Water use and yield of young and mature olive trees: A Review

Ketema Zeleke[1, 2]

[1]School of Agricultural and Wine Sciences, Charles Sturt University, Wagga Wagga
[2]EH Graham Centre for Agricultural Innovation, Wagga Wagga

1. Review of RIRDC Publication nos. 03/048 (2003) and 05/039 (2005)

Olive water use, relationship between water use and yield and irrigation management guidelines for optimum yield were investigated during two olive growing seasons (Sep-May) of 1999/2000 and 2000/2001 on four mature groves in South Australia (Waikerie, Two Wells, Balaklava, Greenock) in the RIRDC project no. UA-47A "*Olive water use and yield – monitoring the relationship*" (Nuberg and Yunusa, 2003). The summary characteristics of these groves is presented in Table 1.

Table 1: Physical, water use and yield characteristics of the olive groves.

	Waikarie	Two Wells	Balaklava	Greenock
Established	1988	1977	1970	1970
Cultivar	Kalamata	Verdale	Kalamata	Unknown
Spacing	8 m x 5 m	7 m x 7 m	10.5 m x 5 m	15 m x 5 m
Irrigation method	Microsprinkler	Drip	Drip	Rainfed
Ground cover	Grass and weed	Sprayed	Winter crop-fallow	Weeds
Annual rainfall (mm)	310	375	400	500
Annual ET (mm)	1850	1770	1850	1710
Water input (ML)	6.1	5.1	5.1	2.9
Water use ET* (mm)	619	652	523	317
Seasonal Kc*	0.39	0.40	0.31	0.23
Basal Kc, Kcb	0.23	0.32	0.14	0.12
Yield (kg/ha)	10998	13837	2165	2090
WUE* (kg/ML)	1777	2122	414	659

*ET – evapotranspiration; *Kc – crop coefficient; *WUE – water use efficiency

Each grower of these groves applied the irrigation amount as per their own management decisions. Actual evapotranspiration was determined from soil water balance of rainfall, irrigation and temporal change in soil water content. Soil water content was measured using neutron soil moisture probe. Transpiration was calculated/measured from weather data and sap flow measurement. The seasonal crop coefficient Kc, calculated as the ratio of actual evapotranspiration ETa (determined using soil water balance) to reference evapotranspiration ETo (determined from the weather data), is presented in Table 1. Basal crop coefficient Kb was calculated as a ratio of transpiration T to ETo. Water use efficiency WUE calculated as the weight of olives produced per unit of water use is shown in Table 1.

Water requirement during a growing season by a typical grove in South Australia was estimated for different crop canopy cover fractions (CCF) (Fig. 1a) with the corresponding crop coefficients Kc (Fig. 1b). The seasonal water requirement varies between 182 mm (1.82 ML) for groves with small trees and 1084 mm (10.84 ML) for groves with large trees. These correspond to Kc values of 0.10 and 0.70.

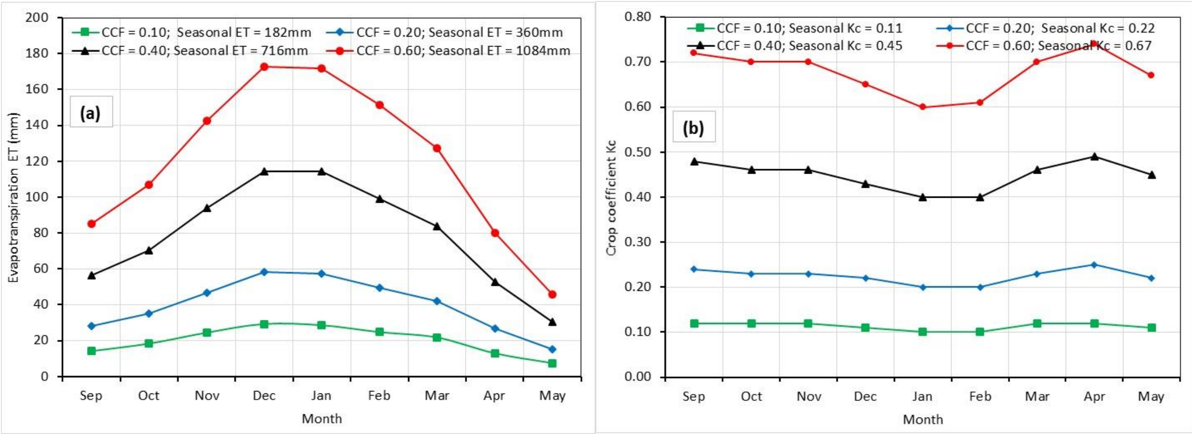

Fig. 1: Evapotranspiration (a) and crop coefficient (b) for olive groves of different canopy cover fraction (CCF) at different times of the olive growing season and the whole season, South Australia.

Water requirement of young olive trees in the period from planting to the first fruit bearing (from 1.5 to 5.5 years) was determined during four growing seasons of 2000/01 to 2003/04 at Weeroona Park, in South Australia in the RIRDC project no. DEB-2A "*From planting to harvest – A study of water requirements of olives, from planting to first commercial harvest*" (De Barro, 2005). The olive trees (cv. Manzanello) were planted in 8m x 5m spacings (250 trees/ha) and irrigated using micro-sprinklers. A research row was selected and isolated for growth and soil moisture monitoring (using C-probe) in a commercial grove. In the research row, irrigation was applied based on the C-probe reading while in the commercial groves there was not set rule for applying irrigation. Then the total amount of applied water was determined as the sum of irrigation and effective rainfall.

Irrigation was scheduled according to olive water demands as indicated by the C-probe placed at 10, 20, 30, 40 and 70 cm depths. The total water applied (irrigation + rainfall) and the corresponding Kc values during the tree development are shown in Fig. 2.

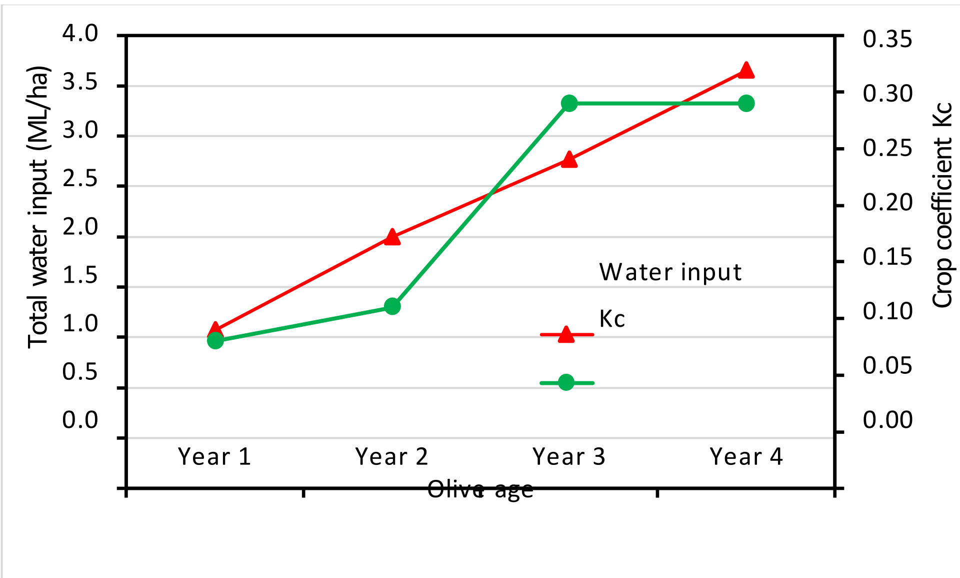

Fig. 2: Total water input (rainfall + irrigation) and crop coefficient Kc during the four years the young olive trees were monitored.

2. Main messages from the review

- There is a large variation in the amount of water applied to matured olives in the region which shows lack of consistent irrigation management strategy or guideline in olives. As a result, there is large variation in Kc, yield, and water use efficiency. In the same region, water use varied from 3.17 ML (Kc = 0.23) to 6.52 ML (Kc = 0.40).
- The relatively low Kc values show low water input in these groves, especially during mid-summer.
- There is large year to year variation in olive yield which is mainly due to the alternate bearing characteristics of olives. Management strategies to increase yield stability are required.
- The developed Kc factors (Fig. 1 and Fig. 2) can be used to calculate water requirement of olives, an initial guideline of how much water to apply, for mature and young olives, respectively. Growers can use these Kc values to estimate the optimum amount of irrigation and evaluate their irrigation practice.
- Young olive trees total water requirement varies almost linearly from year 1 (1.5 ML/ha) to year 5 (4.5 ML/ha). There is a tendency to over-irrigate by up to 1 ML/ha in young olive trees which will not result in any extra benefit.
- Water requirement (rainfall + irrigation) of mature olives is about 7ML/ha when there is no cover crop and 9ML/ha where cover crop is maintained throughout the season. The proportion of ET used as transpiration T depends on the water application method: 73% for drip irrigation; 63% for micro-irrigation; and about 50% for a rainfed grove. Therefore, controlling weeds and using drip irrigation increases water use efficiency. However, it should also be noted that cover crops improve soil structure and increase infiltration.
- The average WUE of 1380 kg/ML is within the range (800 – 1700 kg/ML) of values in the Northern hemisphere (Michelakis, 1990).
- While Kc can be used to determine the amount of irrigation, soil moisture monitoring devices should be used to determine the timing of irrigation. Different management scenarios can be set to trigger irrigation events.
- There is a direct positive relationship between olive yield and the amount of water applied. However, rainfed or water stressed groves might not immediately respond to irrigation and irrigation starts to have impact only when seasonal ET, which is approximately the same as water input, is more than 5 ML/ha. This shows the need for irrigating young olives with full water requirements so that it performs well right from the first fruit bearing. This has also implication when converting rainfed olives to an irrigated system.

3. The conclusions in light of recent research

Kc for mature olive trees

Crop water use ETc calculation is a two-step process from the relation ETc = ETo x Kc: first ETo is calculated from weather data next Kc is determined for the given crop and its growth stage. Since weather naturally varies from region to region, there is no point in comparing values for different regions. However, it is worth evaluating/comparing Kc values since the effect of crop is expressed using crop coefficient Kc which can be similar for different regions. For a typical CCF of 0.40, the proposed Kc values (0.40 – 0.50) were relatively low compared to the 0.55 – 0.78 values proposed by many olive researchers (e.g. Goldhamer et al., 1993; Zeleke, 2014; Grattan et al., 2006; Villalobos et al., 2000; Paco et al., 2019; Paco et al., 2014; Allen and Pereira, 2009).

Kc for young olive trees

The Kc value was found to be varying from 0.15 – 0.34 for the young olive trees of 1.5 – 5.5 years old. In the RIRDC Publication no. 05/039 (De Barro, 2005), CCF was not measured although crop coefficient mainly depends on canopy cover. Most of the crop factor studies in literature separate Kc into basal crop coefficient Kcb and the evaporation component Ke. For young olive trees, Puppo et al. (2019) developed a linear regression between basal crop coefficient (Kcb) and canopy light interception from which they determined mid-season Kcb of 0.35. For young irrigated groves of different ages, Testi et al. (2004) reported Kc of 0.19 (for 2 years with CCF = 0.05), Kc of 0.25 (for 3 years with CCF = 0.15), and Kc of 0.35 (for 3 years with CCF = 0.25). Similarly, Puppo et al. (2019) determined Kc using drainage lysimeter and reported that water consumption and Kcmid (Kc summer) increases with the age of trees and canopy cover as Kcmid = 0.031 (age) + 0.086. This shows that Kcmid = 0.14, 0.15, 0.21, 0.25, 0.30 for 1 yr, 2 yr, 3 yr, 4yr, 5yr, 6yr trees, respectively.

Water use

In south-eastern NSW, using soil water balance approach, Zeleke (2014) estimated that ET of olives is 7.23 ML (723 mm) and 6.73 ML (673 mm) in "on" and "off" years, respectively. This (7.23 ML) agrees with the matured olive trees water requirement of 7 ML reported in the RIRDC report no. 03/048 (Nuberg and Yunusa, 2003). Zeleke (2014) reported that soil water extraction is limited mainly to the top 60 cm, as observed by Nuberg and Yunusa (2003), and root distribution is concentrated mainly in the direction of olive row or drip lateral. This has important implication in the application of inputs such as fertiliser. The results of several studies have concluded that deficit irrigation strategies (sustained and/or regulated) are essential for sustainable olive growing in regions with limited water resources (Goncalves et al., 2020; Iniesta et al., 2009; del Campo et al., 2013, Zeleke and Ayton, 2014, Santos 2018). This means irrigation strategies require precise knowledge of the crop/tree response to water deficits during different phenological/growth stages. However these reports, Nuberg and Yunusa (2003) and De Barro (2005), assume full irrigation throughout the season.

4. Summary on water requirement of olives

Canopy cover fraction (CCF) is the main variable that determines crop's light interception and most of the variations in crop water consumption.

Ground cover (crop or weed) in the grove and irrigation method affects consumptive water use of olives. For example, Allen and Pereira (2009) have shown that when there is no ground cover, Kc is 0.50 while it is 0.70 when there is active ground cover.

Large volume of studies elsewhere and few studies in Australia show that full irrigation of olives is not necessarily required. Deficit irrigation, especially regulated deficit irrigation during the pit-hardening stage, enhances water use efficiency, water productivity, oil content, and increases oil quality. Deficit irrigation (sustained and/or regulated) reduces water use, increases radiation use efficiency and water use efficiency maintaining a good balance between crop load and water productivity. In regions with limited water resources, deficit irrigation strategies can be used for sustainable olive production (Goncalves et al., 2020)

Groves that had been under regimes of water-stress may not respond immediately to improved water-supply regimes as low input management can condition olive trees to produce low yield. As a result, it is important to have an optimum irrigation schedule right from the start when new groves are established. This should prime the trees for producing high and consistent yields. However, there is a tendency to apply too much water to young olives. Too much water use at these growth stages can affect the growth due to water logging, leach nutrients and waste precious water. Too little irrigation can affect the growth and the trees might not be able to respond to irrigation once fruiting begins.

5. **Completed subsequent research on water use and water use efficiency of olives in Australia and elsewhere is given the References section.**

6. **Research currently underway**

Satellite remote sensing has been found to be successfully used to estimate spatial and temporal variability of evapotranspiration of olives with strong correlation with ground truth measurements (Bchir et al., 2019). In this line, the University of New England (UNE) and NSW Department of Primary Industries (DPI) are undertaking a remote sensing project to asses and map dry matter production and yield of olive and other tree crops (https://olivebiz.com.au/wp-content/uploads/2019/11/Alex-Schultz-Remote-Sensing-The-Sky-Is-The-Limit-C.pdf).

7. **Future research needs/gaps to be undertaken**

Although there are some useful research reports on olive water requirement, yield, and water use efficiency in Australia, there are no controlled/replicated experiments on olive water use and water use efficiency for different environments, olive growth stages, and irrigation management scenarios. Since these reports were evaluating just the farmers' practices, there was no replication or rigorous statistical analysis in the trials. As a result, the differences can be just due to chance. So replicated trials at a single or multiple homogenous sites with different irrigation amounts and its effect on olive yield, water use efficiency, oil yield and quality is recommended. This will help to identify optimal management scenario.

Irrigation management in "on" and "off" seasons and water management scenarios to minimise yield fluctuation needs to be determined.

As water is becoming a high value resource, measuring optimum olive water requirement for maximum yield and gross margin which takes into account olive yield and input costs, including cost of water, is becoming important. Some studies have indicated that withholding or reducing irrigation during the pit-hardening period had only minor/no effect on fruit size, timing of maturity, oil content or quality while saving irrigation water (Rosecrance et al., 2015; Zeleke and Ayton, 2014; Zeleke et al., 2012). However, the effect of full irrigation, sustained and/or regulated deficit irrigation on olive yield, water use efficiency, and gross margin is yet to be determined in the region.

In order to develop guidelines for the use of soil moisture monitoring devices for olive irrigation scheduling (when to apply and how much), growth and yield response of young and mature olives for different soil moisture stress levels, as recorded by these devices, needs to be developed using replicated studies.

Olive evapotranspiration needs to be determined following the standard two-step process: reference evapotranspiration from weather data and measurement of potential evapotranspiration from well-watered and well-managed olive grove. Then develop relationship between Kc, ETc, and canopy cover using olives of different age at different times of the year. The separation of Kc into Kcb and Ke will help to relate Kcb to percent radiation interception by the tree canopy which is related to evapotranspiration. Basal crop coefficient Kcb is a function of canopy cover and canopy light interception. Romero-Trigueros et al. (2019), described ETc = Kr x Kc x ETo where Kr is reduction coefficient, calculated from the tree canopy diameter or percentage of soil shaded by the canopy.

8. References

Allen, R.G., Pereira, L.S. (2009). Estimating crop coefficients from fraction of ground cover and height. Irrig. Sci. 28:17–34.

Bchir, A., Mulla, D.J., Dhiab, A.B., Meriem, F.B., Bousetta, W., Braham, M. (2019). Assessing spatial and temporal variability in evapotranspiration for olive orchards in Tunisia using satellite remote sensing. Precission Agriculture' 19:431-436.

De Baro, J. (2005). From planting to harvest – A study of water requirements of olives, from planting to first commercial harvest. RIRDC Publication no. 05/039.

del Campo, M.G., Garcia, J.M. (2013). Summer deficit-irrigation strategies in a hedgerow olive cv. Arbequina orchard: effect on oil quality. *J Agr Food Chem* 61:8899–8905.

Goldhammer, D.A., Dunai, J., Fergusson, L. (1993). Water use of Manzanillo olives and responses to sustained deficit irrigation. Acta Hort. 335: 365–371.

Goncalves, A., Silva, E., Brito, C., Martins, S., Pinto, L., Dinis, L., Luzio, A., Martins-Gomes, C., Fernandes-Silva, A., Riberio, C., Rodrigues, M.A., Moutinho-Pereira, J., Nunes, F.M., Correia, C.M. (2020). Olive tree physiology and chemical composition of fruits aremodulated by different deficit irrigation strategies. *J Sci Food Agric.* 100: 682–694.

Grattan, S.R., Berenquer, M.J., Connell, J.H., Polito, V.S., Vossen, P.M. (2006). Olive oil production as influenced by different quantities of applied water. *Agr. Water Manage* 85:133–140.

Iniesta, F., Testi, L., Orgaz, F., Villalobos, F.J. (2009). The effects of regulated and continuous deficit irrigation on the water use, growth and yield of olive trees. *Eur J Agron* 30:258–265.

Michelakis, N. (1990). Yield response of table and oil olive varieties to different water use levels under drip irrigation. Acta Hort. 286: 271–274.

Nuberg, I., Yunusa, I. (2003). Olive water use and yield – monitoring the relationship. RIRDC Publication no. 03/048.

Paço, T.A., Paredes, P., Pereira, L.S., Silvestre, J., Santos, F.L. (2019). Crop coefficients and transpiration of a super intensive Arbequina olive orchard using the dual Kc approach and the Kcb computation with the fraction of ground cover and height. Water, 11:383.

Paço, T.A., Pocas, I., Cunha, M., Silvestre, J.C., Santos, F.L., Paredes, P., Pereira, L.S. (2014). Evapotranspiration and crop coefficients for a super intensive olive orchard. An application of SIMDualKc and METRIC models using ground and satellite observations. J. Hydrol. 519:2067–2080.

Puppo, L., Garcia, C., Bautista, E., Hunsaker, D.J., Beretta, J.G. (2019). Seasonal basal crop coefficient pattern of young non-bearing olive trees grown in drainage lysimeters in a temperate sub-humid climate. Agric. Water Manage. 226:105732.

Romero-Trigueros, C., Vivaldi, G.A., Nicolas, E.N., Paduano, A., Salcedo, F.P., Camposeo, S. (2019). Ripening indices, olive yield and oil quality in response to irrigation with saline reclaimed water and deficit strategies. Frontiers in Plant Science, 10:1243.

Rosecrance, R. C., Krueger, W. H., Milliron, L., Bloese, J., Garcia, C., and Mori, B. (2015). Moderate regulated deficit irrigation can increase olive oil yields and decrease tree growth in super high density 'Arbequina' olive orchards. Sci. Hortic. 190:75–82.

Santos, F.L. Olive water use, crop coefficient, yield, and water productivity under two deficit irrigation strategies. *Agronomy* 2018, *8:*89.

Testi, L., Villalobos, F.J., Orgaz, F. (2004). Evapotranspiration of a young irrigated olive orchard in southern Spain. Agric. For. Meteorol. 121:1–18.

Villalobos, F.J., Orgaz, F., Testi, L., Fereres, E. (2000). Measurement and modelling of evapotranspiration of olive (*Olea europaea* L.) orchards. Eur. J. Agron. 13:155–163.

Zeleke, K.T. (2014) Water use and root zone water dynamics of drip-irrigated olive (Olea europaea L.) under different soil water regimes. N. Z. J. Crop Hort. Sci., 42 (3):217-232

Zeleke, K.T., Ayton, J. (2014). Fruit and oil quality of olive (Olea europaea L.) under different irrigation regimes and harvest times in south eastern Australia. J. Food Agric. Environ. 12:458–464.

Zeleke, K.T., Mailer, R., Eberbach, P., and Wünsche, J. (2012). Oil content and fruit quality of nine olive (Olea europaea L.) varieties affected by irrigation and harvest times. New Zeal. J. Crop Hortic. Sci. 40:241–252.