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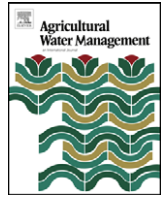
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Contents lists available at ScienceDirect

Agricultural Water Management

journal homepage: www.elsevier.com/locate/agwat

The effects of drought on the water use, fruit development and oil yield from young olive trees

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ARTICLE INFO

Article history:

Received 25 August 2008

Accepted 1 June 2009

Available online 5 July 2009

Keywords:

Olive

Drought

Leaf water potential

Stem sap flow

Stomatal conductance

ABSTRACT

In Marlborough, New Zealand, olives are becoming an important crop alongside grapes. However, despite olives being drought resistant, they are generally planted on the poorer free-draining soils. Also, with the strong increase in cropping area, the demand for irrigation water has increased dramatically. In this research, we investigate the impact of short-term water stress on plant physiological processes, crop yield and oil quality in Marlborough, New Zealand. For that purpose, during the dry summer of 2000–2001, two trees were kept without irrigation for 64 days while two neighbouring trees were irrigated following standard practice. The trees were measured for transpiration (E), leaf and stem water potential (Ψ_L and Ψ_S), every other day, from dawn to dusk for three weeks from just before irrigation was started up again. All four trees were wired up for measuring stem sap flow (T) which was recorded hourly and a basic meteorological station provided weather data. Fruit and shoot development was measured weekly. It was found that under the short period of dry conditions with soil moisture (θ) dropping to <5%, olive trees kept functioning at a very low level with Ψ_L and Ψ_S reduced from -1 to <-4.0 MPa (T) reduced from 20 to 5 mm/h and (E) reduced from 1.5 to 1.0 mmol m⁻² s⁻¹. Within 10 days of restarting irrigation all these parameters were back to pre-drought levels. Both fruit and shoot growth came to a standstill within a week after drought was induced. During the first few days after re-watering, a high variability in Ψ_L was found between leaves from the same trees. This variability disappeared after ~six days. Shoot growth did not recover after re-watering but fruit growth rate, became the same as for continuously irrigated trees within days, but fruit size did not manage to recover before harvest. Yield from the dry trees was low because berry and pit weight were reduced by almost 50% at harvest, had a lower oil and percentage and were lower in phenolics. Stem sap flow was found to give a very good continuous measurement for the hydration status of the olive trees.

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1. Introduction

Marlborough is New Zealand's largest grape-growing region and many of the area's wines are recognised internationally for their high quality, good value, and unique flavours. While vineyard plantings expand rapidly across the region, there has also been widespread interest in growing olive trees (*Olea europaea* L.) for oil production. Marlborough currently has ~250 ha of olive trees and produces about 25% of the country's total olive oil production. New trees are being planted in more marginal areas, on lighter soils that are traditionally quite dry. With these new plantings, irrigation is being applied to supplement the low summer rainfall. As these trees mature, their demand on the limited water resources becomes more urgent.

The aim of the New Zealand olive industry is to produce a high quality, boutique-style oil for the export market, building on the success that has already been achieved with wines from the region. To be successful, the industry will need to achieve a high crop production that consistently yields oil of the desired quality and flavour characteristics. In practice, the growers need a good understanding of the water and nutrient requirements of the trees, as well as knowledge of the potential impact of irrigation on the fruit yield and composition of the olive oil. Adequate irrigation to sustain tree water use requires knowledge of how much water the trees are using in relation to the soil and climate as well as the tree size.

The economic benefits of irrigation to improve olive production have been shown across all olive-growing regions of the world (Michelakis, 1990; Goldhamer et al., 1994; d'Andria et al., 1999; Alegre et al., 2000). In our research, we have been working with the local council on issues of water allocation (Green et al., 2002). Extensive field experiments have been carried out to measure tree

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water use in relation to the size and age of the trees, the local microclimate and water-status of the root-zone soil. This research has led to an understanding of how much water olive trees can use when there is an adequate supply of water in the tree's root-zone (Fernandez and Moreno, 1999). Predictions can be made of the short-term and long-term rates of tree water use based on computer models that have been developed (Dichio et al., 1999; Fernandez et al., 1999; Fernandez et al., 2003). It has been found that even under severe water stress (-6 MPa) photosynthetic activity in olive trees continues to be relatively high (about 10%) compared with other tree crops of well watered plants (Xiloyannis et al., 1999) as olive leaves are well adapted to conditions of water shortage (Connor and Fereres, 2005). In this research, we try to elucidate the impact of short-term water stress on plant physiological processes, crop yield and oil quality in Marlborough, New Zealand.

We investigate the response of olive trees to water stress, by observing the change in stem sap flow (T , kg h^{-1}), leaf water potential (Ψ_L , MPa) and stomatal conductance (g , mm s^{-1}). While both Ψ_L and g are well-established parameters for plant water stress, sap flow was first developed in the 1930s and has more recently been refined by Green and Clothier (1988). Fernandez et al. (2001) showed that sap flow measurements are well suited to quantify transpiration losses from olive trees. Dichio et al. (1999) also showed a good correlation between stem sap flow measurements and actual transpiration as measured with lysimeters, with an error of only 7–8%.

In this study we examine the effect of a brief period of severe drought on total plant hydraulic conductance and we quantify the influence of this stress on fruit yield and oil quality.

2. Materials and methods

The experimental site was in the middle of a 12 ha grove of 5-years-old Australian Verdale olive trees. The 5-years-old trees were ~ 3 – 4 m tall and they were planted at a spacing of 5 m in the row and 6 m between the rows. The orchard floor was grassed except for a 1-m wide strip of bare soil under each row of trees. The soil was a Renwick stony silt loam that comprised 25–50% (V V^{-1}) stones and held just 72 mm of water in the top 1.0 m of the soil profile (derived from physical and hydraulic properties in the NZ Soil Database at Landcare Research). All measurements reported here were carried out during the 2000–2001 growing season. The orchard trees were irrigated using a single row of 2 L h^{-1} pressure-compensated drippers spaced at 0.6 m. The timing and amount of irrigation were determined by the grower. The standard irrigation regime in the grove was set to $20 \text{ L tree}^{-1} \text{ day}^{-1}$, which was in accordance with results from previous experiments done in this olive grove. From sap flow measurements in previous experiments on the same site, maximum water use of olive trees during the warmest week of summer in Marlborough was estimated to be ~ 25 L for small olive trees (2-years-old), 175 L for medium olive trees (4-years-old) and 525 L for large olive trees (8-years-old) (Green et al., 2000).

During the measurement period (October–April) of the research presented here, irrigation on two of the trees was turned off completely over the middle of summer from 15 January 2001 to 20 March 2001. After this period of 64 days without irrigation, the trees were subsequently re-watered at a rate of $135 \text{ L tree}^{-1} \text{ wk}^{-1}$, which was the same irrigation rate as received by the two normally irrigated neighbouring trees, of a similar size, that were used for the comparison.

Soil water holding capacity was calculated on the basis of the available water in the soil between Field Capacity (-0.01 MPa) and Permanent Wilting Point (-1.5 MPa). Changes in soil water content were measured weekly using a digital TDR (Time Domain

Reflectometer, Tektronix Model 1502C, Beaverton, OR, USA). A laptop computer was used to control the TDR and to record and analyse the TDR waveforms. Analysis of the waveforms followed a procedure similar to that of Baker and Allmaras (1990), using the general equation of Topp et al. (1980) to calculate the soil's volumetric water content (θ , L L^{-1}). A total of ten 0.6-m long and ten 0.3-m long waveguides were installed vertically into the soil. One pair of TDR rods (30 and 60 cm) was positioned 100 cm north and one set 100 cm south of the base of each of the four olive trees. Irrigation was in first instance applied by means of a dripper line with two 2 L h^{-1} drippers for each tree. Because the irrigation dripper line was positioned at 40 cm west of the trees, extra pairs of TDR rods were placed in between the dripper line and the two irrigated trees. The total amount of water in the root-zone soil, to a depth of 0.6 m, was approximated using the average of the probes around the irrigated and dry trees.

Diurnal changes in leaf water potential (Ψ_L , MPa) were measured using a pressure chamber (PMS Instrument Company, Corvallis, OR, USA). A value of stem water potential (Ψ_S) was obtained by assuming equilibrium with a foil-covered leaf in the shade near the base of the tree (Alarcon et al., 2003). Corresponding values of leaf stomatal conductance (g , mm s^{-1}) were measured using a steady-state porometer (model LI-1600M, Licor Inc., NE, USA). Measurements at the leaf scale were carried out for a period of about 6 weeks beginning just before the dry trees were re-watered. The purpose of such measurements was to monitor the dry tree's recovery following the short-term period of water stress. Over a period of three weeks, stomatal conductance was measured 4–6 times a day. For each measurement, four leaves were randomly chosen from the north, east, south and west sides of each tree, covering both sunny and shady sides of the trees depending on the time of day.

Sap flow in the trunk of all four trees was measured using the compensation heat-pulse technique (Swanson and Whitfield, 1981). A single set of heat-pulse probes, comprising of a linear heater probe (1.6 mm in diameter) and two temperature probes (with sensors at depths of 5, 12, 21 and 32 mm below the bark) was installed in a clear section of trunk, at a height of about 0.5 m above the ground. One temperature probe was placed 5 mm below the heater probe and the other was placed 15 mm above the heater. The probes were installed into parallel holes drilled radially into the tree trunk. Once every 30 min, the heater generated a 0.5 s pulse of heat and the two temperature probes were used to monitor the corresponding temperature changes as the heat-pulse was transmitted through the sapwood, both by conduction through the woody matrix and convection along with the moving sap stream. A data logger (Model CR10X, Campbell Sci., UT, USA) was used to activate the heat-pulse and to record the sap flow automatically. To compensate for any probe-induced wounding, a theoretical calibration factor was used to calculate the volumetric sap flow rate (Green and Clothier, 1988).

Shoot and fruit growth were measured non-destructively during the course of the growing season. A total of 10 shoots from each tree (5 on north side and 5 on south side) were tagged at the start of the experimental period. Individual lengths of each tagged shoot were recorded once per fortnight. At the same time, the diameter and length of 5-tagged fruit were recorded on 3 branches on the north and 3 on the south side of each tree.

Total yield and fruit number per tree were recorded at harvest time, as well as the average weight of individual fruits. The fruit were further analysed in the laboratory for oil (AOAC, 1995 960.39) and moisture content (AOAC 950.46 mod), pit/fruit ratio, peroxide value (AOAC 965.33), free fatty acids (AOAC 940.28), fatty acid profile (AOAC 963.22) (Horwitz, 1995) and total phenolics (Montedoro et al., 1992a,b).

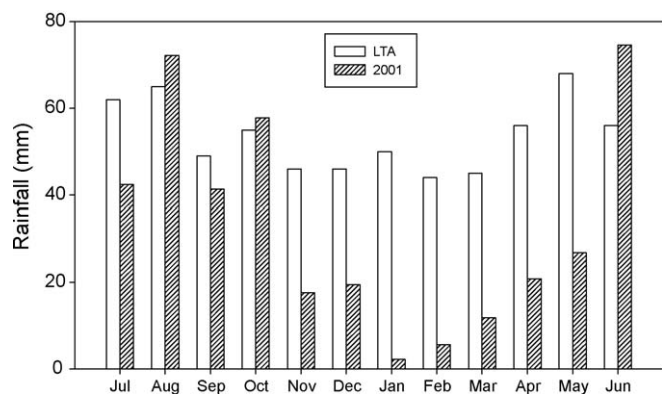


Fig. 1. Average monthly rainfall for 1 July 2000–30 June 2001, compared with the long term average (LTA) for Marlborough, New Zealand.

3. Results and discussion

The 2000–2001 growing season was one of the driest on record in the Marlborough region. Less than half of the average rainfall occurred during November and December and only a trace (i.e. 2 mm) of rain was recorded in January (Fig. 1). The orchard received just 13 mm of rainfall during the entire experimental period.

Fig. 2 shows TDR measurements of soil water content. The field capacity in the top 0.3 m of the Renwick stony silt loam is around 38% ($V V^{-1}$). However, the profile becomes very stony (>50% stones) at depths below about 0.4–0.5 m. Thus, the soil has quite a low water-holding capacity of just 72 mm m^{-1} of plant-available water. Within about a week of stopping the irrigation, soil moisture levels of the non-irrigated 'dry' trees dropped to about 15% ($V V^{-1}$) in the top 0.3 m of the profile. Irrigation maintained the moisture levels of the topsoil at around 30% ($V V^{-1}$) for the irrigated trees. Soil moisture levels at 0.3–0.6 m deep remained above about 25% for irrigated trees, while corresponding soil moisture levels around the dry trees, at depths of 0.3–0.6 m, dropped to under 5% (Fig. 2).

For the Renwick stony silt loam soil, the readily available water (RAW) was estimated to be at 18% ($V V^{-1}$) with field capacity (FC) at 30% ($V V^{-1}$). As can be seen from Fig. 2, the soil around the dry trees was almost permanently below the RAW level while the wet trees received more than ample water from the surrounding soil which was kept at moisture levels well above RAW. Olive trees can potentially grow an extensive but shallow root system without any dominant tap root (Fernandez and Moreno, 1999; Xiloyannis, 2003) especially under irrigated conditions. However, the olive

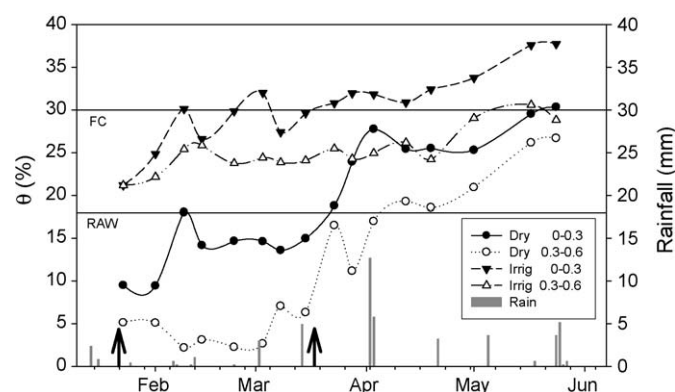


Fig. 2. Soil moisture (θ) change under Irrigated trees and Dry trees (arrows indicate when Dry tree irrigation stopped and started again). The FC and RAW line indicate the soil moisture levels at field capacity and readily available water, respectively.

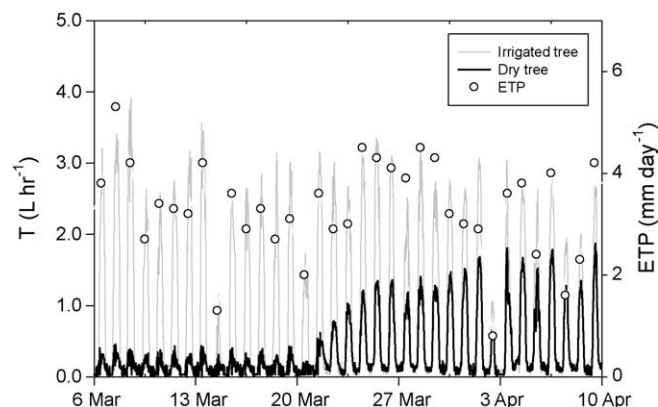


Fig. 3. Stem sap flow (T , $L h^{-1}$) measured in the trunk of 5-year-old olive trees (Australian verdale), compared to the potential evapotranspiration (ETP). The increase in stem sap flow for the dry trees (arrow) on 20 March corresponds with the recommencement of irrigation of the dry trees.

trees in this grove have always been well watered and were found to have only a very shallow rooting system not exceeding 1 m in depth. As the soil in the grove was shallow with a very high stone fraction below 50 cm, together with the very low rainfall, it was unlikely that the trees were capable of finding any water outside the supplied irrigation water.

On warm sunny days, the maximum sap flow in irrigated trees was about 3 $L h^{-1}$ (Fig. 3), and this equates to 30 $L tree^{-1} day^{-1}$. The dry trees exhibited a high degree of water stress. Following just two months without irrigation or significant rainfall, sap flow in the dry trees peaked at just 0.4 $L h^{-1}$ (Fig. 3). Thus, transpiration losses from the dry trees, prior to irrigation, were a factor of 8–10 times less than for the irrigated trees.

The leaf water potential (ψ_L) of the sunny leaves varied between -0.4 MPa at dawn to about -2.1 MPa at noon for the irrigated trees. The stem water potential, ψ_S , stayed much higher at about -1.4 MPa (Fig. 4). On sunny days prior to irrigation, and after a period of at least 2 months without rainfall, the pre-dawn ψ_L of the dry trees went off-scale for our pressure bomb at $\ll -4.0$ MPa (Fig. 4).

Despite the very high-level drought stress we had induced on the dry trees, the olive leaves kept functioning albeit at a reduced capacity. Olive trees typically use osmotic adjustment as drought avoidance mechanisms to maintain turgor potential between the

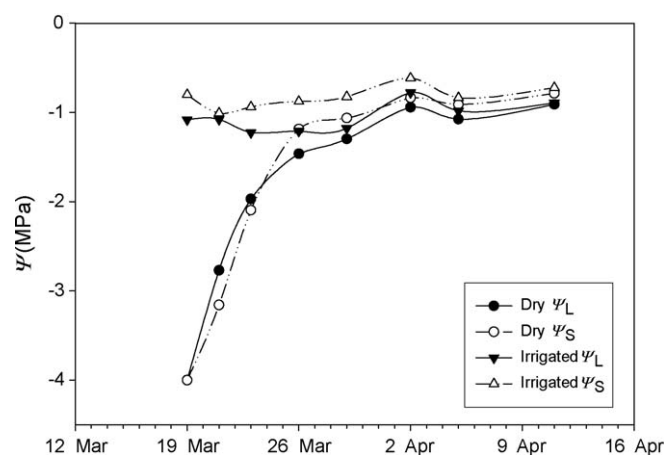


Fig. 4. Changes in daily leaf and stem water potential (ψ_L and ψ_S respectively) of 'Irrigated' and non-irrigated ('Dry') trees that had been without irrigation from 15 January. For the Dry trees, irrigation was restarted on 20 March. Solid lines are average ψ_L (50% sun, 50% shade) and dotted lines are ψ_S .

Table 1

Regression coefficient (R^2 value) between the different water stress indicators [Leaf water potential (Ψ_L), Stem sap flow (T), stomatal conductance (g), stem water potential (Ψ_S) and soil moisture (θ)].

	Ψ_L	T	g	Ψ_S	θ	
Ψ_L		17.1*	25.9***	85.7***	93***	
T	78.4***		52.2***	21.0**	18.0 ns	Dry
g	69.1***	68.6***		26.4**	36.2**	
Ψ_S	85.7***	69.7***	64.5***		90.9***	
θ	5.4 ns	0.5 ns	0.1 ns	1.3 ns		

ns= non significant, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

tissues (Dichio et al., 2006). They are capable of creating the very low Ψ_L needed to utilise water from very dry soils even at very low matrix potentials (Sofo et al., 2007). Here we observed leaf water potentials that dropped below -4.0 MPa (i.e. the measurement limit of our pressure bomb). The olive leaves may well have dropped to much lower leaf water potentials. For example (Dichio et al., 1994) previously reported olive leaves functioning at pre-dawn leaf water potentials of -6 MPa, while (Vitagliano and Sebastiani, 2002) reported values as low as -8 MPa. They showed that at that stage, olive trees can lose almost 40% of their tissue water content and still maintain their re-hydration capacity. This is due to establishment of a high gradient of water potentials between the tissues, roots, and soils, which allows the trees to take up water even in soil potentials below permanent wilting point of -1.5 MPa (Xiloyannis, 2003). However, water use is reduced in very dry soils. Dichio et al. (1994) reported a 70% reduction in leaf transpiration when $\Psi_p < -0.9$ MPa.

As expected, there was a significant positive correlation ($R^2 = 93.0$) between soil moisture content and Ψ_L for the dry trees (Table 1). The leaves needed to induce very low water potentials in order to extract water from the very dry soils. A significant positive correlation ($R^2 = 52.2$) was also found between leaf stomatal conductance of the dry trees and stem sap flow. Consistent diurnal changes gave rise to a high negative correlation between leaf water potential and both stem sap flow and stomatal conductance ($R^2 = 78.4$ and 68.1 , respectively) in the irrigated trees. It made little difference for the correlations whether Ψ_L or Ψ_S was used. However, our results showed almost no correlation between pre-dawn plant water potential and soil moisture for the irrigated trees, simply because plant water potentials are in equilibrium with soil water potentials. Our results are counter to the findings of Giorio et al. (1999) who reported a very strong positive relationship between stomatal transpiration rates, leaf water potentials, and soil moistures all increased but at

different rates (Fig. 5). However Giorio et al. (1999) reported that by the end of the season, even without an increase of soil moisture, there was still a significant increase in both leaf water potential and relative water content.

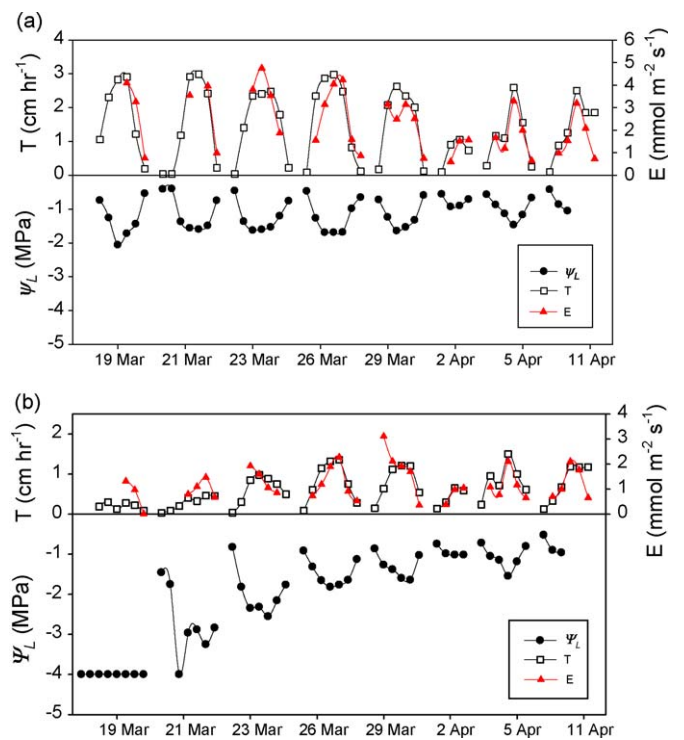


Fig. 5. (a) Relationships between leaf water potential (Ψ_L), stem sap flow (T) and transpiration (E) for irrigated olive trees in Marlborough, New Zealand. (b) Relationships between leaf water potential (Ψ_L), stem sap flow (T) and transpiration (E) for re-hydrating olive trees in Marlborough, New Zealand, after they had been without water for 64 days.

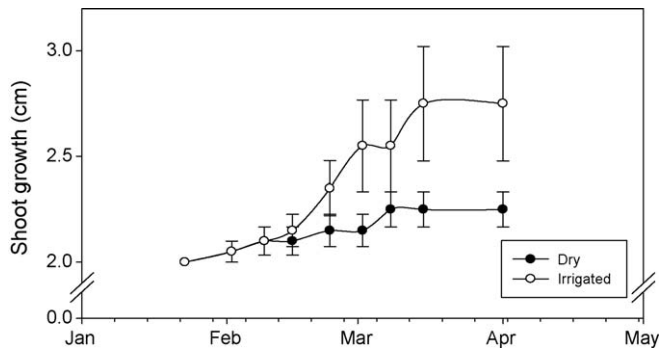


Fig. 6. Shoot growth (cm) on irrigated and dry olive trees. Measurements were started 2 cm back from shoot tip.

The severe water stress of the dry trees resulted in a reduction in both vegetative and reproductive growth. Initial rates of vegetative development were similar for the irrigated and dry trees. However, as the season developed, shoot growth continued for much longer in the irrigated trees compared with the dry trees (Fig. 6). It took about 1 month before shoot growth slowed in the dry trees.

In contrast, fruit growth on the dry trees slowed almost immediately once the irrigation was halted (Fig. 7). Some nine weeks after irrigation was stopped, fruit size from the dry trees was about 40% of the irrigated trees. Surprisingly, no fruit drop was observed despite there being very little growth in those 9 weeks. Once irrigation water was reapplied to the dry trees, some 64 days later, fruit growth restarted. Size initially increased at a rate that was faster than fruit from the irrigated trees (Fig. 6). It is suggested that this initial fast growth of the fruit was caused by the re-hydration of the fruit as they re-establish a more optimal turgor level. As a result, a lower oil and higher moisture level was found in the fruit of the dry trees than in the irrigated trees. By the time of harvest, the irrigated trees yielded over 10.0 kg of fruit per tree while the dry trees yielded only 6.1 kg tree⁻¹. This difference in yield may well have been larger except for the fact that there was a very high fruit number on one of the two dry trees. The average weight of individual fruit was reduced from 4.0 to 2.4 g for wet and dry trees, respectively (Table 1).

Our findings are similar to those of d'Andria et al. (2000) who reported olive fruits from partially irrigated trees exhibited a

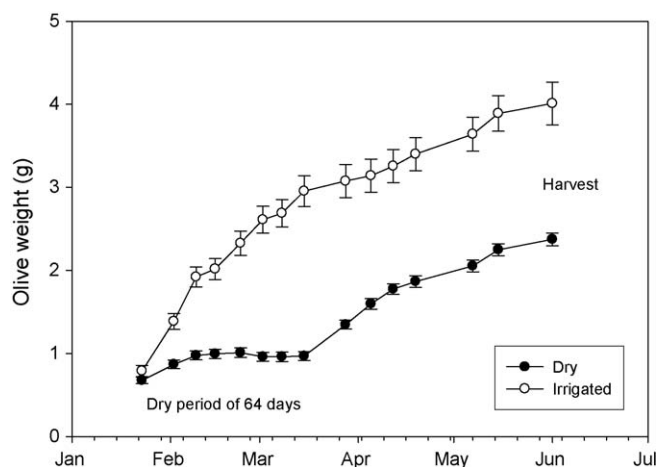


Fig. 7. Olive fruit size development during summer and autumn 2001, measured twice on 15 olives of the two irrigated trees (solid symbol) and similarly of dry trees (open symbol). The jump in fruit growth from the dry trees coincides with the commencement of irrigation on 20 March.

Table 2

Yield parameters (averages of $n = 2$) for Australian verdale olive trees that were not irrigated (dry trees) for 64 days during the summer of 2001 compared with fully irrigated trees.

	Dry tree	Irrigated tree	Significance
Yield (g tree ⁻¹)	6060	10079	***
Fruit/tree	2956	2229	ns
Berry weight (g)	2.06	4.52	***
Pit weight (g)	0.42	0.87	***
Flesh/pit	4.00	4.13	ns

ns = non significant, * $P < 0.05$, ** $P < 0.01$

*** $P < 0.001$.

slowing down of growth. Ippolito and Nigro (2002) reported that olive trees can absorb (translocate) water from their fruit under very dry conditions. Presumably this phenomenon is what we have observed here. After the irrigation was stopped, fruit size initially reduced due to a reduction in fruit turgor. Because the experimental trees in this trial were normally grown under irrigation, it seems likely that stopping the irrigation would produce a much larger response on these trees than would otherwise have been observed for trees grown under dry-land conditions. Dry-land trees would tend to develop a deeper root system and scavenge water when they need it, from deeper in the soil profile if it is present there. Following autumn rainfall, the fruit regained some of their fruit size, though the recovery was not enough to catch up with the fruit from the irrigated treatments. Ippolito and Nigro (2002) also mentioned a clear slow-down in fruit growth during the process of stone hardening, which here coincided with at the driest period of the growing season. The higher number of fruit in dry trees (although not significant), might have created a greater competition for already scarce resources and contributed to the reduction of average fruit and pit weight (Table 2).

While irrigation of these young trees almost doubled the total fruit yield on this very dry year, the corresponding oil content of olives from the irrigated tree was 10.6% (g g⁻¹) compared with 8.3% (g g⁻¹) for fruit from the dry trees (Table 2). The total oil yield from the irrigated trees (1.06 L tree⁻¹) was twice that from the dry trees (0.51 L tree⁻¹). Both treatments were harvested at the same time. This is however unlikely to have had negatively contributed to the amount and quality of the oil from the dry tree as previous research (Greven et al., 2003) showed maturity was reached 4 weeks earlier in non-irrigated trees than in irrigated trees.

The composition of the oil was similar for the two irrigation treatments. The biggest difference was a 33% lower level of phenolics in oil from the dry trees (Table 3). This could be an advantage for oil quality because phenolics are associated with some of the bitter flavours. Nonetheless, both oils were well within the international standards for extra virgin olive oil. It is generally considered that oil synthesis keeps pace with fruit development. In this case however, because of the extra-dry treatment, metabolism of the fruit was probably inhibited. This would explain why both

Table 3

Oil quality attributes for olives from irrigated (Wet) and water stressed (Dry) trees.

Treatment	Wet	Dry	Extra virgin
Oil yield			
Crude oil (g/100g)	10.6	8.3	
Moisture (g/100g)	56.05	55.95	
Peroxide value (mEq/kg oil)	4.1	3.95	<20
Free fatty acids (g/100 g oil)	0.32	0.225	<1.0
Fatty acid methyl esters (g/100 g oil)	88.2	92.4	
Unsaturated fatty acids (%)	87.3	86.8	
Phenolics (mg/L)	675	450	

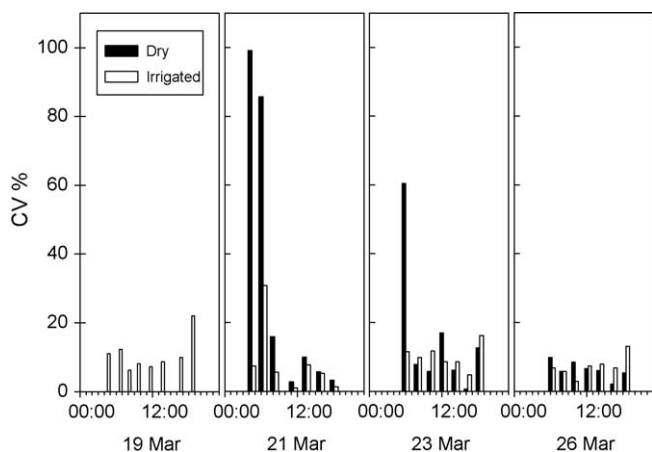


Fig. 8. The standard deviation of the measured daily Ψ_L for four days in Australian verdale olive trees. Irrigation was re-applied after 64 days of drought, early on 21 March. For the Dry trees, the standard deviation for 19 March was nil because Ψ_L reached -4.0 MPa, which was the maximum on the pressure bomb scale, for all measurements.

fruit growth and oil accumulation were reduced by a similar fraction.

When the dry trees were re-irrigated, it appears that physiological processes soon recovered back to normal levels after about one week (Figs. 3 and 4), in accordance with similar data found in olive trees subjected to drought and light excess (Angelopoulos et al., 1996). Such a quick recovery from water stress has previously been reported by Fernandez et al. (1997) who worked near Seville in Spain under very low rainfall conditions but on soils with much higher water holding capacity (230 mm m^{-1}) than the free-draining Renwick silt loams (72 mm m^{-1}) of the current research. They found both Ψ_L and g of olive leaves take some two to three days to recover following a re-watering event from $\Psi_L = -3.7$ MPa. In the present work, different positions on the same tree yielded values of Ψ_L that ranged from -1.5 to <-4.0 MPa just after the recovery irrigation. Fig. 8 shows that values of Ψ_L measured immediately after irrigation was turned on were highly variable ($CV \sim 99\%$). This variability was reduced over the next two days when the CV in Ψ_L from the dry trees agreed more closely with that from the irrigated trees (Fig. 8). Alarcon et al. (2003) related the variation in Ψ_L to the percentage of sunlit leaves. In our case, the recovery of Ψ_L in the different branches of the olive trees may, at least in part, be due to water uptake by roots closest to the drippers since irrigation water was applied from only one side of the tree. Thus, only those parts of the tree that were directly supplied with water from roots in the wetted area would be re-hydrated rapidly. This phenomenon has already been alluded to by Connor and Fereres (2005) but had not been shown in olives before.

The rapid recovery in fruit growth during those three weeks immediately after re-irrigation of the dry trees, when expressed on a weight basis, was probably the result of fruit re-hydration, rather than the fruit achieving additional solids growth or oil content. This was confirmed by the fact that the total moisture content at harvest was similar for fruit from both irrigated and dry trees. The total dry matter content was $55\% (\text{g g}^{-1})$, and the fruit/pit ratio was around 4.0 for both treatments. The fact that the pits were smaller in the dry trees provides evidence that water stress probably developed well before the end of pit development. It is likely that the dry trees were only able to commit resources to oil production once they had been irrigated and regained some of their water-status. This may partly explain the lower oil percentage in olives harvested from the dry trees.

4. Conclusions

It was found that olive trees kept functioning even at severe droughts be it at a very low level of physiological activity. Few species would be able to continue water uptake at a stem water potential of less than -4.0 MPa. Considering the permanent wilting point to be at -1.5 MPa – as for most other plants – is probably too high for olive trees and should be adjusted down. Stem sap flow and transpiration were severely reduced during the period of drought but both bounced back to pre-drought levels within one week of re-watering. Many other physiological processes slowed down almost immediately after irrigation was halted, which was shown by the arrested growth of both fruit and shoots. During the first few days after re-watering, a high variability in leaf water potential was found between leaves from the same trees. This variability disappeared after \sim six days, suggesting a slow redistribution of water through the plant from the limited number of watered roots. Shoot growth did not recover after re-watering. Fruit on the other hand showed, within days after re-watering, a similar growth rate to the fruit from continuously irrigated trees. However, fruit size did not manage to recover to the same weight as fruit from well-irrigated trees, which resulted in 50% lower fruit yield from the dry trees which had a lower oil percentage.

It was shown that despite the drought tolerance of olive trees, irrigation is required in dry years in Marlborough for economic production of olives. However, with a reduced availability of irrigation water in the region, there is little risk of plants dying and production will recover rapidly after a rainfall event or when water for irrigation becomes available.

The use of stem sap flow was found to be an easy method for continuous measurements of the hydration status of olive trees, giving a more accurate indication of diurnal changes than any of the more traditional measurements like leaf water potential or stomatal conductance.

Acknowledgements

Our thanks go to the Marlborough District Council and the New Zealand Foundation for Research Science and Technology who funded the study under contract no C06X0211, and to Mike Ponder who allowed us to carry out the experiment on his property.

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