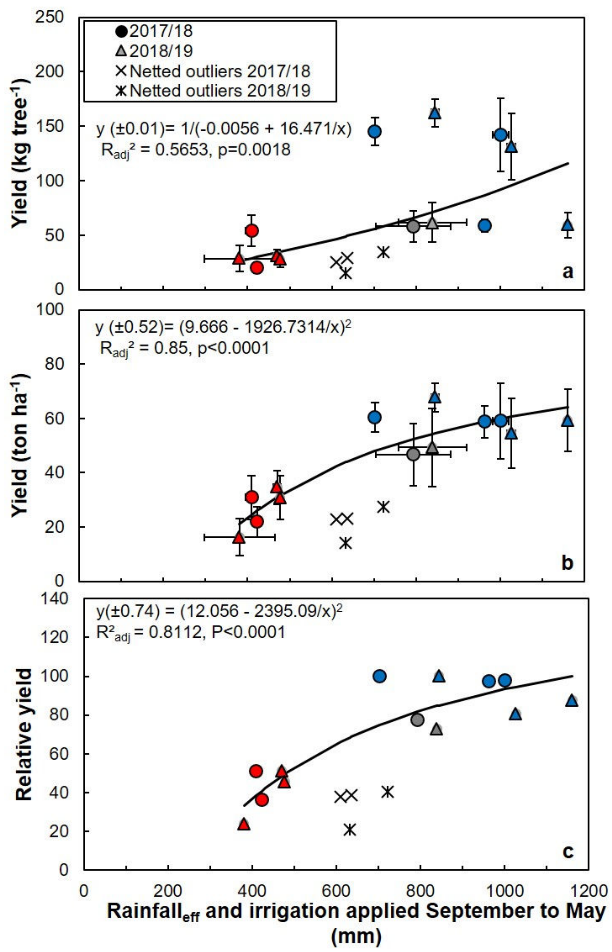

Fig. 26. The relationship between yield (±standard error) per tree (a), per hectare (b) and relative yield (c) of full bearing Wonderful pomegranate orchards in the Bonnievale (blue markers), Gouda (grey markers) and Wellington (red markers) production areas and the amount of effective rainfall (Rainfall$_{eff}$) and irrigation water applied from 1 September until end May during the 2017/18 and 2018/19 seasons. Mathematical models are based on data of both seasons and netted orchards were omitted as outlying values.

A relatively poor mathematical fit was obtained for the relationship between yield per tree and the effective rainfall and irrigation since the microsprinkler irrigated orchards had yield of between 131 and 164 kg per tree, whereas the drip irrigated orchards yielded only 61.7 kg per tree or less (Fig. 26a). Yield per hectare and relative yield though increased non-linearly with more effective rainfall and irrigation applied if data from netted orchards were considered as outlying values (Fig. 26b & c). Based on the mathematical relationship between relative yield and effective rainfall and irrigation (Fig. 26c) it is estimated that 1165 mm of water is needed from September until end May to obtain maximum yield.

3.6.7 Fruit quality

3.6.7.1 Fruit physico-chemical analysis

Fruit dimensions and moisture content

Fruit weight, length and diameter increased linearly or non-linearly with irrigation rate until harvest albeit with different trends for the two seasons, or for data of both seasons combined (Fig. 27a-c). An exception is fruit diameter, for which there was no significant trend with irrigation rate until harvest for the 2018/19 season (Fig. 27c). Fruit peel moisture content increased non-linearly with higher rates of irrigation applied until harvest for fruit from both seasons, with a linear trend for data of the two seasons combined (Fig. 27d).

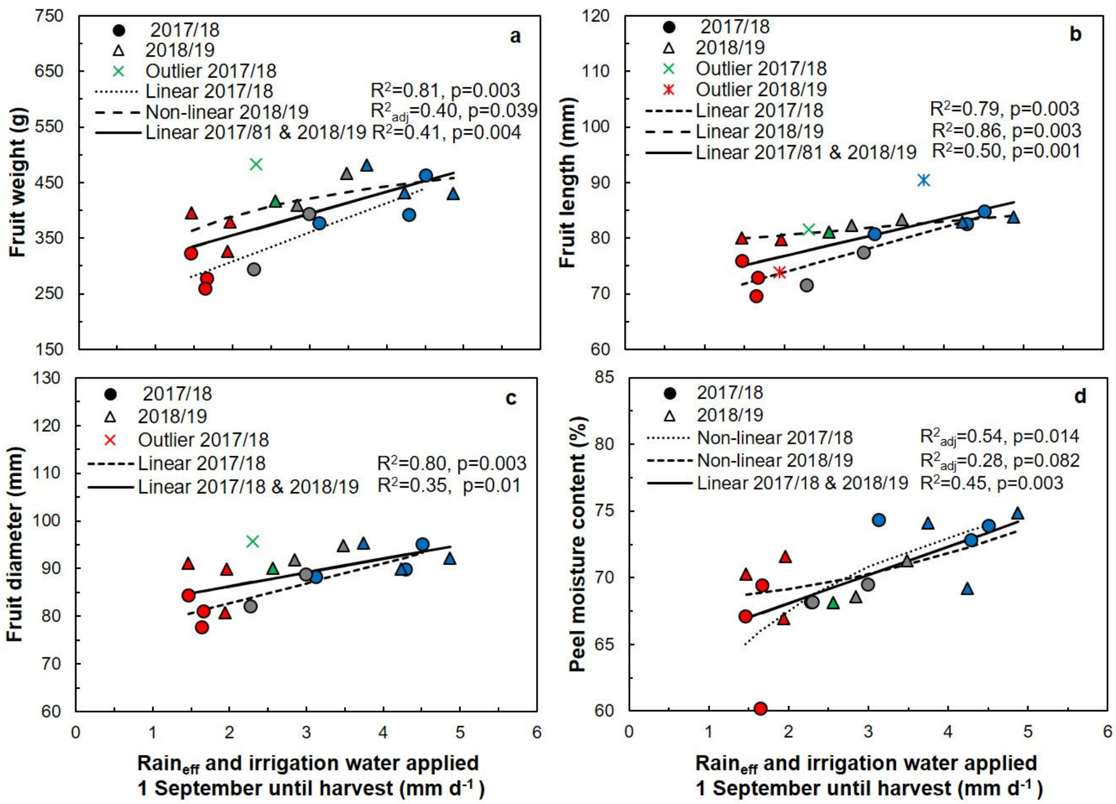

Fig. 27. Pomegranate (cv. Wonderful) fruit weight (a), length (b) and diameter (c) as well as peel moisture content of fruit on average for all harvests vs effective rainfall and irrigation water applied until harvest in the 2017/18 and 2018/19 seasons. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas.

There was no clear trend with regard to peel thickness (range 4.2 mm to 6.6 mm) and rate of effective rainfall and irrigation applied until harvest during both seasons (data not shown). Fruit firmness increased non-linearly and linearly in 2017/18 and 2018/19, respectively, provided some data was omitted as outliers (Fig. 28). Outlying data points were statistically identified as the netted orchards in Wolseley and Gouda for 2017/18 and the level double line drip irrigated loamy sand orchard in Wellington for both seasons. Aril weight of the 2017/18 season increased non-linearly with increased irrigation rate until harvest, with no significant relationship for fruit of the second season (Fig. 29a). Data of the netted orchard at Gouda was identified as an outlying value. Aril moisture content of fruit of the first season increased non-linearly with increased irrigation rate until harvest, with no significant trend for the second season (Fig. 29b).

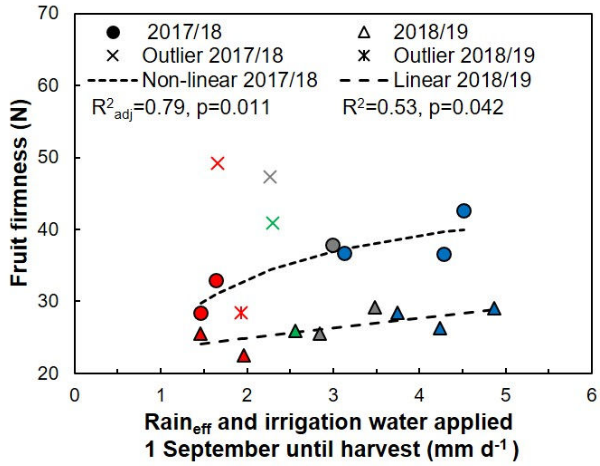

Fig. 28. Pomegranate (cv. Wonderful) fruit firmness vs effective rainfall and irrigation water applied until harvest in the 2017/18 and 2018/19 seasons. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas.

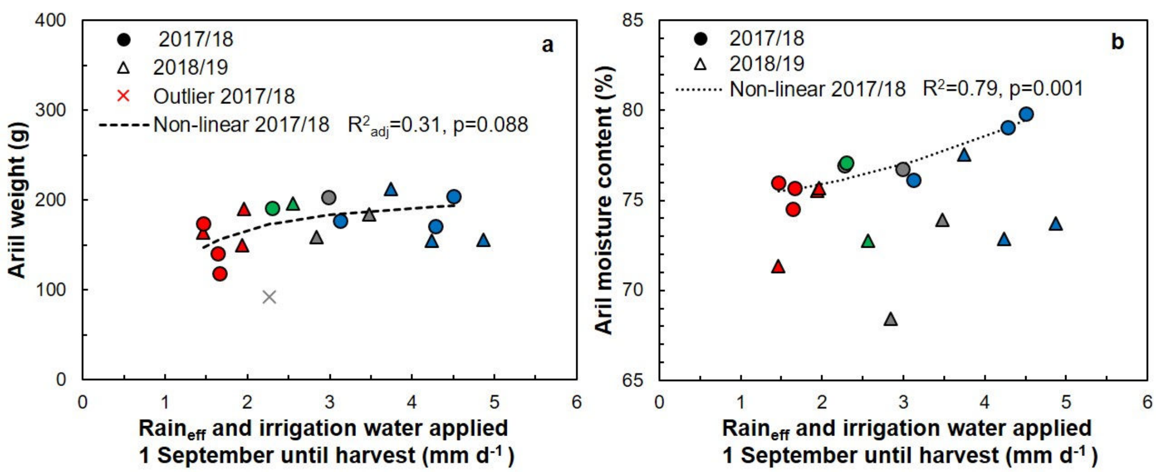

Fig. 29. Pomegranate (cv. Wonderful) aril weight (a) and aril moisture content (b) of fruit on average for all harvests in the 2017/18 and 2018/19 seasons. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas.

Fruit colour

With regard to fruit peel colour measured with a chromameter, lightness (L*) and hue° tended to increase non-linearly in the first season with higher rates of effective rainfall and irrigation applied, with no significant trend for the second season (Fig. 30a & c). For data of both seasons combined, hue° also increased non-linearly as rates of effective rainfall and irrigation increased, whereas no significant trend was found for lightness due to divergent data patterns in the two seasons. Red colouration (a*) decreased with increased rate of effective rainfall and irrigation in both seasons and for the combined data set (Fig. 30b). Chroma tended to decrease with a higher rate of effective rainfall and irrigation applied in the first season, with no significant trend for the second season or the combined dataset of both seasons.

Data for fruit from the double line drip irrigated orchard in Bonnievale was identified statistically as outliers for all variables in the first season, and in the case of red colouration, in the second also. These values were excluded from the mathematical relationships between fruit colour parameters and the rate of effective rainfall and irrigation applied until harvest discussed above. Specific production practice information such as canopy manipulation and fertilizer application for the different orchards that also can affect fruit colouration were not considered in this report and it has to be taken into account that the maturity samples contained only twenty randomly sampled fruit per harvest. According to Galindo et al. (2017), L* and Hue° values of pomegranate peel tended to decrease with accumulated water stress, while a* and C* values increased, resulting in fruit peel with higher redness and darkness values. Likewise, the significant trends in our survey which were mostly confined to the first season with critical drought, indicated a decrease in L* and Hue° and an increase a* and C* with lower rates of effective rainfall and irrigation applied (Fig. 30a-d).

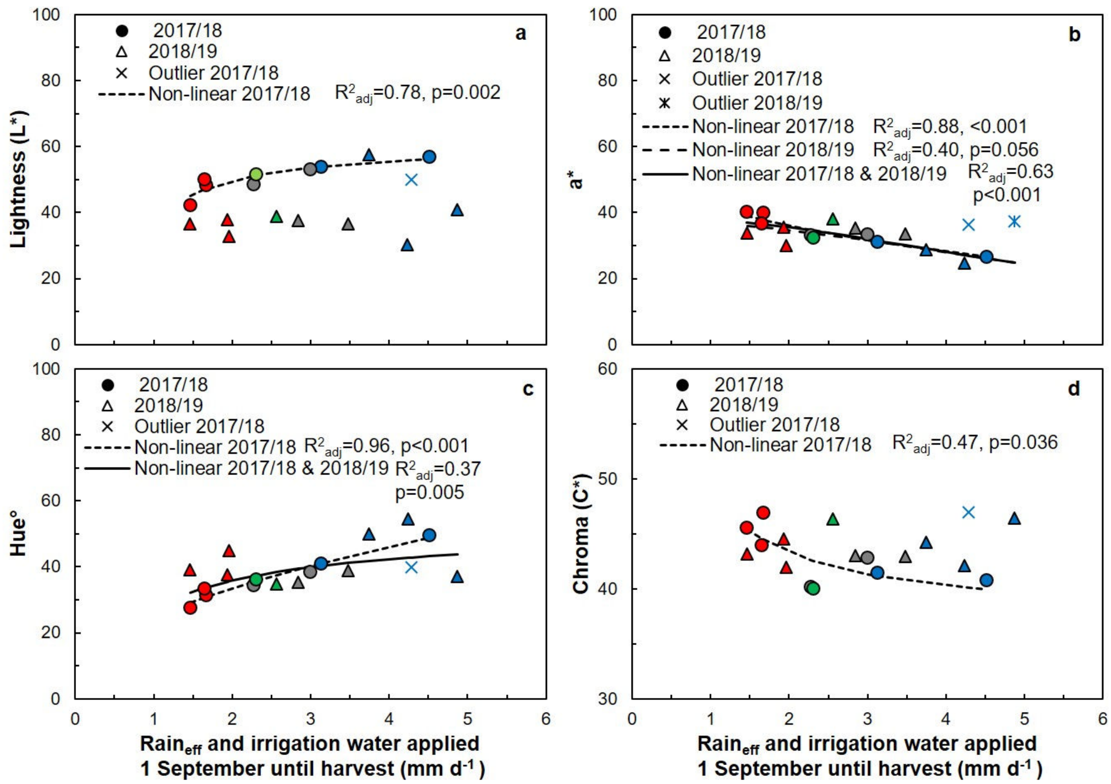

Fig. 30. Pomegranate (cv. Wonderful) fruit skin lightness, red colour or a* (b), hue (c) and chroma (d) of fruit from the 2017/18 and 2018/19 season. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas. Values represent the average of all harvests.

The percentage of fruit with dark red coloured arils varied between 42 and 97% in 2017/18, and between 50 and 100% in 2018/19 (Fig. 31a & b). On average for production regions in 2017/18, Bonnievale had the largest amount of fruit with dark red colour (c. 95% of fruit), followed by Wolseley (c.85%), Gouda (76%) and Wellington (70%). In 2018/19 though the average was comparable for Bonnievale and Gouda (c. 84%), followed by Wellington (73%) and the least fruit with good aril colour from Wolseley (50%). The microsprinkler irrigated sandy clay loam orchard from Bonnievale had in both seasons more than 97% of fruit with dark red coloured arils (97%), whereas 90% and 100% of fruit of the double line drip irrigated sandy loam orchard had sought after aril colour for the two respective seasons. Orchards producing the least fruit with good aril colour included in 2017/18 the Gouda double line drip irrigated sand below net and the Wellington ridged double line drip irrigated loamy sand (c. 68% of fruit) (Fig. 31a). In 2018/19 the single line drip irrigated orchard below net in Wolseley and the microsprinkler irrigated loamy sand/sandy loam orchard in Bonnievale had the least fruit with dark red aril colour (Fig. 31b).

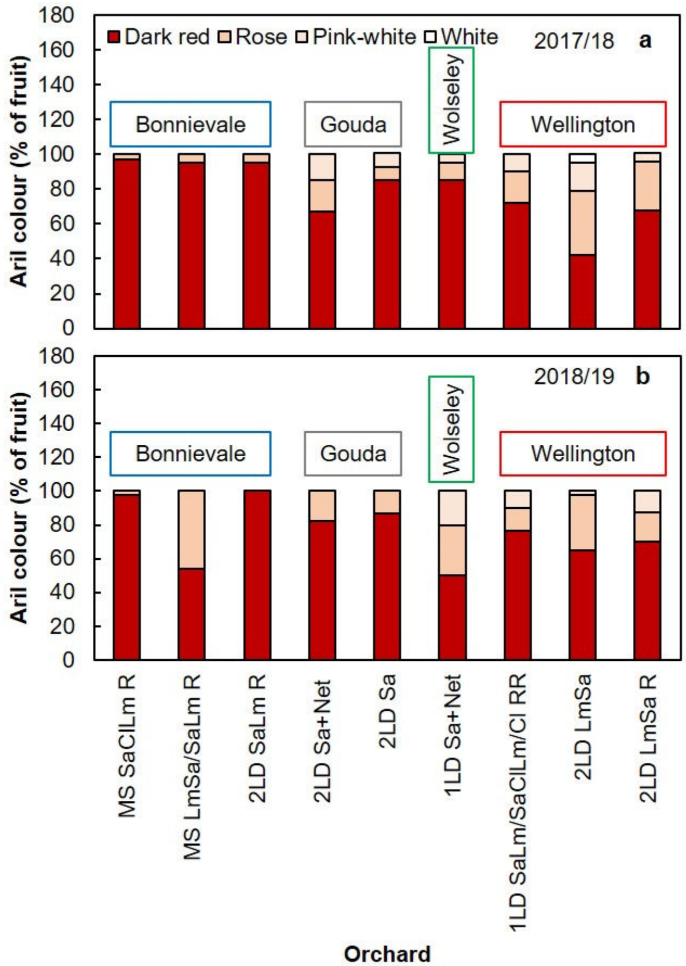

Fig. 31. Pomegranate (cv. Wonderful) aril colour during the 2017/18 (a) and 2018/19 (b) seasons. Data for the double line drip irrigated loamy sand orchard in Wellington for 2017/18 is for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

In 2017/18 about 96% of fruit from microsprinkler irrigated orchards had dark red arils compared to 79% of fruit from drip irrigated orchards, whereas the percentages were comparable in 2018/19. In the two respective seasons, of fruit produced on heavier soils 90% and 82% had dark red arils compared to 76% and 72% of fruit produced on lighter soils. In Gouda, the orchard below net had in 2017/18 21% less fruit with dark red arils compared to the orchard without net, with only a 5% difference between orchards in the second season. In both seasons the percentage of fruit with dark red arils tended to become higher and those with rose coloured arils less with increased rate of effective rainfall and irrigation until harvest (Fig. 32a & b). Data for the microsprinkler irrigated loamy sand/ sandy loam ridged orchard in Bonnievale in 2018/19 was statistically identified as an outlier and omitted from the mathematical relationships established. The high percentage of fruit having dark red arils for the Bonnievale area compared to Wellington may therefore partially be explained by the higher rate of effective rainfall and irrigation applied.

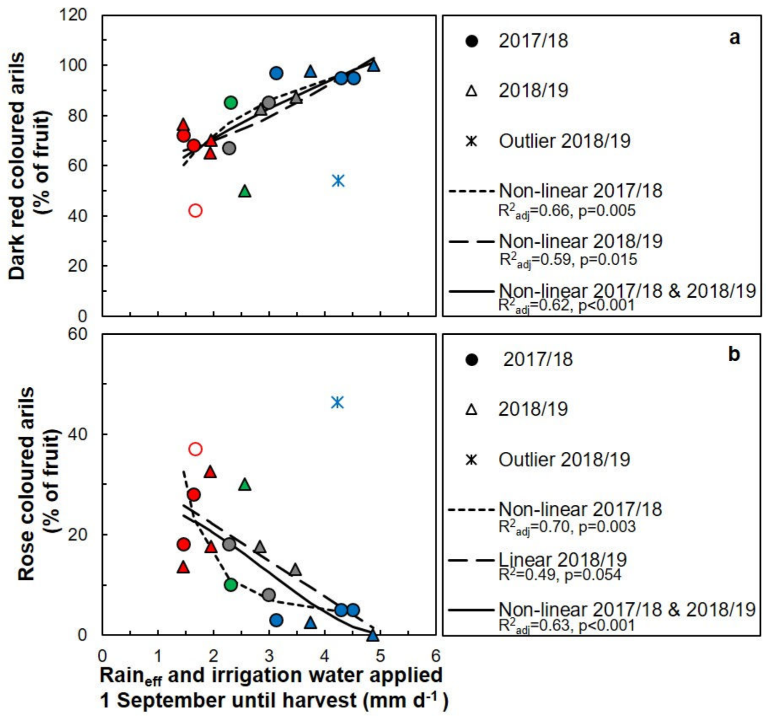

Fig. 32. The effect of rate of effective rainfall and irrigation until harvest on the percentage fruit with a) dark red and b) rose coloured arils during the 2017/18 and 2018/19 seasons. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas. Data indicated by non-filled red markers are for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Total soluble solids, total titratable acidity and pH

The ripeness of all fruit harvested during both seasons conformed to the minimum ripeness requirements for export of the Department of Agriculture, Forestry and Fisheries (14 °Brix) and more stringent requirements of some export companies (16 °Brix) (Fig. 30a).The pomegranate mean (±standard error) total soluble solids (TSS) for 2017/18 ranged between 16.4(±0.05) °Brix and 19.3(±0.27) °Brix, which was comparable to values of between 15.8(±0.05) °Brix and 18.8(±0.32) °Brix for the 2018/19 season. The minimum total titratable acids (TA) in fruit juice was c. 25% lower in the second compared to the first season (0.74(±0.02) g 100 g^{-1}) with the maximum being similar (1.44(±0.14) g 100 g^{-1} malic acid). Juice pH for the two seasons was comparable and ranged between 2.1(±0.01) and 3.1(±0.11). These pH values are considerably lower than the pH of 4.9 reported for the ‘Mollar de Elche’ cultivar produced in Spain (Galindo et al. 2017). The maturity index (MI, ratio of TSS:TA) ranged between 11.4 and 25.5 in 2017/18 and between 11.9 and 30.1 in 2018/19.

With regard to production areas, in 2017/18 the TSS of pomegranate juice was the lowest in Bonnievale (c. 17.5 °Brix), Gouda and Wolseley (c. 17.8 °Brix), with Wellington juice having the highest sugar content (c. 18.7 °Brix). In 2018/19 the TSS of pomegranate juice was the lowest in Bonnievale and Wolseley (c. 17.1 °Brix) and Wellington (c. 17.3 °Brix), with Gouda juice having the highest sugar content (c. 18.2 °Brix). For the respective seasons microsprinkler irrigated orchards had lower pomegranate juice TSS (c. 17.4 and 16.9 °Brix) compared to that of drip irrigated orchards (c. 18.2 and c. 17.5 °Brix). Fruit juice from orchards on heavier soils also had lower sugar levels (c. 17.7 and c. 16.9 °Brix) than that from lighter soils (c. 18.2 and c. 17.9 °Brix). Pomegranate juice TA tended to increase, whereas the TSS, pH and MI decreased with increased rate of irrigation until harvest for the 2017/18 season and for data of both seasons combined (Fig. 33a-d)). However, in 2018/19 there were no significant statistical relationships between the maturity variables and the rate of effective rainfall and irrigation applied until harvest. The occurrence of rainfall during the harvest period in 2018/19 (Figs. 12 & 13) could possibly explain the lack of trends in the second season.

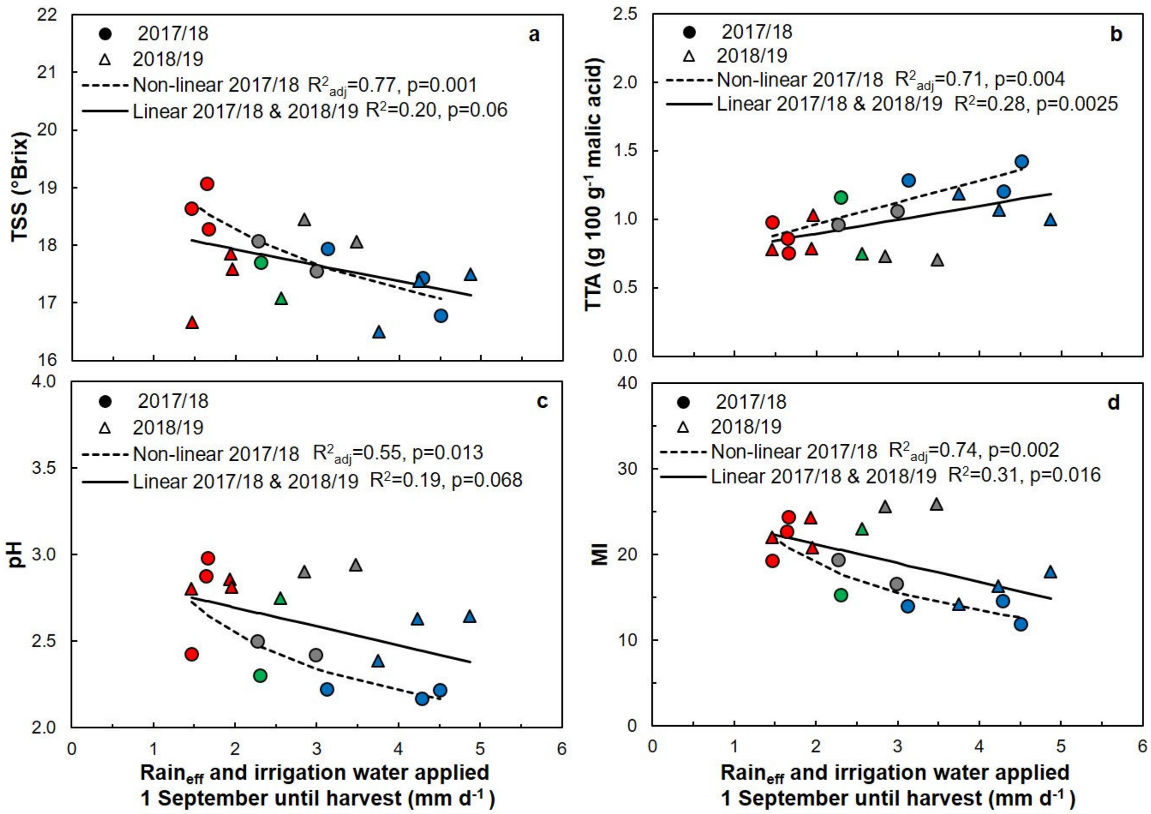

Fig. 33. The relationship between mean pomegranate (cv. Wonderful) juice a) total soluble solids (TSS), b) titratable acids (TA),c) pH and d) maturity index (MI), respectively, and effective rainfall and irrigation water applied until harvest during the 2017/18 and 2018/19 seasons. Fruit are from orchards harvested in the Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas. Data points are averages of all harvests per season.

3.6.7.2 Fruit mineral content

There were no noteworthy significant statistical relationships between macro- or micronutrients in the fruit (Table 18) and leaves (Tables 14 & 15) for either season or for the first season with soil sampled during August 2017 (data not shown). In 2017/18 fruit nitrogen, phosphate, potassium, calcium and magnesium content (mg 100 g^{-1} fresh mass) ranged between 185 to 321; 42 to 78; 261 to 429; 20 to 63 and 19 to 28, respectively. Fruit sodium, manganese, iron, copper, zinc and boron content (mg kg^{-1} fresh mass) varied between 22 and 97, 1.6 and 10.3, 4.2 and 68.9, 0.9 and 14.1, 2.3 and 21.6 and 3.3 and 17. In 2018/19 compared to 2017/18, the content ranges for fruit nitrogen and calcium were slightly higher and that for phosphate and

Table 18. Pomegranate (cv. Wonderful) macro- and micronutrient content of fruit harvested in 2018 in the Bonnievale, Gouda, Wolseley and Wellington production areas. Fruit nitrogen (N), phosphate (P), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), manganese (Mn), iron (Fe), copper (Cu), zinc (Zn) and boron (B) content are displayed. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Season	Production area	Orchard	Macronutrients					Micronutrients					
			N	P	K	Ca	Mg	Na	Mn	Fe	Cu	Zn	B
			(mg 100 g^{-1} fresh mass)					(mg kg^{-1} fresh mass)					
2017/18	Bonnievale	MS SaClLm R	277	73.5	358	27.2	24.2	62.6	9.8	68.9	14.1	21.6	15.3
		MS LmSa/SaLm R	289	73.3	308	23.5	27.8	29.2	3.8	9.7	2.4	4.6	6
		2LD SaLm R	321	73.4	301	25.4	27.4	30.2	6.8	10.2	3.2	5	4.4
	Gouda	2LD Sa+Net	291	47.0	324	41.2	20.8	51.1	2.5	5.3	0.9	2.5	3.3
		2LD Sa	288	42.0	334	36	22.6	46.3	1.9	4.2	1.1	2.3	5.2
	Wolseley	1LD Sa+Net	185	54.8	429	62.8	27.6	43.6	1.6	4.3	1	2.5	4.6
	Wellington	1LD SaLm/SaClLm/Cl RR	296	48.2	261	20.4	20	22	3.7	7.8	2.3	4.3	4.1
		2LD LmSa*	257	55.9	300	22.1	18.7	97	10.3	37.1	7.7	21.2	17
		2LD LmSa R	299	78.0	348	29.5	26.1	55.1	9.9	37.7	9.6	21.3	11.6
2018/19	Bonnievale	MS SaClLm R	248	44.94	404	61.4	23.5	62.6	9.8	68.9	14.1	21.6	15.3
		MS LmSa/SaLm R	368	37.54	348	29.3	17.1	42.2	1.5	12.7	2.0	2.5	3.5
		2LD SaLm R	204	52.80	99	60.7	25.1	38.2	1.8	6.1	1.2	3.0	5.2
	Gouda	2LD Sa+Net	266	64.00	100	59.1	25.6	44.1	2.4	6.7	1.4	3.1	4.1
		2LD Sa	286	48.71	91	50.6	30.5	47.1	2.4	6.9	1.3	3.1	5.0
	Wolseley	1LD Sa+Net	199	35.81	269	28.1	15.6	42.5	1.3	3.9	1.4	2.2	3.0
	Wellington	1LD SaLm/SaClLm/Cl RR	324	53.94	113	58.3	27.5	77.4	2.6	18.8	2.1	3.8	5.8
		2LD LmSa	256	37.42	91	59.8	22.4	40.6	2.0	35.4	1.2	2.8	5.4
		2LD LmSa R	226	43.07	115	75.4	30.5	39.7	2.0	39.1	1.4	3.2	6.2

potassium lower, with the range for magnesium remaining more or less the same. In 2018/19 the fruit sodium content range was between 38 and 77 mg kg^{-1} fresh mass, with that for the other micronutrients being similar to that of the previous season.

There was no significant effect of effective rainfall and irrigation that occurred until harvest on fruit nutrient content, except for magnesium in the 2017/18 season. Fruit magnesium content tended to increase non-linearly with a higher rate of effective rainfall and irrigation until harvest (data not shown, R^2=0.40, p=0.066). If two outlying values were omitted, the magnesium content of fruit increased linearly with effective rainfall and irrigation applied (data not shown R^2=0.96, p<0.001, n=7).

3.6.7.3 External and internal physiological disorders

In 2017/18 scuffmarks were most prevalent for the Bonnievale microsprinkler irrigated sandy clay loam orchard (68% of fruit) and the Gouda double line drip irrigated orchard on sand without net (60% of fruit), and the least in the single line drip irrigated orchard below net in Wolseley (5%) (Fig. 34a). The Bonnievale, Gouda and Wellington production areas had on average 52%, 42% and 34% fruit with scuffmarks. Microsprinkler irrigated orchards had almost double (58%) the percentage of fruit with scuffmarks compared to drip irrigated orchards (33%), while orchards on heavier soils produced 47% fruit with scuff marks compared to 31% on lighter soils. In Gouda the orchard below net had 23% fruit with scuffmarks, compared to 60% in the orchard without net.

In 2018/19 the prevalence of scuffmarks in all orchards on average was about a third compared to the 40% of fruit for 2017/18 (Fig. 34a & b). It was once again most prevalent in the Bonnievale microsprinkler irrigated sandy clay loam orchard, but the occurrence was less than half that of the previous season (33% of fruit). The least scuffmarks occurred in the double line drip irrigated orchard in Gouda below net (3%), which was 10% less compared to the orchard without net. For the other orchards fruit having scuffmarks amounted to 15% or less of the total. The Bonnievale, Gouda, Wolseley and Wellington production areas had on average 18%, 8%, 10% and 11% fruit with scuffmarks. Microsprinkler irrigated orchards had 19% fruit with scuffmarks compared to 11% for drip irrigated orchards, while orchards on heavier soils produced 17% fruit with scuff marks compared to 8% on lighter soils.

Russeting occurred in 2017/18 and in 2018/19 on average for all orchards on 42% and 37% of fruit, respectively (Fig. 34c & d). The occurrence in orchards ranged on between 10% and 73% of fruit in 2017/18, and between 8% and 58% in 2018/19. Russeting appeared to be more severe in the second season, since on average for all orchards 35%, 43% and 21% of the fruit had slight, moderate and severe russeting in 2017/18 compared to 6%, 16% and 78%, respectively, in 2018/19. In 2017/18, *a* more or less similar trend was found for russeting as for scuffmarks, since the same orchards that had the highest and lowest scuffmarks were scored as having the highest russeting, although the single line drip irrigated orchard in Wellington had more russeting (55%) than scuffmarks (Fig. 34c). On average for the Bonnievale, Gouda, Wellington and Wolseley production regions russeting occurred on 58%, 50%, 41% and 10% of fruit. Microsprinkler irrigated orchards had 46% more fruit with russeting compared to drip irrigated orchards, and orchards on heavier soils 65% more than those on lighter soils. In Gouda the orchard below net had about half the percentage of fruit with russeting compared to the orchard without net. In 2018/19, on average for the Bonnievale, Gouda, Wellington and Wolseley production regions russeting occurred on 22%, 50%, 46% and 40% of fruit. In contrast with the previous season microsprinkler irrigated orchards had 31% less fruit with russeting compared to drip irrigated orchards (45%), and orchards on heavier soils 14% less than those on lighter soils. In Gouda the orchard below net had 16% more russeting compared to the orchard without net, whereas it was less compared to the open in the previous season.

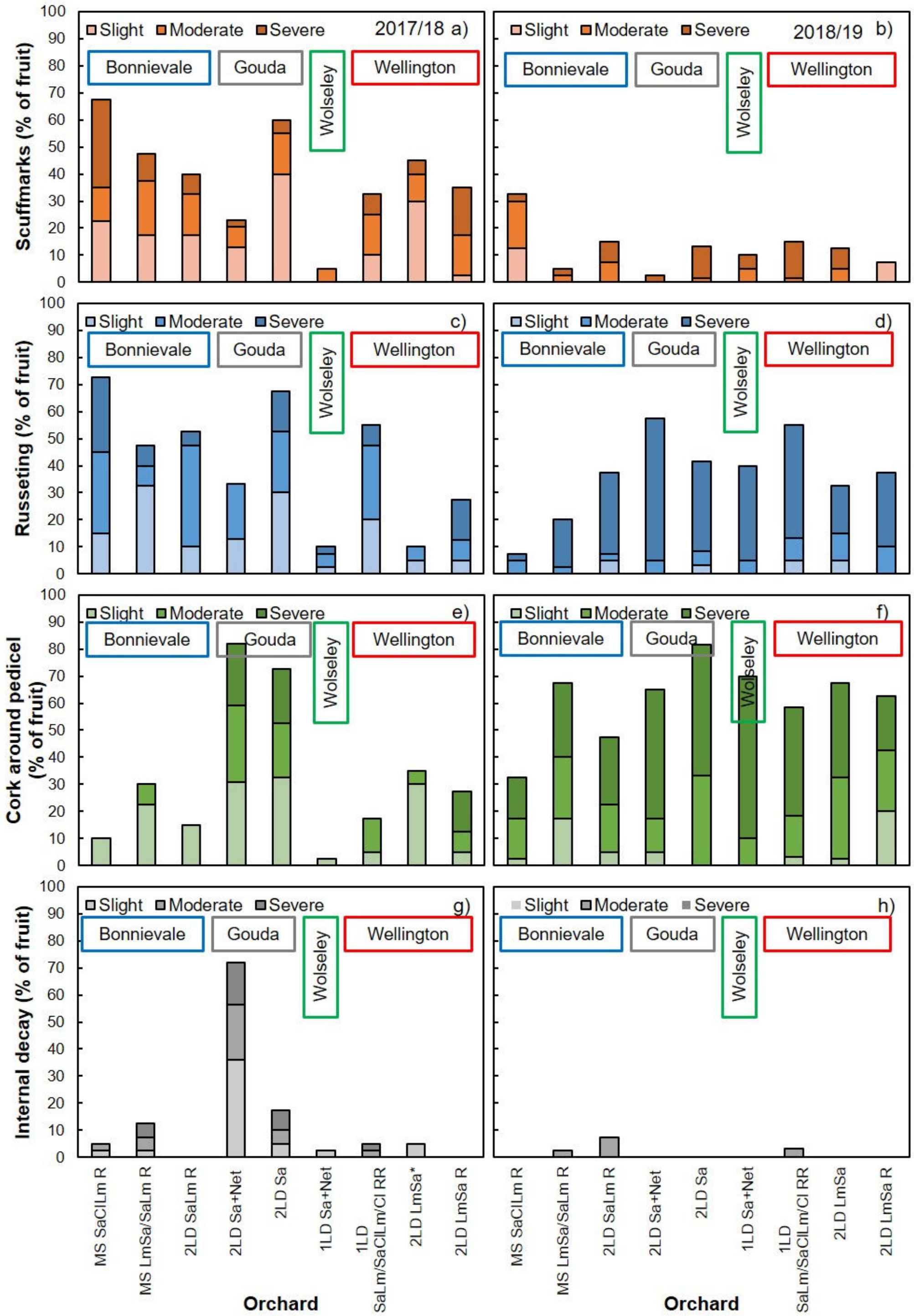

Fig. 34. External and internal physiological disorders of pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 (a, c, e, g) and 2018/19 (b, d, f, h) seasons. Data for the orchard marked with an asterisk is for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

In 2017/18 cork around the pedicel (Fig. 34e) was clearly a problem in the Gouda production area (77% of fruit), whereas in 2018/19 the problem appeared to be more widespread between orchards (Fig. 34f). Cork around the pedicel occurred in 2017/18 and in 2018/19 on average for all orchards on 32% and 61% of fruit, respectively. The occurrence in orchards ranged between

3% and 82% of fruit in 2017/18, and between 33% and 82% in 2018/19. Cork around the pedicel also appeared to be more severe in the second season, since on average for all orchards 52%, 28% and 20% of the fruit had slight, moderate and severe degrees of cork around the pedicel in 2017/18 compared to 10%, 32% and 58%, respectively, in 2018/19. The Bonnievale, Gouda, Wolseley and Wellington production areas, respectively, had in 2017/18 on average 18%, 77%, 3% and 23% fruit with cork around the pedicel, and in 2018/19, 49%, 73%,70% and 60%.

Microsprinkler irrigated fruit had in 2017/18 c. 20% fruit having cork around the pedicel compared to 36% irrigated by drip systems, and 21% and 40%, respectively in 2018/19. In both seasons the disorder tended to be less on heavier soils (18% and 27% of fruit) compared to lighter soils (46% and 44% of fruit). In Gouda, the orchard below net had in 2017/18 13% more fruit with cork around the pedicel than the orchard without net, and in 2018/19, 17% less.

Orchards had in 2017/18, except for those in Gouda and the microsprinkler irrigated sandy loam/ loamy sand orchard in Bonnievale, 5% or less fruit with internal decay (Fig. 34g) and in 2018/19 less than 8% (Fig. 34h). In 2017/18 about 40% of the sampled fruit from the Gouda orchard below net was FCM infested, and 72% of all fruit had internal decay, compared to 18% of the orchard without net, and 12% in the Bonnievale orchard mentioned above. The Gouda orchard below net is also the only one in which cracks in the fruit skin was reported (c. 5% of fruit), and it was also only for the 2017/18 season, with no occurrence in 2018/19 in any orchards. There were no significant trends between the physiological disorders discussed above and the rate of effective rainfall and irrigation applied until harvest for both seasons (data not shown).

3.6.7.4 Marketability

Based on individual fruit weight of all nine orchards combined, c. 88% of fruit were eligible for export (i.e. >180 g) for the 2017/18 season (n=8995), and c. 93% for 2018/19 (n=7524). According to colour classification using the POMASA fruit colour chart, 19.7% and 7.3% of fruit were Extra class (Photo 1 and 2), c. 63.5% and 60.3% Class 1 (Photo 3 to 6) and c. 16.8% and 32.4% destined for processing (Photo 7 to 9) in the two respective seasons. In both seasons about 69% of fruit did not have sunburn, (Class 1), c. 12% light and dark brown (Processing) and c. 6% black (Fallout) coloured sunburn, whereas fruit had in the 2018/19 season slightly more light brown sunburn (c. 16%) compared to in 2017/18 (c. 11%). The degree of sunburn was fairly similar for the two seasons and occurred on less than 10% of the surface (Class 1) for about 15% of fruit and on more than 10% of the fruit surface (Processing) for c. 14% fruit. Cracking in 2017/18 and 2018/19, respectively, was limited to c. 4.7% and 1.8% of fruit having cracks up to the integument, and c. 7% and c. 2% of fruit having cracks reaching the arils. With regard to blemishes for the two respective seasons c. 37% and 33% of fruit were Extra class (no blemishes), c. 37% and 35% Class 1 (blemishes on less than or equal to 10% of the fruit surface), c. 14% and 18% Processing (blemishes on more than 10%, but less than or equal to 25% of the fruit surface) and c. 12% and 14% Fallout (blemishes on more than 25% of fruit surface).

Please note that for the 2017/18 seasons means of variables for production areas, microsprinkler vs drip irrigated and heavier vs light soils exclude data of the level double line drip irrigated orchard in Wellington. Harvest data were not complete and quality data in graphs depicts only the first harvest. Heavier soils refer to soils including sandy clay loam, sandy loam or clay in their classification, whereas lighter soils refer to loamy sand and sand.

Individual fruit weight

Based on individual fruit weight, more than 85% of fruit from 6 of the 9 orchards were suitable for export (i.e. weighed >180 g) in 2017/18, whereas in 2018/19 more than 83% of fruit from all orchards qualified for export (Fig. 35a & b). The exceptions in 2017/18 were the microsprinkler irrigated ridged sandy clay loam orchard of Bonnievale, and the level and ridged double line drip

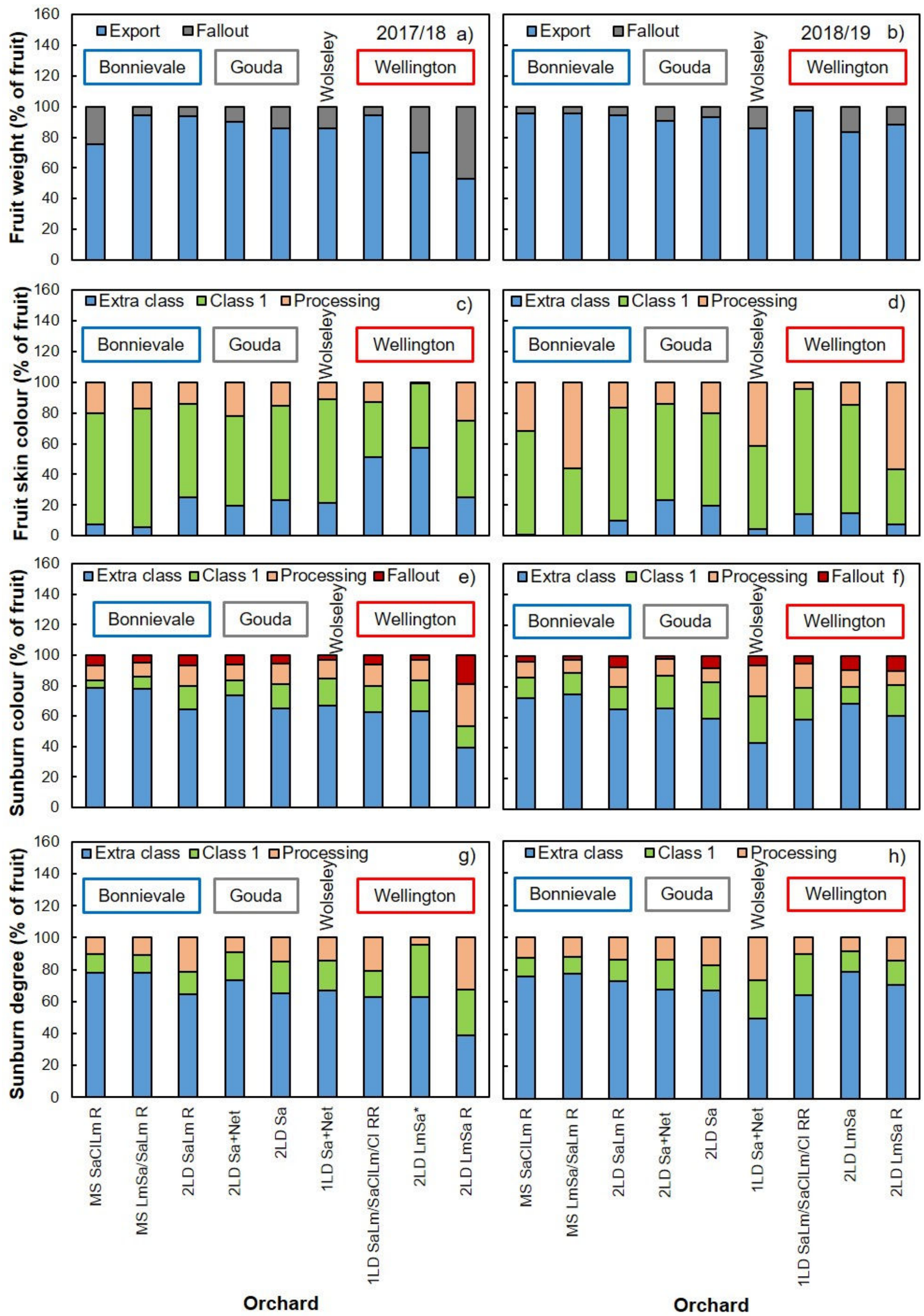

Fig. 35. Fruit marketability classification (Extra class, Class 1, Processing and Fallout) for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 (a, c, e, g) and 2018/19 (b, d, f, h) seasons for individual fruit weight (a, b), fruit skin colour (c, d), sunburn colour (e, f) and sunburn degree (g, h). Data for the orchard marked with an asterisk is for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

irrigated loamy sand orchards of Wellington, of which c. 76%, c. 70% and c. 53% of fruit, respectively, were eligible for export (Fig. 35a). With regard to the different production areas, c. 88% of Bonnievale and Gouda fruit, c. 86% of Wolseley fruit and c. 74% of Wellington fruit were suitable for export based on individual fruit weight of more than 180 g in 2017/18. In 2018/19 more fruit of Bonnievale,(c. 95%) Gouda (c. 92%) and Wellington (c. 90%) passed the export standard, whereas the situation remained similar for Wolseley. Although there was no real difference in the percentage exportable fruit based on fruit weight between microirrigated and drip irrigated orchards in 2017/18, the former had 5% more fruit for export in 2018/19 than the latter. Of fruit produced in the respective seasons on heavier soils (sand clay loam, sandy loam) c. 89% and 95% qualified for export compared to 79% and 88% on lighter (sand, loamy sand) soils. At Gouda, the orchard below net had in 2017/18 c. 4% more fruit that qualified for export than the open orchard, and in 2018/19, 2% less.

Fruit skin colour

According to skin color, the microsprinkler irrigated orchards in Bonnievale had in both seasons the least fruit (< c. 8% and <c. 1%, respectively) suitable for extra class (Photo 1 and 2 on POMASA fruit colour chart, Fig. 35c & d). In 2017/18 about half of the fruit of the Wellington single line drip irrigated sandy loam/ sandy clay loam/ clay ripped ridge orchard had excellent colour, but in 2018/19, the first season trees had been trained on a trellis system, it decreased to 14% of fruit (Fig. 28b). For this orchard though 87% and 96% of fruit was in the first and second season, respectively, either extra class or class 1 (Fig.32d). The saline irrigation water used in this orchard (Table 4) may have improved fruit colour. Borochov-Neori et al. (2014) found that pomegranate (cv. Wonderful) peel anthocyanin accumulation increased as irrigation water salinity increased from 100 mSm^{-1} to 600 $mS\ m^{-1}$. The high percentage extra class fruit for the level Wellington sandy loam orchard (c. 57%) reflect fruit quality only of the first harvest in 2017/18 (Fig. 35c). For the other orchards about a quarter (c. 23%) of fruit were suitable for extra class in the first season. In 2018/19 the Gouda orchards had on average 22% extra class fruit, with the drip irrigated orchards in Bonnievale, Wolseley and Wellington having less than 15%.

In 2017/18 the microsprinkler irrigated orchards in Bonnievale had, based on colour, between 72% and 77% Class 1 fruit, followed by the single line drip irrigated sandy soil orchard below net in Wolseley (c. 68%) (Fig. 35c). The drip irrigated orchards in Bonnievale and Gouda had on average c. 60% Class 1 fruit, and the single line drip irrigated orchard on sandy loam/ sandy clay loam/ clay in Wellington, c. 36%. The Wellington ridged double line drip irrigated loamy sand orchard, which was subjected to severe water deficits (refer Table 13), had c. 50% Class 1 fruit and the most fruit for processing due to poor colour development (i.e. c. 25%). In 2018/19, the Wellington single line drip irrigated sandy loam/ sandy clay loam/ clay ripped ridge orchard had the most Class 1 fruit (81%), followed by the Bonnievale drip irrigated sandy loam (74%) and the level double line drip irrigated loamy sand orchard in Wellington (71%) (Fig. 35d). The microsprinkler irrigated sandy clay loam orchard of Bonnievale had 68% Class 1 fruit, compared to 44% for trees on the loamy sand/ sandy loam. The Gouda orchard below net had 63% Class 1 fruit compared to 60% for the open orchard. Both the Wolseley and the double line drip irrigated ridged loamy sand orchard in Wellington had 14% less Class 1 fruit compared to the previous season. More than half of the fruit (56%) from the latter orchard and the microsprinkler irrigated loamy sand/ sandy loam orchard in Bonnievale was suitable only for processing due to poor colour development. Shoot growth rate of the loamy sand/ sandy loam orchard in Bonnievale was of the highest in 2018/19 and dense canopies may partially explain poor colour development. However, this was not the case for the Wellington orchard (Fig. 15b). In Gouda in 2017/18, the orchard below net had, based on colour, c. 4% less extra class, c. 2% less Class 1 and c. 6% more fruit destined for processing compared to the orchard without net (Fig. 35c). In 2018/19, the orchard below net had c. 3% more extra class (23%) and Class 1 (63%) fruit, respectively, and c. 6% less fruit destined for processing compared to the orchard without net (Fig. 35d).

With regard to the different production areas in the 2017/18 and 2018/19 seasons, c. 13% and 4% of Bonnievale fruit, c. 21% and 22% of Gouda fruit, 21% and 4% of Wolseley fruit and c.

38% and 12% of Wellington fruit had Extra Class colour, with c.70% and 60%, 60% and 61%, c.68% and 54%, and 43% and 63% of fruit in the respective areas being Class 1. In 2017/18 the Wolseley orchard, even though it was below net, had the least poorly coloured fruit (c. 11%), with Bonnievale, having c. 17% and Gouda and Wellington c. 19% of fruit destined for processing based on colour. In contrast to the previous season Wolseley had in 2018/19 the most fruit destined for processing based on colour (41%), followed by Bonnievale (34%), Wellington (25%) and Gouda (17%). In 2017/18 the majority of fruit from the microirrigated orchards was Class 1 (c. 75%), with a mere c. 6% Extra class fruit. In 2018/19 though only 56% was Class 1, with less than 1% Extra class fruit. Fruit from drip irrigated orchards appeared to have better colour as c. 28% and 13% of fruit was Extra class and c. 56% and 63% of fruit Class 1 in 2017/18 and 2018/19, respectively. There was on average for fruit from heavier and lighter soils, respectively, in 2017/18 no meaningful difference in colour classification. However, in 2018/19 heavier soils had 10% more Class 1 fruit (67%) and 8% less Extra class fruit (6%) compared to fruit from the lighter soils, with no real difference in the amount of fruit destined for processing (on average c. 28%).

Sunburn colour

Sunburn per orchard varied between c. 22% and 61% of harvested fruit in the 2017/18 season, and between 25% and 57% in 2018/19. In 2017/18 the microirrigated orchards in Bonnievale and the double line drip irrigated sandy soil orchard below net at Gouda had the least sunburnt fruit (c. 22% and c. 27%, respectively), with between c. 5% and 10% of fruit having light brown (Class 1) and c. 10% light and dark brown sunburn (Processing) (Fig. 35e). The percentage of sunburnt fruit in the other drip irrigated orchards ranged between 33 and 37%, except for the ridged double line drip irrigated loamy sand orchard in Wellington, which had c. 61 % of fruit with various degrees of sunburn.

In 2018/19 the microirrigated orchards in Bonnievale once again had the least sunburnt fruit (on average c. 26%) with between c. 14% of fruit having light brown (Class 1), c. 10% light and dark brown sunburn (Processing) and 3% black (Fallout) (Fig. 35f). The drip irrigated orchard in Bonnievale had 35% of sunburnt fruit, of which c. 14% of fruit had light brown (Class 1), c. 12% light and dark brown sunburn (Processing) and 8% black (Fallout). The double line drip irrigated sandy soil orchards at Gouda below net and in the open had 34% and 41% sunburnt fruit, respectively. The orchard in the open had 6% more black sunburn fruit than the one below net (2%). The Wellington ridged double line drip irrigated level and ridged loamy sand orchards as well as the single line drip irrigated sandy loam/ sandy clay loam/ clay ripped ridge orchard had 31%, 39% and 41% of sunburnt fruit, respectively. The amount of black sunburn in the loamy sand orchards amounted to c. 10%, and in the single line drip irrigated orchard to 5%. Wolseley had the highest amount of sunburnt fruit which increased by 24% compared to the previous season (33%), with 30% being light brown, 20% light and dark brown and 7% black.

The percentage light brown sunburnt fruit in the orchards ranged between 14.5% and c. 18%, in the first, and between 11% and 30% in the second season. In the 2017/18 season the amount of light and dark brown sunburnt fruit was between c. 12% and 14%, except for the ridged double line drip irrigated loamy sand orchard in Wellington, which had about double the amount of fruit for processing (c. 28%). It is most likely that severe water deficits in the latter orchard (refer Table 13) contributed to the c. 19% of fruit with unacceptable levels of sunburn (i.e black) compared to between c. 3% and c. 6% in the other orchards. In 2018/19 the amount of light and dark brown sunburnt fruit ranged between 9% and 12%, except for the single line drip irrigated orchards in Wellington and Wolseley, where it reached 16% and 20% respectively.

The percentage sunburnt fruit at harvest increased with lower (i.e. more negative) shoot xylem water potential during fruit growth stage, provided two outlying values were omitted from statistical analysis in 2018/19 (Fig. 36). Further research is needed to confirm the effect of tree water status on amount of fruit having sunburn at harvest. Although there was large variation, the total percentage of fruit with sunburn decreased with increased rate of effective rainfall and irrigation between fruit growth stage and harvest (Fig. 37).

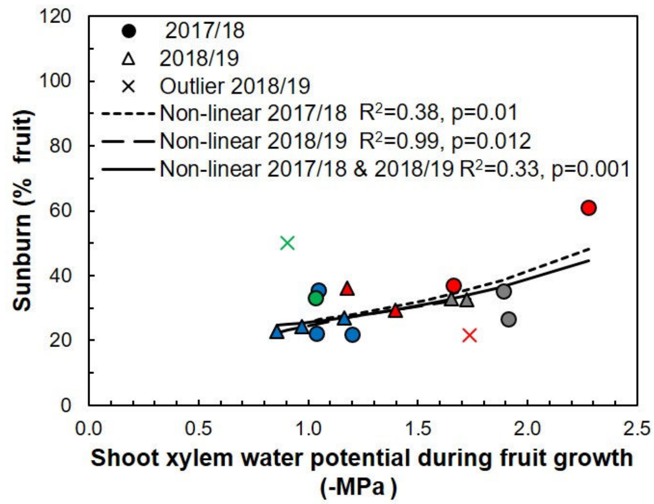

Fig.36. The relationship between the percentage sunburnt fruit at harvest and shoot xylem water potential of pomegranate trees (cv. Wonderful) measured during fruit growth stage in 2017/18 and 2018/19. The Bonnievale (blue markers), Gouda (grey marker) and Wellington (red markers) production areas are indicated. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

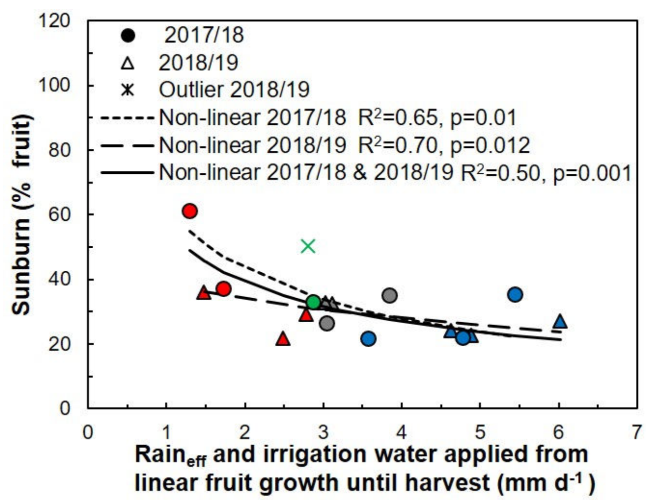

Fig. 37. The relationship between percentage sunburnt fruit of pomegranate (cv. Wonderful) trees at harvest and the rate of effective rainfall and irrigation during linear fruit growth until harvest of the 2017/18 and 2018/19 seasons. The Bonnievale (blue markers), Gouda (grey markers), Wolseley (green marker) and Wellington (red markers) production areas are indicated. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

With regard to the different production areas, in 2017/18 and 2018/19 on average c. 26% and 29% of Bonnievale, 31% and 38% of Gouda, c. 33% and 57% of Wolseley and c. 49% and 37% of Wellington fruit had some sunburn. In the respective areas and seasons, c. 9% and 14%, 13% and 22%, 18% and 30% and 16% and 17% of these fruit were light brown; whereas c. 11% for both seasons, c. 12% and 10%, c. 12% and 20% and c. 21% and 12% was light and dark brown. The percentage fallout (i.e. black) in 2017/18 and 2018/19, respectively, was the highest in Wellington (c. 12% and 8%), with that in Bonnievale and Gouda being 6% and 5% and in Wolseley 3% and 7%. Microsprinkler irrigated trees had 16% and 13% less sunburnt fruit than drip irrigated orchards in the two seasons. The microsprinkler irrigated orchards had 9% and 6%

less Class 1, 5% and 3% less Processing and 2% and 4% less Fallout than drip irrigated trees in the 2017/18 and 2018/19 seasons, respectively. Likewise had trees on heavier soils 10% and 8% less sunburnt fruit compared to those on lighter soils in the two respective seasons. The orchards having heavier soils had 3% and 6% less Class 1, 4% less or similar Processing and 3% and 2% less Fallout than orchards on lighter soils. The Gouda orchard with net in the 2017/18 and 2018/19 seasons, respectively, 9% and 7% less sunburnt fruit compared to the orchard without net. The orchard with net had 6% and 2% less Class 1, 4% less and 2% more Processing and 0.7% more and 6% less Fallout than the orchard without net.

Sunburn degree

In 2017/18, as in the case of sunburn colour, the microsprinkler irrigated orchards in Bonnievale had the lowest degree of sunburn, with almost similar amounts of fruit being Class 1 and Processing (c. 11%) (Fig. 35g). In the other orchards in 2017/18 the Class 1 degree sunburn and fruit having sunburn on more than 10% of the fruit surface (Processing) varied between c.14% and 21%, except for the orchard below net, which had only 9% fruit destined for processing due to sunburn. The other exception was the ridged double line drip irrigated loamy sand orchard in Wellington of which c. 29% of fruit had sunburn on less or equal to 10% of the fruit surface and c. 31% of fruit had sunburn on more than 10% of the fruit surface.

In 2018/19 the degree of sunburn were once again of the lowest in the Bonnievale microsprinkler irrigated orchards i.e. c. 23%, with c. 11% being Class 1 and 12% Processing. It was in the second season though the lowest in the Wellington level double line drip irrigated loamy sand orchard (22%), with 13% of fruit being class 1 and 9% suitable for processing. For the rest of the orchards the Class 1 degree sunburn ranged between c.13 and 26%, with fruit having sunburn on more than 10% of the fruit surface (Processing) varying between 10 and 17%. The total percentage of fruit having sunburn ranged between 27 and 36%. The single line drip irrigated orchard in Wolseley below net had the highest amount of fruit with sunburn, i.e. 50% of which 23% were Class 1 fruit and 27% of fruit destined for processing.

With regard to the different production areas in 2017/18 and 2018/19, c. 12% of Bonnievale, 19% and 17% of Gouda, c. 19% and 23% of Wolseley and c. 22% and 18% of Wellington fruit had sunburn on less than or equal to 10% of the fruit surface in the respective seasons. In 2017/18 the percentage fruit having sunburn on more than 10% of the surface ranged between c. 12% and c. 14% for the Bonnievale, Gouda and Wolseley areas, but increased to c. 27% in the Wellington area. In 2018/19 though fruit suitable for processing grade were 13%, 16%, 27% and 11% of the total in the respective areas. Microsprinkler compared to drip irrigated orchards had according to degree of sunburn in 2017/18 c. 8% less fruit destined for Class 1 and Processing, respectively. In 2018/19 microsprinkler irrigated orchards had 7% less Class 1 and 3% less fruit for processing than the drip irrigated orchards. In 2017/18 and 2018/19, respectively, orchards on heavier soils had 8% and 3% less Class 1 fruit and 2% and 4% less fruit for processing compared to orchards on lighter soils. In Gouda in the two respective seasons, the orchard below net had c. 3% less and 4% more fruit of Class 1, and c. 6% and 3% less fruit for Processing compared to the orchard without net.

Blemishes

Although blemishes are not a direct effect of applied irrigation water, blemishes may increase with excessive vegetative growth, which may occur under conditions of luxurious irrigation combined with the presence of wind. The percentage fruit with blemishes ranged for the two seasons from 45% to 79% between orchards (Fig. 38a & b). Orchards below net had the lowest percentage of blemishes in 2017/18 (c. 45%), but in 2018/19 the blemishes increased in the Wolseley orchard to 63% with that in Gouda being comparable to that of the first season.

In 2017/18 the orchards with the highest percentage of blemishes included the microsprinkler irrigated sandy clay loam orchard in Bonnievale and the ridged double line drip irrigated loamy sand orchard in Wellington Fig. 38a). Both these orchards had more than 40% Class 1 fruit (blemishes <10% fruit surface) and c. 17% of fruit unsuitable for export (blemishes > 25% fruit surface). In 2018/19 the microsprinkler irrigated sandy clay loam orchard in Bonnievale once again had the highest percentage of blemishes (73%) with 41% Class 1 fruit and 13% of fruit not suitable for export. The Gouda double line drip irrigated sandy soil orchard had 71% of fruit with blemishes of which 29% was Class 1 and 23% not suitable for export. For the rest of the orchards blemishes ranged between 64% and 68% of fruit with between 11% and 18% of fruit not suitable for export. The microirrigated orchards had in the 2017/18 and 2018/19 seasons 12% and 6% more blemishes than the drip irrigated orchards, with the orchards on heavy soils having a mere 4% and 7% more blemishes than orchards on lighter soils. In Gouda, the orchard below net had in the respective seasons 15 and 26% less fruit with blemishes than the orchard without net, of which c. 10% and 14% was attributed to less fallout.

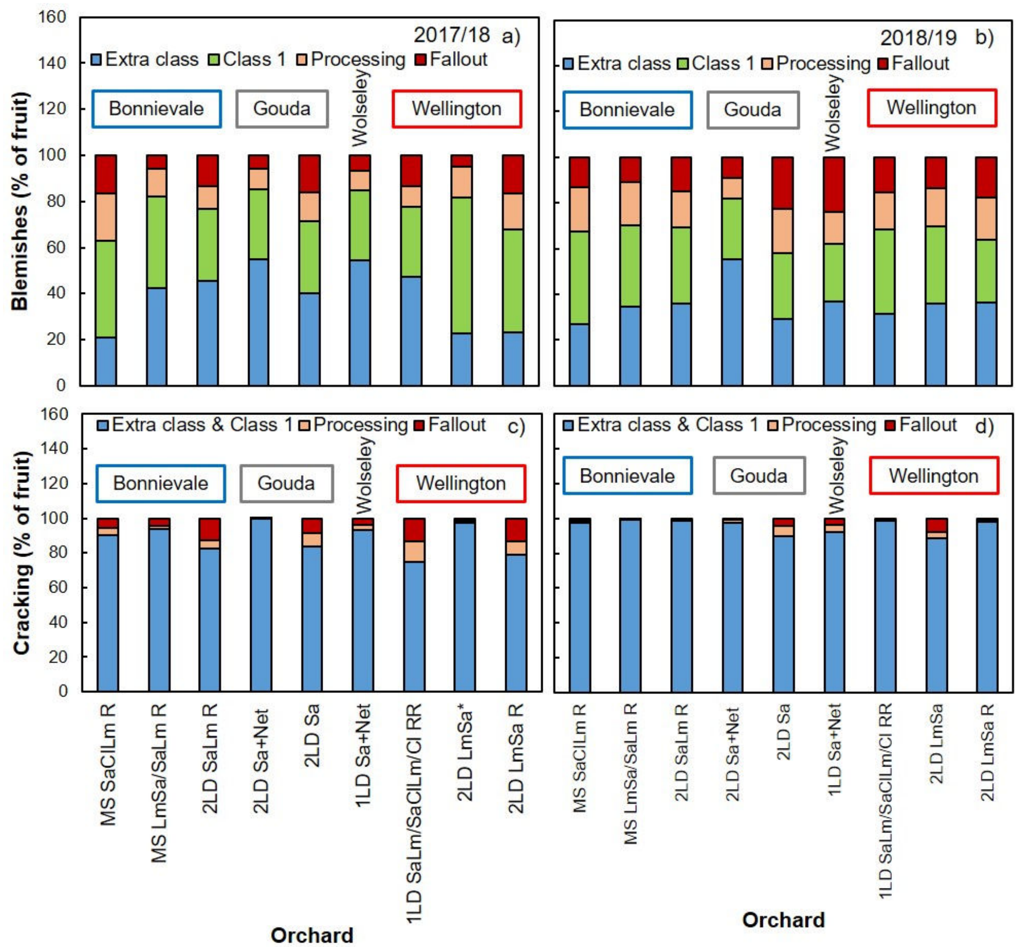

Fig. 38. Fruit marketability classification (Extra class, Class 1, Processing and Fallout) for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 (a, c) and 2018/19 (b, d) seasons for blemishes (a, b) and cracking (c, d) of fruit. Data for the orchard marked with an asterisk is for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

Cracking

The amount of cracking in orchards ranged in 2017/18 between less than 1% to c. 25%, and in 2018/19 between 1 and 12% (Fig. 38c & d). In 2017/18 orchards where cracking of fruit was the least included the microsprinkler irrigated orchards in Bonnievale (between c. 6% and c. 10% of fruit) and the orchards below net in Gouda (0.5% of fruit) and Wolseley (c. 6.5% of fruit). The percentage of fruit with cracks in the other orchards ranged between 16.5% and c. 25% (Fig. 38a). In 2018/19 though cracking was 3% or less in all orchards except for Wolseley (8%), the double line drip irrigated orchard at Gouda without net (10%) and the level double line drip irrigated orchard in Wellington (12%) (Fig. 38b). With regard to cracking of fruit in the different production areas in 2017/18 and 2018/19, Wolseley, Gouda, Bonnievale and Wellington had respectively c. 6% and 8%, c. 8% and 6%, c. 11% and 2% and c. 23% and 5% of cracked fruit in the respective seasons.

Microsprinkler compared to drip irrigated orchards had on average c. 7% less cracked fruit, with c. 3% less in Class 1 and c. 4% less fruit destined for processing. In 2018/19 the difference in cracking between microsprinkler and drip irrigated orchards was minor and amounted to only 3%. In 2017/18 orchards on heavier soils had c. 4% more cracked fruit than those on lighter soils, of which c. 3 % were processing class. In 2018/19 though orchards on heavier soils had 5% less cracked fruit than those on lighter soils, of which c. 2 % were processing class. In Gouda in 2017/18, the orchard below net had c. 16% less cracked fruit compared to without net, with equal amounts of fruit of the orchard without net destined for Processing and Fallout (c. 8%). In 2018/19 the orchard below net had 7% less cracked fruit than the orchard without net, with 6% and 4% of fruit from the open orchard suitable for Processing and Fallout.

Collective quality

Marketability of fruit taking collectively into account individual fruit weight, fruit skin colour, sunburn (colour and degree), degree of cracking and blemishes is depicted in Fig. 39. In 2017/18 the highest percentage of exportable fruit (c. 83%) came from the microsprinkler irrigated loamy sand/ sandy loam orchard in Bonnievale, compared to c. 23% exportable fruit in the Gouda double line drip irrigated sandy orchard. A very high percentage fallout from the latter orchard was due to false codling moth infestation. However, the low percentage exportable fruit in the ridged double line drip irrigated loamy sand orchard in Wellington (c. 38%) can most likely be attributed to the indirect effects of water deficits (Figs. 17a, 23a, 36) on individual fruit weight (Figs. 25b, 27a, 35a) and sunburn (Fig. 35e, 36, 37). In 2018/19 the same orchard from Bonnievale had the most fruit for export (84%), whereas the lowest export percentage was for the Wolseley orchard (63%). The latter orchard had the least Class 1 fruit (19%) and the most Fallout (37%), most likely to the effect of blemishes (Fig. 35b). The percentage fruit in Extra class was in general below 6% for all orchards in both seasons, except for the single line drip irrigated orchard in Wellington (12.7%), which had more favourable fruit colour in 2017/18 (Fig. 35c).

The percentage Class 1 fruit was in 2017/18 the highest in the Bonnievale microsprinkler irrigated loamy sand/ sandy loam (49.5%) orchard, followed by the single line drip irrigated orchard below net in Wolseley (47%) and the double line drip irrigated sandy loam orchard in Bonnievale (45.7%). For the other orchards the percentage Class 1 fruit ranged between c. 30% and c. 38%, except for the Gouda orchard below net (c. 13%) and the Wellington ridged double line drip irrigated loamy sand orchard (c. 17%). In 2018/19 the single line drip irrigated orchard in Wellington had the most Class 1 fruit (47%), followed closely by the double line drip irrigated orchards in Gouda below net (46%), Bonnievale (45%) and the level loamy sand orchard in Wellington (44%). The better performance of the single line drip irrigated orchard in Wellington is probably due to favourable fruit weight and colour (Fig. 35b &d). The microsprinkler irrigated orchards had 35% and 24% Class 1 fruit for the sandy clay loam and the loamy sand/ sandy loam orchards, respectively. The rest of the orchards had between 19% and 33% Class 1 fruit.

The percentage of fruit exported for processing ranged in 2017/18 between 18.3% and 22.2 %, except for the Bonnievale microsprinkler irrigated orchards which had c.32%, and the Gouda orchard below net (c. 8%). In 2018/19 the microsprinkler irrigated loamy sand/ sandy loam orchard had 60% of fruit for processing, most likely due to poor fruit colour (Fig. 35d). The amount of processing fruit exported for the other orchards varied between 22% and 45% (Fig. 39). The percentage fruit in fallout class was quite high in 2017/18 (i.e. between 25.7% and 77.2%) except for the Bonnievale microsprinkler irrigated loamy sand/ sandy loam orchard (c. 18%). The percentage fruit not suitable for export was less in 2018/19 compared to the previous season and ranged between 16% and 37%. The Wolseley orchard had the highest percentage fallout and the microsprinkler irrigated loamy sand/ sandy loam orchard in Bonnievale the least. Fallout class included fruit weighing less than 180 g (Fig. 35a & b), fruit with black sunburn (Fig.

35c & d), blemishes on more than 25% of the fruit surface (Fig. 38a & b) and cracking up to the arils (Fig. 38c & d).

With regard to production areas in 2017/18, Bonnievale and Wolseley had the highest percentage exportable fruit (c. 75%), followed by that in Wellington (50%) and Gouda (38%). The FCM infestation was the main reason behind the poor marketability of the Gouda fruit. In 2018/19 the amount of fruit for export, relative to the previous season, increased for Bonnievale (81%), Wellington (73%) and Gouda (75%) and decreased for Wolseley (63%). Microirrigated orchards had in the two seasons c. 77% and 82% fruit suitable for the export market compared to 54% and 73% (Gouda orchards excluded for 2017/18, 61%) from drip irrigated orchards. Drip irrigated orchards had in both seasons about double the percentage fallout of microirrigated orchards (Gouda orchards excluded for 2017/18, c. 40% more). Of fruit produced in the respective seasons on heavier soils, 72% and 80% could be exported, compared to 47% and 71% (Gouda orchards excluded for 2017/18, 56%) on lighter soils. In Gouda, 23% and 81% of fruit from the orchard below net could be exported, compared to 52% and 70% of fruit produced without net.

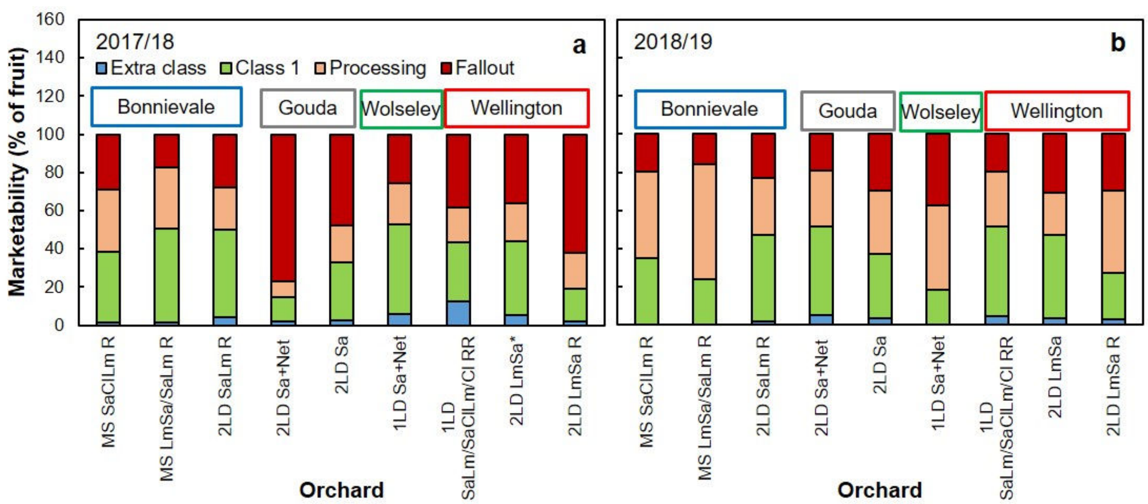

Fig. 39. Fruit marketability classification (Extra class, Class 1, Processing and Fallout) for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2018/19 and 2019/20 seasons. Data for the orchard marked with an asterisk is for Harvest 1 only. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm).

3.6.8. Water use efficiency and productivity

Water use efficiency (WUE, kg fruit produced per hectare per mm water used) and water productivity (WP, gross farm income per hectare per mm of water used) were calculated. Both indices were expressed on the basis of irrigation water applied as well as on the total of efficient rainfall and irrigation applied. The WUE based on irrigation applied ($WUE_{Irrigation}$) appeared to be higher in the first season compared to the second, with exception of the microsprinkler irrigated loamy sand/ sandy loam orchard in Bonnievale (Fig. 40). In 2017/18, the single line drip irrigated orchard in Wellington had the highest $WUE_{Irrigation}$, followed by that of the microsprinkler irrigated sandy clay loam (Fig.40a). The $WUE_{Irrigation}$ of the double line drip irrigated orchards without net in Bonnievale, Gouda and Wellington ranged between c. 85 and 93 kg ha^{-1} mm^{-1}. The microsprinkler irrigated loamy sand on a sandy loam orchard in Bonnievale had somewhat lower efficiency (c. 70 kg ha^{-1} mm^{-1}). However, the double and single line drip irrigated orchards below net in Gouda and Wolseley, respectively, had the lowest $WUE_{Irrigation,}$ i.e. c. 67 and 59 kg ha^{-1} mm^{-1}. The latter value was comparable to the $WUE_{Irrigation}$ for four, five and six year old subsurface drip irrigated trees in California (USA), which amounted to 60.4, 61 and 59.7 kg ha^{-1}

mm^{-1}. (Ayars et al., 2017). The $WUE_{Irrigation}$ for surface drip irrigated trees of similar age in the same experimental orchard amounted, respectively, to 51.5, 53.5 and 55.8 kg ha^{-1} mm^{-1}.

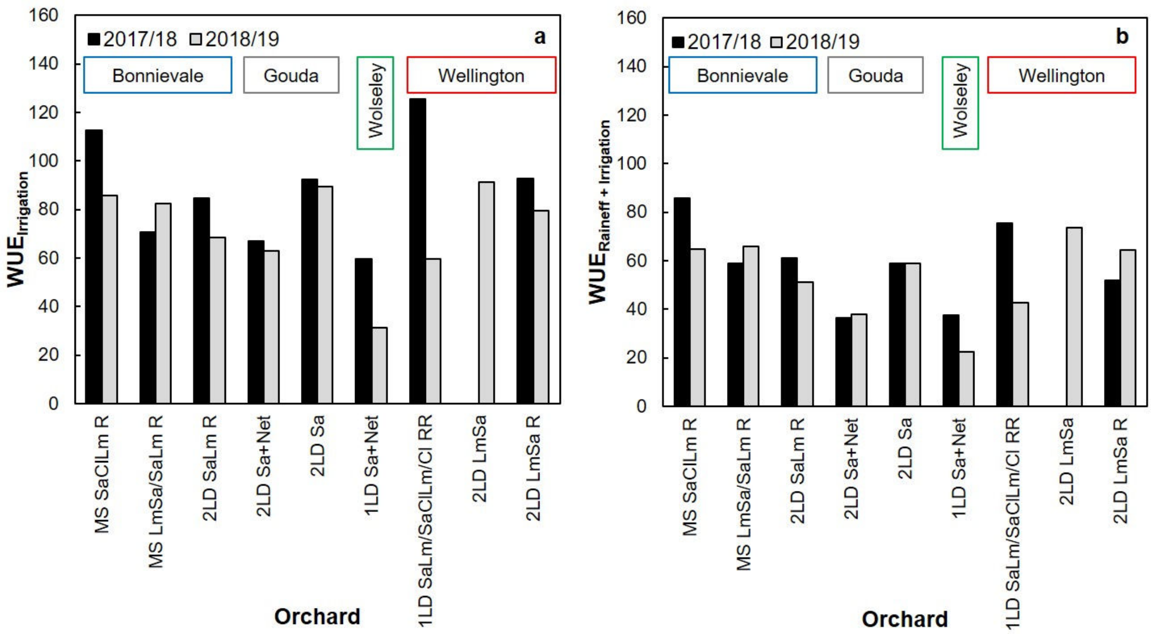

Fig. 40. Water use efficiency (WUE) based on yield per a) irrigation applied ($WUE_{Irrigation}$) and b) effective rainfall and irrigation applied ($WUE_{Raineff\ +\ Irrigation}$) for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2017/18 and 2018/19 seasons. Data values are relative to the maximum water productivity achieved. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm). Data for the 2LD LmSa orchard for 2017/18 is not available.

In 2018/19, the $WUE_{Irrigation}$ of the single line drip irrigated orchard was impacted negatively by a change in orchard training system, reducing it by more than 50% (Fig. 40a). The highest $WUE_{Irrigation}$ was obtained in the level double line drip irrigated orchards on loamy sand in Wellington and on sand in Gouda (c. 90 kg ha^{-1} mm^{-1}), followed closely by the microirrigated orchards in Bonnievale with a $WUE_{Irrigation}$ of 83 and 86 kg ha^{-1} mm^{-1}. The $WUE_{Irrigation}$ of the ridged double line drip irrigated orchards in Wellington and Bonnievale was about 80 and 68 kg ha^{-1} mm^{-1}, respectively. The lower $WUE_{Irrigation}$ of the latter orchard compared to the previous season may be attributed to the application of more irrigation water in the second season (Fig. 11), since yield was fairly similar during the two seasons (Table 16). The $WUE_{Irrigation}$ of the double and single line drip irrigated orchards below net in Gouda and Wolseley, respectively, was 63 and 31 kg ha^{-1} mm^{-1}. Lower $WUE_{Irrigation}$ of the Wolseley orchard compared to the previous season was due to lower yield as a result of less fruit, not of smaller size, and application of about 19% more irrigation water (Table 17, Fig. 22a & b).

If effective rainfall is also taken into account in the WUE ($WUE_{Raineff\ +\ Irrigation}$), the microsprinkler irrigated sandy clay loam orchard of Bonnievale had the highest $WUE_{Raineff\ +\ Irrigation}$ (c. 86 kg ha^{-1} mm^{-1}) in the first season, followed by the single line drip irrigated orchard in Wellington with c. 76 kg ha^{-1} mm^{-1} (Fig. 40b). The $WUE_{Raineff\ +\ Irrigation}$ for the double line drip irrigated orchards without net in Bonnievale and Gouda was similar to that of the microsprinkler irrigated orchard having loamy sand on sandy loam, ranging between c. 59 and 61 kg ha^{-1} mm^{-1}. The ridged double line drip irrigated orchard in Wellington had $WUE_{Raineff\ +\ Irrigation}$ of c. 52 kg ha^{-1} mm^{-1}, whereas that for the netted orchards in Gouda and Wolsley was c. 37 kg ha^{-1} mm^{-1}. In 2018/19 the level double line drip irrigated orchard in Wellington had the highest $WUE_{Raineff\ +\ Irrigation}$ (c. 74 kg ha^{-1} mm^{-1}), whereas it was comparable for the ridged double line drip irrigated orchard in Wellington and the microsprinkler irrigated orchards of Bonnievale (c. 65 kg ha^{-1} mm^{-1}). The $WUE_{Raineff\ +\ Irrigation}$ for the double line drip irrigated orchard in Bonnievale dropped by 20% in the second season, and that for the single line drip irrigated orchard in Wellington by c. 78%. The reasons for these decreases have been explained in the foregoing paragraph. The $WUE_{Raineff + Irrigation}$ for the netted orchards remained the lowest of all, with that in Wolseley decreasing further in the second season to 22 kg ha^{-1} mm^{-1}. In Spain, deficit irrigation resulted in increasing WUE (Fruit yield divided by irrigation applied + rainfall) of 'Mollar de Elche' pomegranate trees (Intrigliolo et al., 2013). The increase in WUE on average over three years relative to the control (39 kg ha^{-1} mm^{-1}) was particularly noticeable in the sustained deficit irrigation (59 kg ha^{-1} mm^{-1}) treatment and where regulated deficit irrigation was applied during flowering and fruit set (49 kg ha^{-1} mm^{-1}). The sustained deficit irrigation and regulated deficit irrigation treatments were successful in increasing WUE and water productivity.

Relative income of the Western Cape pomegranate orchards increased with more effective rainfall and irrigation applied in both seasons, and for data of both seasons combined (Fig. 41a, b & c). The higher income of the Bonnievale area compared to the other areas is most likely due to the high yield obtained in these orchards (Table 17) and a high percentage of exportable fruit (refer Collective quality, section 9.6.7.4). In 2017/18 Extra Class fruit earned between 2 and 9% of the relative income for orchards, except for the single drip irrigated orchard in Wellington, which had 21% Extra Class fruit (Fig. 42a) mainly due to excellent fruit colour (Fig. 35c). In the second season though only six orchards had Extra class fruit which contributed a maximum of 8% to the relative income (Fig. 42b). Class 1 fruit tended to be the main earner of income (i.e. between 58 and 77%) in both seasons, with few exceptions in 2018/19. These included the microsprinker irrigated orchard on loamy sand/ sandy loam orchard in Bonnievale and the single line drip irrigated orchard in Wellington.

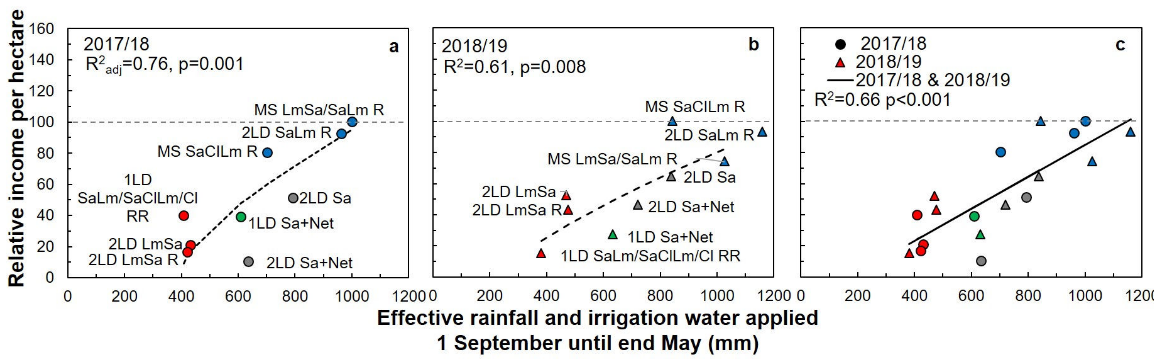

Fig. 41. Relative income for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale blue markers), Gouda (grey markers), Wolseley (green markers) and Wellington (red markers) production areas during the 2018/19 (a) and 2019/20 (b) seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm). Income is expressed relative to the maximum income earned.

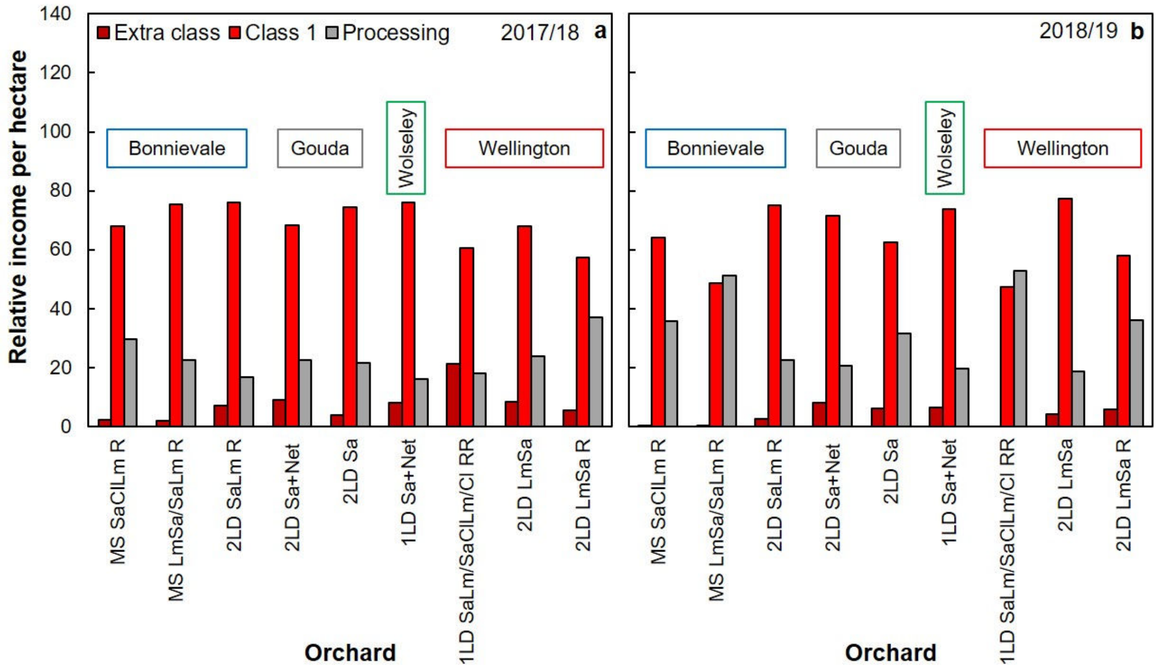

Fig. 42. Relative income per quality class for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2018/19 (a) and 2019/20 (b) seasons. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm). Data for the 2LD LmSa orchard for 2017/18 reflects only Harvest 1.

More fruit of the Bonnievale orchard was destined for processing due to poor colour (Fig. 35d), whereas the change of the training system in the Wellington orchard probably impacted the Class 1 income negatively through smaller fruit size and lower fruit numbers (Table 17). Relative income earned by Class 1 fruit tended in 2017/18 to increase linearly with more effective rainfall and irrigation applied, but in the second season there were no consistent trends (data not shown). Relative income earned by fruit for processing ranged in the two seasons between 16% and 37% of the total per orchard, except for the two orchards discussed above for which fruit only suitable for processing exceeded 50% in the second season (Fig. 42).

Relative WP based on irrigation applied or $WP_{Irrigation}$ (Fig. 43a) was in the first season the highest in the single line drip irrigated orchard in Wellington, followed closely by the Bonnievale orchards (74 to 93%) and the Wolseley orchard below net (63%). Although the Gouda orchards were affected in the first season by FCM infestation, the orchard without net also achieved 63% relative $WP_{Irrigation}$, whereas $WP_{Irrigation}$ of the Gouda orchard below net was severely affected (18%). Poor relative $WP_{Irrigation}$ of the ridged double line drip irrigated orchard in Wellington (43%) was probably due to sunburnt fruit with more fruit destined for processing and fallout (Fig. 35c & e, Fig. 41a). In the second season the relative $WP_{Irrigation}$ of the single line drip irrigated orchard in Wellington dropped to 36% due to a change in orchard training system which required severe winter pruning (Fig. 43a). In the 2018/19 season, the microsprinkler irrigated orchard on sandy clay loam in Bonnievale and the level double line drip irrigated orchard in Wellington (88%) had the highest relative $WP_{Irrigation}$. The relative $WP_{Irrigation}$ for the double line drip irrigated orchards in Bonnievale, Gouda and the ridged orchard in Wellington ranged between 68 and 75%. The low relative $WP_{Irrigation}$ of the Wolseley orchard (38%) was probably due to low fruit numbers (Table 17) combined with poor fruit colour development and sunburn on 57% of fruit (Fig. 35d & f) as well as some degree of blemishes on 63% of fruit (Fig. 38b).

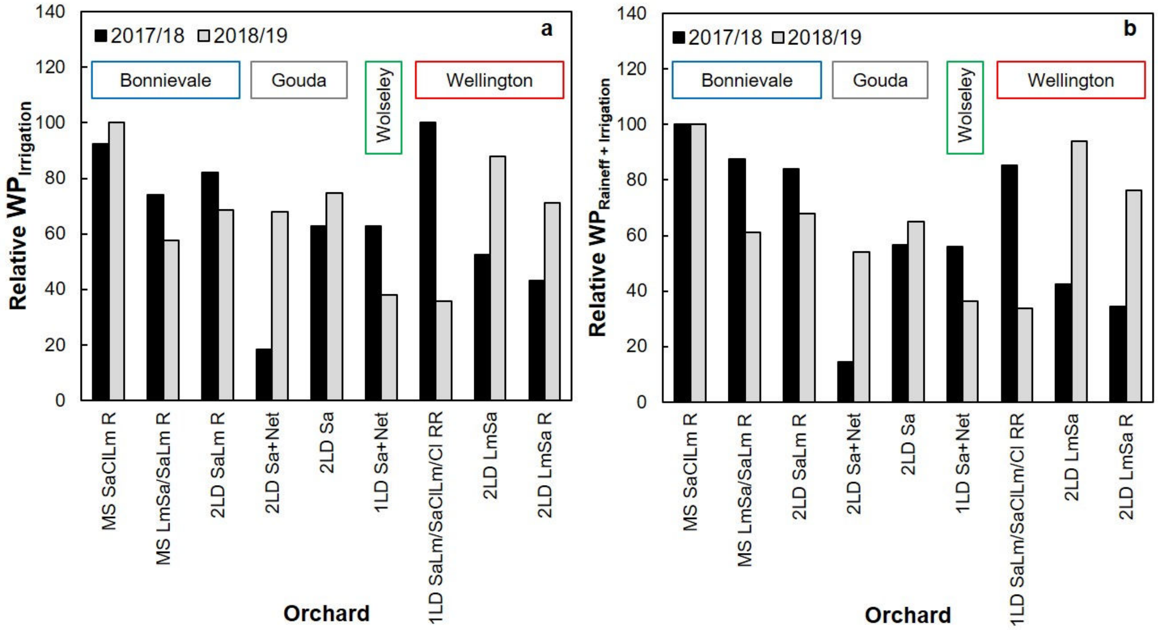

Fig. 43. Relative water productivity (WP) based on income (R) per a) irrigation applied and b) effective rainfall (Raineff) and irrigation applied for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2018/19 and 2019/20 seasons. Data values are relative to the maximum water productivity achieved. MS, 1LD and 2LD, R and RR refers to microsprinkler, single and double line drip, ridge and ripped ridge, respectively. The soil texture class codes include sand (Sa), clay (Cl) and loam (Lm). Data for the 2LD LmSa orchard for 2017/18 reflects only Harvest 1.

Relative WP based on the total of effective rainfall and irrigation applied ($WP_{Raineff + Irrigation}$) was in both seasons the highest for the Bonnievale microsprinkler irrigated orchard on sandy clay loam (Fig. 43b). In the first season, the other microsprinkler irrigated orchard had the second highest relative $WP_{Raineff + Irrigation}$ (87%), followed by the single line drip irrigated orchard in Wellington (85%) and the double line drip irrigated orchard in Bonnievale (84%). Despite the FCM infestation, the Gouda orchard without net had relative WP comparable to that of Wolseley (56%). The FCM infestation may have decreased the relative $WP_{Raineff + Irrigation}$ in the Gouda orchard below net to 14%. The reasons for the poor relative $WP_{Raineff + Irrigation}$ in the ridged double line drip irrigated orchard in Wellington (34%) has already been mentioned in the foregoing paragraph. In the second season though the double line drip irrigated orchards in Wellington had of the best relative $WP_{Raineff + Irrigation}$, i.e. 94% for the level and 76% for the ridged orchard. More Class 1 fruit and/ or less Fallout fruit in combination with the low amount of effective rainfall and irrigation probably contributed to the improved relative $WP_{Raineff + Irrigation}$ of these orchards in the second season compared to the first (Fig. 36, 37a & b). In 2018/19 the relative $WP_{Raineff + Irrigation}$ of the double line drip irrigated Bonnievale orchard and the Gouda orchard without net was 68% and 65%, respectively Fig. 43b). Poorer $WP_{Raineff + Irrigation}$ for the Gouda orchard below net (54%) compared to the one without it, despite the former having a higher percentage Extra Class and Class 1 fruit (Fig. 41b) was 45% lower yield (Table 16) as a result of 42% less fruit of 21% lower weight (Table 17). In the case of the single line drip irrigated orchard in Wellington and the Wolseley orchard the relative $WP_{Raineff + Irrigation}$ was 2% less when rainfall and irrigation applied was taken into account compared to where only irrigation applied was used.

On average for production areas either Bonnievale or Wellington had in the two seasons the best $WUE_{Irrigation}$ (i.e. between 77 and 109 kg ha^{-1} mm^{-1}), with that in Gouda being c. 10% less (Table 19). However, the $WUE_{Irrigation}$ for Wolseley was 34% and 63% lower compared to Bonnievale for 2017/18 and 2018/19, respectively. If rainfall is taken into account, Bonnievale had the highest $WUE_{Raineff + Irrigation}$ for both seasons, with that in Wellington, Gouda and Wolseley being c. 7% and 8%; 31% and 26%; and 45% and 66% less efficient in the respective seasons.

Bonnievale also had the best relative $WP_{Irrigation}$ and $WP_{Raineff + Irrigation}$ for both seasons (Table 19). In 2017/18 and 2018/19, respectively, the relative $WP_{Irrigation}$ for Wellington, Gouda and Wolseley was 18% and 14%; 42% and 8%; and 20% and 41% less compared to that of Bonnievale. The $WP_{Raineff + Irrigation}$ for the respective seasons in Wellington, Gouda and Wolseley was 36% and 12%; 55% and 21% and 34% and 44% less compared to Bonnievale. Wolseley and Wellington had comparable $WP_{Irrigation}$ and $WP_{Raineff + Irrigation}$ for the first season, but it decreased for Wolseley by 27% and 32%, respectively, compared to Wellington in the second season.

Table 19. Comparison of mean water use efficiency (WUE) and water productivity (WP) based on irrigation applied (Irrigation) or effective rainfall and irrigation applied (Raineff + Irrigation) for pomegranate (cv. Wonderful) orchards harvested in the Bonnievale, Gouda, Wolseley and Wellington production areas during the 2018/19 and 2019/20 seasons. Relative data values are compared to the maximum achieved.

Group mean	$WUE_{Irrigation}$ (kg ha^{-1} mm^{-1})		$WUE_{Raineff + Irrigation}$ (kg ha^{-1} mm^{-1})		Relative $WP_{Irrigation}$		Relative $WP_{Raineff + Irrigation}$	
	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19	2017/18	2018/19
Bonnievale	89	84	69	65	83	79	90	80
Gouda	80	76	48	48	41	71	35	59
Wolseley	59	31	37	22	63	38	56	36
Wellington	109	77	64	60	65	65	54	68
Microsprinkler	92	84	72	65	83	79	94	80
Drip	87	69	54	50	60	63	53	61
Heavier soils	98	74	70	56	87	65	89	66
Lighter soils	78	71	46	51	48	68	41	65
Net (Gouda)	67	63	37	38	18	68	14	54
Nonet	93	90	59	59	63	75	57	65

The $WUE_{Irrigation}$ for microsprinkler orchards compared to that for drip irrigated orchards was in 2017/18 and 2018/19, 5% and 18% higher, whereas the $WUE_{Raineff + Irrigation}$ for the respective seasons was 26% and 23% higher for microsprinkler vs drip. Likewise microsprinkler irrigation increased the $WP_{Irrigation}$ and $WP_{Raineff + Irrigation}$ for orchards compared to drip irrigation by 23% and 15%; respectively, in 2017/18, and by 40% and 19%, respectively, in 2018/19. In this survey, the microsprinkler irrigated orchards were planted on heavier soils, which on average had higher WUE compared to the lighter soils, especially in the first season. The $WP_{Irrigation}$ and $WP_{Raineff + Irrigation}$ of orchards on heavier soils was in the first season 39% and 48%, respectively, higher compared to that from the lighter soils, with minor differences in the second season. Greater water holding capacity of heavier soils (Fig. 4) may have contributed to higher WP especially during a season of critical drought such as the 2017/18 season. If the first season, where FCM infestation most likely impacted tree performance is ignored, the orchard below net had 29% lower $WUE_{Irrigation}$ and 37% lower $WUE_{Raineff + Irrigation}$ compared to the orchard without net. In the second season $WP_{Irrigation}$ and $WP_{Raineff + Irrigation}$ was 7% and 11%, respectively, less for the orchard below net compared to the one without net.

4. CONCLUSIONS AND RECOMMENDATIONS

Water restrictions due to the Western Cape drought prevented pomegranate producers from supplying irrigation according the tree water requirements. Despite this, valuable information was obtained regarding the local production areas and the effect of irrigation application on yield and fruit quality.

The evaporative demand that drives water use and irrigation water requirements in Wellington, Bonnievale, Gouda and Wolseley was for the 2017/18 and 2018/19 seasons (September to May), respectively, c. 1168 mm and 1137 mm; 1092 mm and 1070 mm; 1003 mm and 1184 mm; and 942 mm and 1095 mm. In 2017/18 the evaporative demand in the Bonnievale, Gouda and Wolseley areas were therefore c. 7%, c. 14% and c. 19% less compared to Wellington. In 2018/19 though differences in total ET_o between production regions diminished with that for Bonnievale and Wolseley being 6% and 4% less, and that for Gouda becoming c. 4% more than that for Wellington. The total ET_o from 1 September to 31 May in 2018/19 compared to 2017/18 decreased by 3% and 2% for Wellington and Bonnievale, whereas it increased for Gouda and Wolseley by 18% and 16%, respectively.

With regard to irrigation management, soil water dynamics indicated instances of under- and overirrigation during the two seasons. The amount of irrigation water applied during the season to the nine full bearing Wonderful pomegranate orchards ranged in 2017/18 between 237 mm and 834 mm, and in 2018/19 between 272 mm and 867 mm. In both the 2017/18 and 2018/19 seasons most water was applied in Bonnievale (688 mm and 775 mm), followed by Gouda (426 mm and 492 mm), Wolseley (385 mm and 456 mm) and Wellington (243 mm and 346 mm). On average over seasons Gouda, Wolseley and Wellington applied 63%, 57% and 40% of that applied to the Bonnievale area. Irrigation applied in the 2018/19 compared to the 2017/18 season was 13%, 15%, 19% and 42% more for Bonnievale, Gouda, Wolseley and Wellington, respectively. Effective rainfall also supplies in crop water requirements. Rainfall corrected for evaporation losses amounted during the 2017/18 and 2018/19 growing seasons, respectively, on average for Bonnievale, Gouda, Wolseley and Wellington to 201 mm and 236 mm; 289 mm and 288 mm; 226 mm and 177 mm; and 173 and 95 mm. The total amount of effective rainfall and irrigation ranged for 2017/18 between 409 mm and 1001 mm, and for 2018/19 between 381 mm and 1161 mm. As in the case for irrigation, Bonnievale had in both seasons the highest total effective rainfall and irrigation (889 mm and 1011 mm), followed by Gouda (715 mm and 780 mm), Wolseley (611 mm and 633 mm) and Wellington (421 mm and 443 mm). On average over seasons the total effective rainfall and irrigation for Gouda, Wolseley and Wellington was 79%, 66% and 46% of that for the Bonnievale area. The total of effective rainfall and irrigation for Bonnievale, Gouda, Wolseley and Wellington, respectively, for the 2018/19 season was 14%, 9%, 4% and 5% more than for the 2017/18 season. The total effective rainfall and irrigation for the 2017/18 and 2018/19 seasons, respectively, equalled 78% and 94%; 71% and 66%; 65% and 58%; and 36% and 39% of the seasonal total ET_o for the Bonnievale, Gouda, Wolseley and Wellington production areas, respectively.

Tree water status indicated that the Gouda and Wellington orchards were subjected to either moderate or severe water stress levels during the fruit growth or ripening stages, which impacted negatively on fruit growth rate. Relative fruit growth rate during fruit set and ripening tended to increase non-linearly with an increased amount of effective rainfall and irrigation water applied daily. Increased rates of effective rainfall and irrigation applied from September until end fruit set enhanced shoot growth rate in the second season, but not in the first, during which effective rainfall and irrigation rates were 2.5 mm d^{-1} or less. Effective rainfall and irrigation did not affect leaf macro- and micronutrients, except for leaf phosphate and magnesium content which increased either non-linearly or linearly with higher rates of effective rainfall and irrigation applied until end linear fruit growth.

Final fruit size (fruit weight, length and diameter), also related positively with increased irrigation rate until harvest, and yield and average fruit weight with higher rates of water application for the total season. Total yield for the 2017/18 and 2018/19 seasons, respectively, varied between 21.9 t ha^{-1} and 60.3 t $ha^{-1;}$ and 14.2 t ha^{-1} and 67.7 t ha^{-1}. The Bonnievale area on average had the highest yield in the respective seasons (59.4 t ha^{-1}, 60.5 t ha^{-1}), followed by Gouda (35 t ha^{-1} and 38 t ha^{-1}), Wellington (26.4 t ha^{-1} and 27.2 t ha^{-1}) and Wolseley (22.9 t ha^{-1} and 14.2 t ha^{-1}). Yield for Bonnievale compared to Gouda, Wellington and Wolseley was in 2017/18 and 2018/19, respectively, 41% and 37%, 56% and 55%, and 62% and 77% higher.

Fruit peel moisture content and fruit firmness tended to increase with higher rates of effective rainfall and irrigation until harvest. Aril weight and moisture content also tended to increase with increased effective rainfall and irrigation rate until harvest, but only in the first season. The percentage of fruit with dark red arils increased with more effective rainfall and irrigation applied in both seasons. In contrast, fruit skin red colouration tended to decrease with increased rate of irrigation until harvest.

Fruit of all orchards conformed to the ripeness standards expected for export. Pomegranate juice TA tended to increase, whereas the TSS, pH and MI decreased with increased rate of irrigation until harvest in the first season, but not in the second. Rainfall occurring during harvest may probably partially explain the lack of significant trends for the second season. There were no significant trends between the physiological disorders (scuffmarks, russeting, cork around the pedicel, internal decay) and the rate of effective rainfall and irrigation applied until harvest. The percentage sunburnt fruit at harvest increased with lower tree water status during fruit growth stage. Although there was large variation, the total percentage of fruit with sunburn decreased with increased rate of irrigation between fruit growth stage and harvest. There was no meaningful relationship between the amount of effective rainfall and irrigation applied until harvest and cracking or blemishes of fruit.

Fruit suitable for export during the 2017/18 and 2018/19 seasons, respectively, was 75% and 81% for Bonnievale, 74% and 63% for Wolseley, 50% for 73% for Wellington and 38% and 75% for Gouda. However, there was no simple relationship between effective rainfall and irrigation applied and marketability of fruit. Water use efficiency (kg fruit produced per hectare per mm water used) of the orchards was high compared to some published data for pomegranate from other countries/ cultivars. Water use efficiency based on irrigation water applied varied between 59.4 kg ha^{-1} mm^{-1} and 125.5 kg ha^{-1} mm^{-1} for the 2017/18 season, and 31.1 kg ha^{-1} mm^{-1} and 91.3 kg ha^{-1} mm^{-1} for the 2018/19 season. If effective rainfall is also taken into account the water use efficiency ranged between 36.6 kg ha^{-1} mm^{-1} and 85.9 kg ha^{-1} mm^{-1} in the first, and 22.4 kg ha^{-1} mm^{-1} and 73. kg ha^{-1} mm^{-1} in the second season. Water use efficiency with effective rainfall and irrigation taken into account was the highest in Bonnievale for both seasons, with that in Wellington, Gouda and Wolseley being c. 7% and 8%; 31% and 26%; and 45% and 66% less efficient in the respective seasons.

Relative income of pomegranate orchards (expressed vs maximum income earned) increased with more effective rainfall and irrigation applied in both seasons. Bonnievale also had the best relative water productivity (gross farm income per hectare per mm of water used) for both seasons for scenarios where only irrigation water or the total of effective rainfall and irrigation water applied was taken into consideration. In 2017/18 and 2018/19, respectively, water productivity based on effective rainfall and irrigation applied was in Wellington, Gouda and Wolseley compared to Bonnievale 36% and 12%; 55% and 21% and 34% and 44% less.

Based on the data collected and trends established between effective rainfall and irrigation water applied, pomegranate yield and quality parameters the following research needs were identified:

- There is potential for some production areas to increase yield and fruit quality through improved irrigation scheduling. Research is required on the water use (transpiration and evapotranspiration) of a range of pomegranate orchards with the objective to develop a model that will enable estimation of water use for individual orchards. Such a model will aid producers to schedule irrigation according to tree water requirements and prevent over- or underirrigation which impacts the environment (leaching of fertilizers and water losses) and fruit tree performance (yield and quality).

- Research is needed on deficit irrigation strategies for pomegranate orchards to maximize yield and fruit quality under drought conditions. Crop phenological stages that are the least vulnerable to drought should be identified in order to develop these strategies. Although literature indicated the stage from bud break until fruit set has potential to save water without negative impacts on yield, our survey indicated that fruit growth rate during this stage increased with higher rates of effective rainfall and irrigation applied. The effect of different levels of water stress during this stage on fruit set and development needs to be researched further and compared to that applied during linear fruit growth and ripening until harvest.

- The amount of water application through rainfall and irrigation appears to have opposite effects on quality related consumer preferences such as red skin colour and dark red arils, with more water resulting in poorer skin red colour, but better aril red colour. Research regarding irrigation and/or production strategies that may result in better red colouration of both skin and arils are needed. If that is not possible the economic feasibility of production for specific markets should be looked into.

- The effect of irrigation and cover alternatives should be researched on pomegranate tree performance and fruit quality. Sunburn and windmarks are quality defects of pomegranate fruit that, depending on the degree thereof, can decrease export volumes. In order to prevent sunburn, farmers in sunburn susceptible production areas enclose fruit after final fruit set stage in cloth or paper bags until shortly before harvest. This is a labour intensive exercise. An alternative, and probably more cost-effective solution to curb sunburn and wind damage could be the use of drape-netting, as is currently practiced in apple orchards. Inadequate irrigation may also lead to tree water stress and increase sunburn of fruit. Less sunburnt and chafed fruit could increase export volumes and foreign or local income earned by commercial and/small holder famers. An important secondary benefit of drapenetting may be a reduction in false codling moth (FCM) infestation.

- Decreased availability of adequate volumes of high quality water for agricultural purposes or during drought periods requires that irrigation and production practices for irrigation of pomegranates, which are according to literature moderately salt tolerant, with saline water are optimized. Research in this regard is needed under local conditions.

Irrigation research requires substantial funding due to the specialized equipment needs especially for measurement of evapotranspiration and transpiration. It is envisioned that the industry, agricultural and water sectors could co-fund the research, which would benefit not only the pomegranate industry and its dependents, but also the South African economy. If irrigation scheduling is optimized it can also aid in sustainability of the water and soil resources of the country.

Technology developed

None. The purpose of the project is to identify research needs.

Human resources developed/trained

None

Patents

None

Publications (popular, press releases, semi-scientific, scientific)

Volschenk, T and Mulidzi AR. (2019) Pomegranate tree performance during critical drought. SA Fruit Journal 18(3):65-67.

Presentations/papers delivered

Volschenk T, Mulidzi AR. (2018) Irrigation and pomegranate tree performance – a survey. Slide show presentation at POMASA Information day and Annual general meeting, Diamant estate, Paarl, 26 October 2018.

Volschenk T, Mulidzi AR. (2018) Irrigation of pomegranates: tree and fruit response. Presentation at SAPEX GRANATE TERUGVOERSESSIE –, Picardie guest farm, Paarl, 15 November 2018.

Volschenk T, Mulidzi AR. (2018) Irrigation of pomegranates: tree and fruit response. Presentation at Alternative Crop Funds Report Back Meeting, Auditorium, Elsenburg, 15 August 2019.

5. Budget for the following year: 1 April [2020] to 31 March [2021]

	WCDA	**Other***					**TOTAL**
FUNDING REQUIRED FOR FOLLOWING YEAR: TOTAL	**0**	**0**					**0**
Personnel costs							
Running costs							
Equipment (capital items*) **[List capital items HERE]**							
Other							

* Specify other sources

6. Total estimated budget for project (insert actual cost when available)

	Year	*WCDA*	**Other**				**ARC**	**TOTAL**
Total cost in real terms for year 1	2017/18	268 860					279 834	548 694
Total cost in real terms for year 2	2018/19	307 359					319 904	627 263
Total cost in real terms for year 3	2019/20	219 747					228 717	448 464
Total cost in real terms for year 4								
Total cost in real terms for year 5								
TOTAL		**795 966**					**828455**	**1 624 421**

EVALUATION BY ALTERNATIVE CROPS FUND STEERING COMMITTEE

This section is for office use only

Comments on project:

Recommendation by Alternative Crops Fund Steering Committee	
Designation	Designation
Signature	Signature
Date:	Date: