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The effect of combined deficit irrigation and summer trunk girdling on the internal fruit quality of 'Marisol' Clementines

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Abstract

The influence of girdling, deficit irrigation, and a combination of girdling and deficit irrigation on fruit quality of 'Marisol' Clementines was investigated over two seasons, 1998 and 1999, at two different sites in South Africa. Girdling increased the total soluble solids (TSS) by 2–10%, however, the effect was not always significant. There were no trends observed for external fruit colour, fruit diameter, juice content (%), titratable acidity (TA) and TSS:TA ratios due to girdling. Deficit irrigation increased the TSS (by 2–17%) and the TA levels (by 9–13%) in both seasons and at both sites, increased the TSS:TA ratio at Citrusdal in 1998 (4–8%), and decreased the TSS:TA ratio (by 7%) in the second season (1999) at both sites due to the increased acidity levels (by 11–13%). Deficit irrigation had no major effects on external fruit colour and juice content in 1999, but decreased fruit diameter (by 10%) at Citrusdal. According to these results, deficit irrigation, summer trunk girdling, or a combination of both, can be used as cultural practices to improve internal fruit quality. The combination of girdling and deficit irrigation increased the TSS more than when the practices are executed on their own.

Keywords: Reduced water amounts; Girdling; Citrus; Total soluble solids; Titratable acidity; Irrigation

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1. Introduction

Girdling is a horticultural practice (Krezdorn, 1960) that has a history of affecting fruit quality and the date of maturity (Hochberg et al., 1977; Iwahori et al., 1977; Barry and Veldman, 1997). Citrus productivity and tree response to girdling depend on girdling date, girdle width and the position, i.e. on the trunk or branches, cultivar and climatic differences (Peng and Rabe, 1996). Church (1933) found an increase in total soluble solids (TSS), reducing sugars, and total sugar content in Navel fruit after girdling. Peng and Rabe (1996) reported that girdling at 2–4 weeks after the fruit-drop period (December drop in southern hemisphere–June drop in northern hemisphere) increased TSS levels and TSS:TA ratios. Goren and Monselise (1971) and Cohen (1984) detected that summer girdling had no effect on internal fruit quality.

Deficit irrigation is the deliberate and systematic under-irrigation of crops and is a common practice in many areas of the world, especially in arid countries (English and Raja, 1996). Grape growers use deficit irrigation to reduce vegetative growth of vines and improve grape quality (Wardle, 1991). In citrus, deficit irrigation is conducted in an attempt to enhance internal fruit quality, mainly by increasing the TSS (Erickson and Richards, 1955; Goell and Levy, 1970; Goell and Cohen, 1981; Goell, 1988; Castel and Buj, 1990; Dasberg, 1992; Peng and Rabe, 1997, 1998). Yakushiji et al. (1996, 1998) found that the sugar accumulation (increase in total sugars per fruit) in Satsuma mandarin fruit due to water stress was not caused by dehydration, but rather that sugars were accumulated by active osmoregulation. The monosaccharides, glucose and fructose, were largely responsible for the active osmoregulation (Yakushiji et al., 1996).

The effects of water deficits on fruit quality also depend on the intensity and duration of the water stress period, as well as the phenological phase when the deficit is introduced (Shalhevet and Bielorai, 1978; Sanchez-Blanco et al., 1989; Castel and Buj, 1990). Ginestar and Castel (1996) found that deficit irrigation affected fruit quality mainly during the final fruit growth period and the beginning of the ripening period (August–October in northern hemisphere) by increasing the sugar content and acidity. Therefore, Peng and Rabe (1998) introduced deficit irrigation only after the fruit-drop period.

According to Goell and Cohen (1981), girdling also intensifies moisture stress. Therefore, it is expected that the combination of deficit irrigation and girdling would promote internal fruit quality more than deficit irrigation and girdling executed on its own. Previous studies only looked at the effect of girdling and deficit irrigation executed on their own on internal fruit quality, but in this study the separate and combined effects of girdling and deficit irrigation on internal fruit quality were evaluated.

Fruit of marginal quality (low TSS) will lead to a reduction in the number of exportable fruit (Peng and Rabe, 1996), low prices on the markets and a loss of market share. The objective of this study is to evaluate the separate and joint effects of deficit irrigation and girdling, performed at different times, on the internal fruit quality of ‘Marisol’ Clementine fruit. ‘Marisol’ is an early-maturing Clementine selection which tends to produce fruit of inherently lower sugar levels. The irrigation levels used in this study may also be used to establish an irrigation schedule, especially for the summer months, which should maximise internal fruit quality.

2. Materials and methods

2.1. Plant material

Four trials were conducted over two seasons at two sites, Somerset West (34°S–19°E) and Citrusdal (32°30′S–19°E), South Africa. ‘Marisol’ Clementine trees on Carrizo citrange rootstock were used for both studies. The orchard at Somerset West was planted in 1993. Tree spacing was 4.5 m between rows and 2.0 m within rows with a north–south row orientation. Trees in the same irrigation block were girdled in the first year (1998) of the study, but trees in two adjacent irrigation blocks were used in the second year (1999) for a combination of girdling and deficit irrigation.

At Citrusdal, trees in two adjacent irrigation blocks were used over two consecutive years of the study. In the first year (1998), the trees were used for a deficit irrigation study and in the second year (1999), for a combination of girdling and deficit irrigation. Both blocks were planted in 1993 with a spacing of 5.0 m between rows and 2.5 m within rows and a north–south row orientation. Only visually healthy trees with uniform canopy size were used.

2.2. Girdling procedures, irrigation procedures and treatments

A single knife cut was made through the bark of the main trunk at 10 cm above the bud union. Bark was not removed.

Irrigation treatments at both sites consisted of a block with normal irrigation (control) and a block with deficit irrigation. All the deficit irrigation studies were based on reducing the amount of water the trees in the deficit block receive. While the irrigations in both the deficit and normal blocks were done at the same time, the amounts given to each block differed. In their study, Peng and Rabe (1998) irrigated once a certain stress level was attained. Therefore, different treatments were irrigated at shorter or longer intervals, depending on the desired level of stress. Additional irrigation information for both sites is presented in Table 1. The start of the deficit irrigation period at both sites was timed to coincide with the end of the fruit-drop period for ‘Marisol’ Clementines.

Table 1
Irrigation information for deficit irrigation trials in 1998 at Somerset West and in 1999 at Somerset West and Citrusdal

	Citrusdal, 1998		Citrusdal, 1999		Somerset West, 1999	
	Normal	Deficit	Normal	Deficit	Normal	Deficit
USDA soil classification	Lithic Haploxeralf	Typic Haploxeralf	Lithic Haploxeralf	Typic Haploxeralf	Aquic Haploxeralf	Aquic Haploxeralf
Soil	Sand with stone fraction	Sandy	Sand with stone fraction	Sandy	Sandy loam	Sandy loam
Water ($m^3\ ha^{-1}$)	5108	4338	3857	2206	5257	3445
% of normal irrigation	85		57		66	
Stress period	1 January 1998 to 1 May 1998		1 February 1999 to 1 May 1999		1 January 1999 to 30 April 1999	
Irrigation system	Microjets		Microjets		Microjets	
Delivery rate ($mm\ h^{-1}$)	4		4		5.56	
Scheduling	Neutron probe		Neutron probe		'Enviroscan' and neutron probe	

Soil moisture measurements were taken every four days at every 10 cm and the probes were calibrated at the site using gravimetric soil water content samples.

2.2.1. Experiment 1

Girdling was carried out during 1998 at Somerset West on trees in the same irrigation block. Treatments consisted of an ungirdled control and three girdling treatments. The girdling treatments were conducted 2 weeks apart. The actual girdling dates are provided in Table 4. The earliest girdling dates were timed to coincide with the end of the normal physiological fruit-drop period for 'Marisol' Clementines. The trial consisted of a randomised complete block design with four treatments and 10 two-tree replicates per treatment.

2.2.2. Experiment 2

During 1998, at Citrusdal, a deficit irrigation trial was conducted by using two adjacent irrigation blocks. One block received normal irrigation and one block deficit irrigation. The deficit irrigation block was based on approximately 66% of the amount of water the normal block received.

2.2.3. Experiment 3

Girdling and deficit irrigation were combined in 1999 at Somerset West, using two adjacent irrigation blocks. The theoretical deficit irrigation was based on approximately 60% of the amount of water the normal block received. Girdling was carried out in each irrigation block (both normal and deficit blocks). Treatments consisted of an ungirdled control and three girdling treatments conducted 20 days apart, starting end of December and ending mid-February. The actual girdling dates are provided in Table 2. The earliest girdling dates were timed to coincide with the end of the normal physiological fruit-drop period for 'Marisol' Clementines. The girdling trial consisted of a randomised complete block design with four treatments and 10 single-tree replicates per treatment in both irrigation blocks.

2.2.4. Experiment 4

Girdling and deficit irrigation were combined in 1999 at Citrusdal, using two adjacent irrigation blocks. The deficit irrigation block was based on approximately 66% of the amount of water the normal block received. Girdling was carried out in each irrigation block (both normal and deficit blocks). Treatments consisted of an ungirdled control and three girdling treatments conducted 20 days apart, starting end of December and ending mid-February. The actual girdling dates are provided in Table 3. The earliest girdling dates were timed to coincide with the end of the normal physiological fruit-drop period for 'Marisol' Clementines. The girdling trial consisted of a randomised complete block design

Table 2
The effects of summer trunk girdling and deficit irrigation during the summer months of 1999 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Somerset West area

	Date	Degrees of freedom	Colour		Diameter		Juice (%)		TSS		Acid		Ratio[a]	
			Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit
Treatment														
Control (no girdling)			3.5 a[b]	2.9 a	51.31 a	48.68 a	62.16 a	61.95 a	9.73 b	10.15 a	1.00 a	1.15 a	9.76 a	8.94 a
Girdling	28 December 1998		3.5 a	2.6 a	51.11 a	49.47 a	62.21 a	61.70 a	9.58 b	10.31 a	1.00 a	1.15 a	9.65a	9.07 a
Girdling	18 January 1999		2.5 b	2.5 a	48.93 a	49.31 a	61.32 a	59.34 a	10.08 b	10.56 a	1.05 a	1.12 a	9.76 a	9.54 a
Girdling	8 February 1999		3.0 ab	2.7 a	48.43 a	49.73 a	61.35 a	60.16 a	10.71 a	10.64 a	1.04 a	1.17 a	10.41 a	9.13 a
Mean			3.1	2.7	49.95	49.30	61.76	60.79	10.03	10.42	1.02	1.15	9.90	9.17
LSD			0.671	0.506	5.307	6.393	1.997	3.077	0.590	0.628	0.123	0.153	0.828	0.790
SE			0.231	0.174	1.829	2.203	0.688	1.060	0.203	0.216	0.0423	0.0527	0.285	0.272
Source														
Treatment		3	0.0125	0.3979	0.5890	0.9887	0.6784	0.2682	0.0026	0.3706	0.7877	0.9401	0.2417	0.4511
Control vs girdling		1	0.0703	0.1754	0.3969	0.7487	0.5107	0.2154	0.1053	0.1687	0.5712	0.9092	0.5892	0.3379
Girdling linear		1	0.1168	0.6881	0.3101	0.9356	0.3820	0.3136	0.0005	0.2903	0.5745	0.7904	0.0704	0.8773
Girdling quadratic		1	0.0139	0.3338	0.7086	0.9152	0.5901	0.2320	0.7960	0.7508	0.5295	0.5815	0.4463	0.1980

[a] Rounding off causes TSS/acid values to differ from actual ratio values.
[b] Means with the same letter are not significantly different at the 5% level (LSD).

Table 3
The effects of summer trunk girdling and deficit irrigation during the summer months of 1999 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Citrusdal area

	Date	Degrees of freedom	Colour		Diameter		Juice (%)		TSS		Acid		Ratio[a]	
			Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit	Normal	Deficit
Treatment														
Control (no girdling)			5.1 a[b]	5.1 a	60.54 b	53.88 b	52.29 a	54.25 a	10.40 b	10.50 b	0.98 a	0.98 b	10.71 a	10.75 a
Girdling	29 December 1998		5.0 a	4.9 a	63.81 ab	63.06 a	50.41 a	52.29 a	11.08 a	10.46 b	1.00 a	1.03 b	11.31 a	10.31 ab
Girdling	19 January 1999		5.3 a	5.1 a	65.97 a	54.01 b	49.33 a	53.13 a	10.59 ab	11.63 a	0.98 a	1.21 a	10.82 a	9.78 b
Girdling	9 February 1999		5.1 a	5.2 a	62.34 ab	55.92 b	50.15 a	52.66 a	10.83 ab	11.27 ab	0.97 a	1.14 ab	11.33 a	10.07 ab
Mean			5.1	5.1	63.17	56.72	50.55	53.08	10.73	10.97	0.98	1.09	11.04	10.23
LSD			0.431	0.506	4.530	6.072	4.104	4.212	0.555	1.055	0.111	0.180	0.889	0.835
SE			0.148	0.174	1.561	2.092	1.415	1.452	0.191	0.364	0.0382	0.0620	0.307	0.288
Source														
Treatment		3	0.6205	0.8228	0.1148	0.0136	0.5146	0.7947	0.0923	0.0778	0.9445	0.0529	0.3602	0.1327
Control vs girdling		1	0.9233	0.7806	0.0627	0.1292	0.1659	0.3621	0.0603	0.1515	0.8811	0.0528	0.2210	0.0454
Girdling linear		1	0.5723	0.3804	0.5098	0.0229	0.8975	0.8568	0.3639	0.1270	0.5588	0.2085	0.9635	0.5601
Girdling quadratic		1	0.2368	0.8529	0.1417	0.0419	0.5887	0.7159	0.1311	0.0974	0.9662	0.0972	0.1940	0.2546

[a] Rounding off causes TSS/acid values to differ from actual ratio values.
[b] Means with the same letter are not significantly different at the 5% level (LSD).

with four treatments and 10 single-tree replicates per treatment in both irrigation blocks.

2.3. Fruit quality measurements

2.3.1. Experiment 1

At harvest (14 April 1998), fruit samples were picked at Somerset West in 1998 (girdling trial) from the outside of the canopy, at shoulder height. The samples consisted of 12 fruit (six small and six large fruit) from a four-tree replicate (fruit picked randomly around the tree).

2.3.2. Experiment 2

Fruit samples were picked at Citrusdal in 1998 (deficit irrigation) in both blocks at harvest (7 April 1998) from the outside of the tree canopy at shoulder height. In each irrigation block, five samples of 24 fruit (12 small and 12 large fruit) were picked per three-tree replicate (randomly around tree), trees randomly selected in the orchard. Fruit were only picked from healthy trees with uniform canopy size.

2.3.3. Experiments 3 and 4

In 1999, 50 fruit per single-tree replicate were harvested at both sites (5 May 1999 for Somerset West and 26 April 1999 for Citrusdal) from the outside of the canopy at shoulder height at random around the tree. Fruit colour was determined based on the no. 36 Outspan colour chart for soft citrus, with eight being dark-green and one being fully coloured (orange). Fruit diameter (measured by electronic calliper) of each fruit was also measured. From the 50 fruit, a subsample of 12 fruit of average diameter was used for further quality determinations. In both years, juice was extracted using a citrus juicer. Juice was filtered through a layer of cheesecloth in 1998, and through two layers of muslin cloth in 1999 and juice content (%) was determined in 1999 by subtracting the weight of reamed peel from the original fruit weight and dividing by the original fruit weight. The juice was then used for the determination of the TSS by using a hand-held refractometer (Atago N1). Titratable acidity (TA), expressed as citric acid content, was determined by titration against 0.1 N sodium hydroxide, using phenolphthalein as an indicator. The TSS:TA ratio was calculated by dividing the TSS values by the TA values.

2.4. Statistical analysis

Analyses of variance were performed using the GLM (general linear models) procedure in the SAS (statistical analysis system) computer program (SAS, 1990). For the irrigation studies, values for the different parameters in both blocks, were averaged and their standard errors were determined since it was not a randomised block design. Therefore, the two blocks were compared with each other by using the averages and standard errors.

3. Results

3.1. Girdling

There were no significant trends in external fruit colour development due to girdling in both normal and deficit blocks at both sites in 1999 (Tables 2 and 3). At Citrusdal, fruit from girdled trees were slightly larger (by 0.2–17%), although not always significant (Table 3). In the deficit irrigation block, however, a quadratic trend was observed indicating a smaller stimulation in fruit size with later girdling. At Somerset West there was no trend in fruit diameter due to the girdling treatments (Table 2). Girdling in 1999 also had no significant effect on juice content (%) in both normal and deficit irrigation blocks at both sites.

Most of the girdling treatments in both years and at both sites increased the TSS, although not always significantly. Girdling carried out on 18 February 1998 at Somerset West significantly increased the TSS (by 4%) compared to the control, but there was no significant difference in TSS between different fruit sizes ($P = 0.7622$) (Table 4).

Girdling at Somerset West in 1999 significantly increased the TSS by 10% in the normal block when girdled on 8 February 1999 (Table 2), and girdling at Citrusdal in 1999 significantly increased the TSS by 7% ($P = 0.0603$) in the normal block when girdled on 29 December 1998, and in the deficit block by 11% when girdled on 19 January 1999 (Table 3). There were no other significant differences in TSS due to girdling at both sites.

There were no general trends in TA levels and TSS:TA ratios due to girdling in 1998 at Somerset West (Table 4) and in 1999 in normal and deficit blocks at both sites, except for a TA increase of 24% and a TSS:TA ratio decrease of 9% in the deficit block at Citrusdal. In 1998 at Somerset West, small fruit had a significantly higher (13%) TA content ($P = 0.0001$) and a lower TSS:TA ratio (12%) ($P = 0.0001$) than large fruit (Table 4).

3.2. Deficit irrigation

Deficit irrigation had no major effect on fruit colour development and juice content (%) in 1999 at both sites (Tables 2 and 3). Deficit irrigation also had no major effect on fruit diameter in 1999 except at Citrusdal (Table 3), where deficit irrigation decreased fruit diameter by 10%. Deficit irrigation increased TSS by 17 and 14% and TA levels by 9 and 10% in the small and large fruit samples in 1998

Table 4
The effect of summer trunk girdling performed in 1998 at different times on the internal fruit quality of 'Marisol' Clementines in the Somerset West area

	Date	Degrees of freedom	TSS	Acid	Ratio[a]
Treatment					
Control (no girdling)			10.03 bc[b]	1.18 a	8.60 a
Girdling	4 February 1998		9.93 c	1.18 a	8.48 a
Girdling	18 February 1998		10.46 a	1.22 a	8.67 a
Girdling	4 March 1998		10.40 ab	1.20 a	8.67 a
LSD			0.379	0.0656	0.467
Fruit size					
Small			10.19 a	1.27 a	8.04 b
Large			10.23 a	1.12 b	9.17 a
LSD			0.268	0.0464	0.330
Source					
Treatment		3	0.0161	0.4673	0.8073
Control vs girdling		1	0.1339	0.3349	0.9915
Girdling linear		1	0.0170	0.4601	0.4047
Girdling quadratic		1	0.0764	0.3049	0.6149
Size		1	0.7622	0.0001	0.0001
Treatment × size		3	0.8804	0.3975	0.2953

[a] Rounding off causes TSS/acid values to differ from actual ratio values.
[b] Means with the same letter are not significantly different at the 5% level (LSD).

at Citrusdal (Table 5) and in 1999 at Citrusdal by 2 and 11% and Somerset West by 4 and 13% (Tables 2 and 3). The TSS:TA ratio increased in 1998 at Citrusdal by 4–8% due to deficit irrigation, but deficit irrigation decreased the TSS:TA ratio in 1999 at Somerset West and Citrusdal by 7%. Neutron probe values for the normal and deficit irrigation blocks at Somerset West in 1999 are provided in Fig. 1.

3.3. Combination of girdling and deficit irrigation

At Somerset West (Table 2) and Citrusdal (Table 3) in 1999, the combination of girdling and deficit irrigation increased the TSS (10.50 ± 0.216 and 11.12 ± 0.364, respectively), compared to the ungirdled, normal irrigated control (9.73 ± 0.203 and 10.40 ± 0.191). The combination also increased the TA at Somerset West (1.14 ± 0.153; Table 2) and Citrusdal (1.13 ± 0.062; Table 3), compared to the ungirdled, normal irrigated control (1.00 ± 0.0423 and 0.98 ± 0.0382, respectively). The combination decreased the TSS:TA ratio at Citrusdal (10.05 ± 0.288), compared to the ungirdled, normal irrigated control (10.71 ± 0.307; Table 3).

Table 5
The effect of deficit irrigation during the summer months in 1998 on the internal fruit quality of 'Marisol' Clementines on Carrizo rootstock in the Citrusdal area (means ± standard errors)

	Diameter	TSS	Acid	Ratio[a]
Small fruit				
Normal irrigation	55.9 ± 0.542	10.0 ± 0.127	1.1 ± 0.033	9.0 ± 0.201
Deficit irrigation	51.9 ± 0.223	11.7 ± 0.282	1.2 ± 0.048	9.7 ± 0.324
% of control		117.0	109.0	108.0
Large fruit				
Normal irrigation	65.5 ± 0.420	10.1 ± 0.098	1.0 ± 0.020	9.8 ± 0.123
Deficit irrigation	62.9 ± 0.934	11.6 ± 0.244	1.1 ± 0.126	10.2 ± 0.486
% of control		114.0	110.0	104.0

[a] Rounding off causes TSS/acid values to differ from actual ratio values.

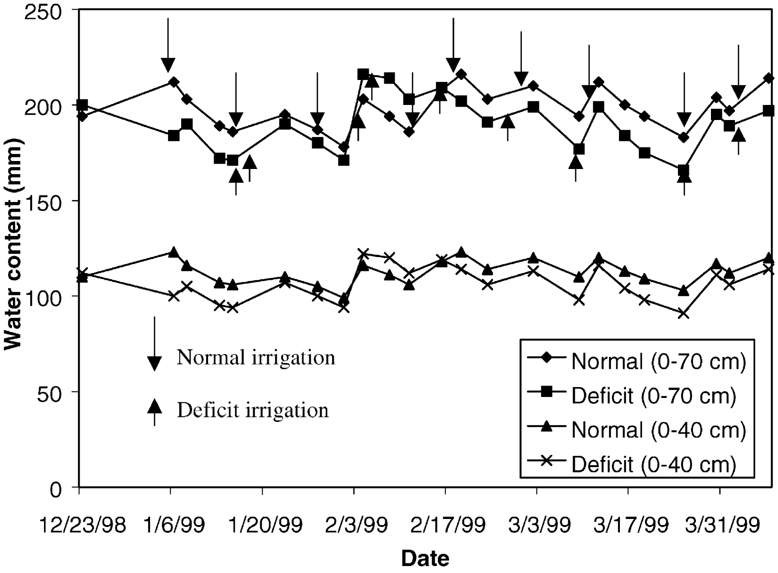

Fig. 1. Soil moisture content for 'Marisol' Clementines in 1999 at Somerset West in the normal and deficit irrigation blocks for 0–40 and 0–70 cm soil profiles from late December until time of harvest.

4. Discussion

The combination of girdling and deficit irrigation could be used as a cultural practice, since, according to Goell and Cohen (1981), girdling intensifies moisture stress. Judging from our results in 1999 at both sites, it seems that although girdling and deficit irrigation conducted on its own increased the TSS, the combination of girdling and deficit irrigation enhanced the TSS increase.

Therefore, the combination of deficit irrigation and girdling would be advisable where fruit quality problems are experienced.

Significant increases in TSS due to girdling have been reported by Church (1933) on Navels and by Peng and Rabe (1996) on Satsumas. Although the increased TSS due to girdling was not always significant, our results confirm that girdling can be used to manipulate TSS levels in 'Marisol' Clementines as well.

The higher TA content and the lower TSS:TA ratio in small fruit, compared to larger fruit in 1998 at Somerset West, were expected according to Sites and Reitz (1949) and Krezdorn (1988).

Previous studies reported that deficit irrigation increases TSS levels in fruit of 'Salustiana' orange (Castel and Buj, 1990) and Satsumas (Peng and Rabe, 1998), increases juice acidity (Goell and Levy, 1970; Goell and Cohen, 1981; Goell, 1988; Sanchez-Blanco et al., 1989; Peng and Rabe, 1997), results in smaller fruit (Goell and Levy, 1970; Peng and Rabe, 1996) and a lower juice content (Goell and Levy, 1970). In the three deficit irrigation trials, the deficit irrigation resulted in no marked effects on the fruit colour and juice content, but caused a slight decrease in fruit diameter, an increase in TSS and TA levels, and a slight decrease in TSS:TA ratios. The reason for the large differences between the studies in 1998 and 1999, especially in the TSS:TA ratios, may be related to more representative fruit sampling in 1999 (more samples taken in 1999). Deficit irrigation can, therefore, be utilised as a cultural practice to improve internal fruit quality, especially for cultivars producing fruit of marginal quality. The timing of introduction of the deficit irrigation, however, seems to be important, i.e. it should commence as soon as possible after the physiological fruit-drop period.

No major differences between the water content of the deficit and normal blocks is evident from Fig. 1. This is unexpected, since the deficit block received 66% of the normal block. Therefore, the normal block was probably continuously over-irrigated with excess being lost to drainage. The 'deficit' of 66% of normal irrigation thus still resulted in adequate moisture levels in the root zone and the trees may not have been subjected to stress levels.

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References

Barry, G., Veldman, F., 1997. A preliminary study on the effect of girdling on fruit set and quality of Ambersweet mandarin hybrid. Citrus J. 7, 25.

Castel, J.R., Buj, A., 1990. Response of Salustiana oranges to high frequency deficit irrigation. Irrig. Sci. 11, 121–127.
Church, C.G., 1933. Composition of juice of oranges from girdled and normal trees. Calif. Citrogr. 18, 348–349.
Cohen, A., 1984. Effect of girdling date on fruit size of Marsh seedless grapefruit. J. Hort. Sci. 59, 567–573.
Dasberg, S., 1992. Irrigation management and citrus production. Proc. Int. Soc. Citric. 3, 1307–1310.
English, M., Raja, S.N., 1996. Perspectives on deficit irrigation. Agric. Water Mgmt. 32, 1–14.
Erickson, L.C., Richards, S.J., 1955. Influence of 2,4-D and soil moisture on size and quality of Valencia oranges. Proc. Am. Soc. Hort. Sci. 65, 109–112.
Ginestar, C., Castel, J.R., 1996. Responses of young Clementine citrus trees to water stress during different phenological periods. J. Hort. Sci. 71, 551–559.
Goell, A., 1988. Citrus irrigation in Israel — making do with less water. In: Proceedings of the Sixth International Citrus Congress, pp. 699–706.
Goell, A., Cohen, A., 1981. Combining irrigation regimes with girdling techniques in citrus trees (a new experimental mode). Proc. Int. Soc. Citric. 2, 514–518.
Goell, A., Levy, Y., 1970. The effects of irrigation stress on fruit quality (Abstract). Proc. XVIII Int. Hort. Congr. 1, 221–222.
Goren, R., Monselise, S.P., 1971. Effects of ringing on yields of low-bearing orange trees (*Citrus sinensis* (L.) Osbeck). J. Hort. Sci. 46, 435–441.
Hochberg, R., Monselise, S.P., Costo, J., 1977. Summer girdling and 2,4-D effects on grapefruit sizes. HortScience 12, 228.
Iwahori, S., Matsumoto, R., Oohata, J.T., 1977. Effects of trunk ringing and defoliation on maturation of Ponkan (*Citrus reticulata* Blanco) fruit. Bull. Fac. Agric. Kagoshima Univ. 27, 1–6.
Krezdorn, A.H., 1960. The influence of girdling on the fruiting of Orlando tangelos and navel oranges. Proc. Fla. State Hort. Soc. 73, 49–52.
Krezdorn, A.H., 1988. Pollination and related factors affecting fruit quality. In: Ferguson, J.J., Wardowski, W.F. (Eds.), Factors Affecting Fruit Quality. Proceedings, Citrus Short Course. Citrus Research and Education Center, Lake Alfred, FL, pp. 43–48.
Peng, Y.H., Rabe, E., 1996. Effect of summer trunk girdling on fruit quality, maturation, yield, fruit size and tree performance in Mihowase Satsumas. J. Hort. Sci. 71, 581–589.
Peng, Y.H., Rabe, E., 1997. Postharvest storage behaviour, respiration rate and ethylene evolution of fruit from deficit and normal irrigation in Mihowase Satsuma trees. J. South Afr. Soc. Hort. Sci. 7, 44–47.
Peng, Y.H., Rabe, E., 1998. Effect of differing irrigation regimes on fruit quality, yield, fruit size and net CO_2 assimilation of Mihowase Satsuma. J. Hort. Sci. Biotechnol. 73, 229–234.
Sanchez-Blanco, M.J., Torrecillas, A., Leon, A., Del Amor, F., 1989. The effect of different irrigation treatments on yield and quality of Verna lemon. Plant Soil 120, 299–302.
SAS, 1990. SAS/STAT User's Guide, Version 6, 4th Edition, Vols. 1 and 2. SAS, Cary, NC.
Shalhevet, J., Bielorai, H., 1978. Crop water requirement in relation to climate and soil. Soil Sci. 125, 240–247.
Sites, J.W., Reitz, H.J., 1949. The variation in individual Valencia oranges from different locations of the tree as a guide to sampling methods and spot-picking for quality. I. Soluble solids in the juice. Proc. Am. Soc. Hort. Sci. 54, 1–10.
Wardle, P., 1991. Science and Water Smooth Growing. Orchard, New Zealand, pp. 20–22.
Yakushiji, H., Nonami, H., Fukuyama, T., Ono, S., Takagi, N., Hashimoto, Y., 1996. Sugar accumulation enhanced by osmoregulation in Satsuma mandarin fruit. J. Am. Soc. Hort. Sci. 121, 466–472.
Yakushiji, H., Morinaga, K., Nonami, H., 1998. Sugar accumulation and partitioning in Satsuma mandarin tree tissues and fruit in response to drought stress. J. Am. Soc. Hort. Sci. 123, 719–726.