Australian Government
Rural Industries Research and Development Corporation

From Planting to Harvest

— A study of water requirements of olives, from planting to first commercial harvest

A Report for the Rural Industries Research and Development Corporation

by James De Barro

June 2005

RIRDC Publication No 05/039
RIRDC Project No. DEB-2A

ISBN 1 74151 138 0
ISSN 1440-6845

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Published in June 2005
Printed on environmentally friendly paper by Canprint

Foreword

The majority of commercial olive production requires irrigation in spring and summer and various methods of irrigation are used including overhead and micro sprinkler systems. When this research commenced in September 2000 the water requirements of olive trees in the period before fruit bearing had not been quantified but was based on loose "rules of thumb", speculation and research from other continents on established trees. Young trees are generally irrigated and nursed at any cost until they bear fruit. The irrigated olive grower has inherited responsibilities to use the water resource in an efficient and ecologically sustainable manner. Such responsibility is under increasing political and social scrutiny as the demand for the resource increases coinciding with traditional dryland agricultural enterprises suffering poor returns. Present day and future olive producers need to be seen by all sections of the community to be actively researching a solution to efficient and effective water use thereby justifying existing demand for irrigation in a sustainable system.

This cost-effective research aimed to increase the understanding of young olive water use and water requirements in the period from planting to early fruit bearing. Quantification of the volumetric water requirements of olives from planting to early fruit bearing would permit optimising tree development and provide a reference point for developing specific irrigation strategies.

This report includes rationale for the research, an outline of the methodology, the summarised data collected from the project and discussion of the results in relation to commercial relevance.

This project is funded by De Barro Agricultural Consulting and RIRDC core funds, which are provided by the Australian Government.

This report is an addition to RIRDC's diverse range of over 1200 research publications, forms part of our New Plants Product R&D program, which aims to facilitate the development of new industries based on plants or plant products that have commercial potential for Australia.

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Peter O'Brien
Managing Director
Rural Industries Research and Development Corporation

Acknowledgments

The author wishes to acknowledge Weeroona Pastoral in providing the research sites and co-operating with all requests pertaining to irrigation and site management. Additionally RIRDC, Agrilink, and staff of De Barro Agricultural Consulting are acknowledged for their contributions.

About the author

James De Barro owns and manages De Barro Agricultural Consulting. James has an honours degree in Agricultural Science and a Graduate Diploma of Business and was awarded a Churchill Fellowship in 2000. James resides in Keith in South Australia and specialises in consulting to lucerne seed producers and industry regarding all facets of seed production in dryland and irrigated systems. James is responsible for the ongoing research focus of the business that finances several projects.

The outcome of any serious research can only be to make two questions grow where one question grew before.

Thorstein Veblen

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"I don't know what I may seem to the world, but as to myself, I seem to have been only like a boy playing on the sea-shore and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me"
Issac Newton

Not wanting to generalise, but most irrigation enterprises irrigating any type of crop from annual to perennial species can improve in the efficiency of their irrigation delivery. No doubt there are irrigators who actively seek peak performance of their irrigation equipment and invest considerably in improved infrastructure for pumping, and storing water which improves water, fertiliser and, in some instances, herbicide delivery. However there is still considerable room for even the elite irrigation operations to improve in the timing of irrigation delivery and the volumes applied per irrigation if possible to regulate. Whilst there is still a national lack of experienced consulting personnel to provide accurate advice and undertake appropriate research into irrigation scheduling and specific volume application, rapid advances since the mid to late 1990's has taken place and irrigators should utilise and learn from their knowledge to improve their water application efficiency.

The phrase 'irrigation efficiency' seems to be fast losing its meaning as it is readily interpreted as the act of efficiently pumping water onto a crop at least cost or with least wastage of pumped water, whereas once it inferred applying water based on crop needs. It may be time to modify this phrase to explicitly define the action of applying irrigation specific to the crop's requirements based upon its daily water use through its growth phases and cycles. Such a phrase could be 'prescribed irrigation'. This research shows that appropriate timing of prescribed volumes of irrigation provides adequate supplies to service the crop requirements whilst minimising water wastage. Prescribed irrigation is a simple process enhanced by the use of soil moisture monitoring devices to determine the volume to apply to attain particular depths of penetration to service the demands of the active root zone. Irrigation scheduling using particular devices is not a new phenonomen but it is one that is readily overlooked as an optional extra in an irrigation operation rather than a fundamental tool with the same importance as the pump and pipe work.

Prescribed irrigating is a skill that can be learnt by the irrigator by trial and error and can be enhanced by experienced professional assistance. Such professional assistance should be knowledgeable regarding the appropriate tool to monitor soil moisture levels with the cost of the tool being secondary to its suitability. The ease of device installation, type of irrigation system, ease of data retrieval and resolution of the data determine suitability. Prescribed irrigation is a fine tuning of the irrigation infrastructure and optimises the efficiency.

An enhancement of prescribed irrigation is to understand the soil moisture holding capacity of the active root zone, which can be judged from the soil moisture device. By using readily available computer software that permits calculation of evapotranspiration using models such as the modified Penman Monteith model, the daily water use potential of the olive tree at any stage of development can be calculated and hence permit timing of irrigation based on cumulative water use compared to the available water storage in the active root zone. There is no need to become 'bogged' down in the theory of such models but provided the appropriate advice is available this approach to prescribed irrigation is accurate and successful.

This research project highlights what is suspected to be a common occurrence in irrigation operations, especially those embarking on the irrigation of a new type of crop, irrigating for the first time or irrigating to "be sure" that the financial investment to establish the irrigation enterprise results in a visually thriving enterprise. The degree of irrigation of the commercial olive orchard studied was significantly higher than the research site studied, yet there was no detectable or significant difference between the trees either annually through the four years of monitoring or at the time of the first commercial harvest. The over irrigation appeared to have no detrimental or beneficial impact on the trees.

State Governments are having an increasing regulatory role over the irrigation industries and are not as active in designated research and extension into areas such as prescribed irrigation as they could or should be. This is not a specific criticism of the State’s role but just a fact of the services they can fund and a sign of our times. Consequently it is up to the industry itself (i.e. the industry associations as well as individual entities) to progress towards prescribed irrigation via research such as this project as well as private investigations using sound experienced advice.

This research reveals that as much as there is talk of irrigation efficiency the message is not being understood or listened to.

1. Introduction

1.1 Industry snapshot

In the 1990's, following an international increase in the acceptance of olive oil as a natural and healthy product, a rapid increase in the planting of olive orchards, predominantly for the production of oil, has occurred in Australia. Australia imported 30,000 tonnes of olive oil in 2000/01 and imports over $30 million of table olives annually[1]. Prior to the commencement of this research, in 1996/97 South Australia produced an estimated 350 tonnes of oil, which represented the majority of Australian production. Historically South Australia has produced more olives than the remainder of Australia and whilst Australian oil production is currently well below the volume imported it is estimated that by 2006 there will be in excess of 7.5 million commercial trees producing up to 28,000 tonnes of oil[7]. Oil production is forecast to be 40,000-50,000 tonnes per annum by 2011[8]. Commercial olives are grown in orchards mainly for oil production and under some form of irrigation system using dam, ground water or mains stored water. The increase in Australian production involves both existing primary producers as well as investment or hobby farmers. As in indication of the national trend, 37% of the olive growers in Western Australia have less than 500 trees and 90% have less than 5000 trees (or no more than 20 hectares of production)[1]. The majority of olive orchards are small and given the varying levels of primary production knowledge, diverse family origins and finance availability, there is a need for reliable information for use in production programs as the expansion of olive production increases demand on all water resources as well as the cost of production.

1.2 Research Importance

The increase in value of olive production to the Australian economy delineates itself as a commodity that requires research designed to improve yields; grower returns and, being an intensive high input horticultural crop, develop sustainable practices that are environmentally acceptable. The rapid expansion of the Australian industry continues to reveal inadequacies in technical information necessary for efficient and sustainable production. This sentiment is outlined in the Australian Olive Industry's Research and Development Plan 2003-2008, managed by RIRDC. As suggested in 2000 when this research commenced, sustainable irrigation strategies that minimize water use but maintain yield and quality are still important priorities for the Australian Olive Industry in 2005 and beyond.

1.3 Research Area

The research area is located in Keith in the south east of South Australia, 230 km from Adelaide. The Mediterranean climate is suitable for many irrigated crops provided they can tolerate the saline water resource. Soil types are variable ranging from deep sands, sandy loams to shallow clay soils, with significant areas of shallow limestone. Such variability presents opportunities for a variety of crop production enterprises.

Lucerne seed production in the research region is the district's key crop. By virtue of the naturally saline ground water, lucerne is a reliable perennial crop as it persists and provides profitable seed yields for the region's irrigators, and in particular, border check flood irrigators. The irrigation of lucerne for seed production adds significant economic and social stability for the communities concerned.

The commencement of commercial olive orchards in the region in the mid 1990's introduced a new crop into the research area that could cope with moderate levels of water salinity and provide a potentially viable alternative to irrigators.

1.4 Lack of information

Australian and overseas literature reviewed does not specifically explain the water requirements of young olives from planting to fruit bearing age. Two internationally recognised references: The 'Olive Production Manual'[2] and 'Irrigation requirements of Olive trees and responses to sustained deficit irrigation' [3] base the review of olive water requirements on established olives. Goldhamer, Dunai and Ferguson, University of California [3] suggests mature olives require between 5-10 ML of water per year (irrigation and rainfall combined) for maximum gross yield. Total water requirement varies depending on many factors such as soil type, variety and climate and irrigation costs per annum vary from property to property and are quoted to range from $180-$500/ha to apply from 2.5 – 8 ML/ha[4].

Determination of irrigation requirements using indices such as the crop coefficients (Kc values) for use with reference crop evapotranspiration data are well documented for established trees by research performed by Goldhamer et al. in California. The Kc values for established olives are calculated and published as Kc = 0.65-0.70[(9)], but there are no calculations published in any cited literature, from anywhere in the world, for young olives. Publications made available to olive producers in Australia only speculate on the irrigation requirements of young trees using loose 'rules of thumb' such as "if the olive canopy shades 10% of the floor of the orchard (at mid-day) then apply 20% of the irrigation water which will be needed by a mature (7 year old) orchard". [5] Similar recommendations are cited in publications supplied to olive growers such as a young tree "(0-1 year old) requires about 10 litres per week in a single application during the summer and less in winter"[6] and then comment on the requirements of 5 and 10 year old trees without referring to the requirements of an actively growing young tree before it fruits.

Commercial olive production requires irrigation across the spring and summer seasons. In southern Australia irrigation is used in commercial orchards utilising various methods including overhead and micro sprinkler systems. Water requirements of young olive trees in the period up to the first harvest have not been quantified and there is currently reliance on loose "rules of thumb", speculation and utilising research results determined in other continents. To date, young trees are irrigated and nursed at any cost until they bear fruit. As water is a precious and limited resource it should be supplied to any crop on the basis of understanding the crop requirements hence improving the efficiency of the irrigation system. Benefits of determining young tree water requirements are that irrigation efficiency can be enhanced and initial grove development can be made with quantified understanding of irrigation demands. Knowledge of water requirements can be utilised in any soil type in any region, which will allow efficient use of the water resource as well as improving the efficiency of nutrition management.

1.5 Industry responsibility

The landowner's ability to irrigate provides an opportunity to produce an income that otherwise would not be possible or obtain yields above that of a dryland system. However the landowner has also inherited responsibilities to use the resource in an efficient and ecologically sustainable manner. Such responsibility is under increasing political and social scrutiny as the demand for the resource increases coinciding with traditional dryland agricultural enterprises suffering poor returns. Present day and future olive producers need to be seen by all sections of the community to be actively researching a solution to efficient and effective water use thereby justifying existing demand for irrigation in a sustainable system. The research results will support increases in irrigated olive production across Australia and the olive industry could promote the research results to relevant government authorities and communities as evidence of their consciousness of the importance of developing management systems that permit profitable yet ecologically sustainable irrigation water use.

1: R&D Plan for the Australian Olive Industry 2003-2008. RIRDC Publication No. 03/

2: **Olive Production Manual**. (1994), Edited by Ferguson, L., Sibbett, G.S. and Martin, G.C.. University of California Publication 3353.

3: **Goldhamer D.A., Dunai J. & Ferguson L.**. (1993). *Irrigation requirements of Olive trees and responses to sustained deficit irrigation.* Acta Horticulturae 356: 172 – 175.

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5: **Thomson T**. (1998). *Olive Irrigation*. Primary Industries and Resources. Lenswood, South Australia.

6: Archer, R. & D. Water requirements for olive orchards. OLIFAX – 5: Olives Australia, Grantham, Queensland.

7: **Sweeney, S.** (2000). *Olive tree numbers 2000*. The Olive Press. Summer 2000. p25-26.

8: **Taylor, D.** (2002). Quarterly outlook of the Olive Industry. Dept. of Agriculture WA.

9: FAO Irrigation and Drainage Paper No. 56, pp113-114.

1.6 Water resource issues

1.6.1 Licencing system

Across most of the South East of South Australia a ground water resource exists in the form of unconfined and confined aquifers. The South East of South Australia is divided into regional Prescribed Wells Areas and the area of research was located in the Tatiara Prescribed Wells Region. Water salinity in this area ranges from 2000 to in excess of 7000 mg/l and is the water source at the research site was X ppm total dissolved salts. In 1984 the Tatiara region was prescribed due to concerns of increasing water salinity. The development of an area based volumetric water allocation system based on estimated crop water requirements was instituted in 1988. The ground water allocation plan was an Irrigation Equivalent System where the allowable area of any irrigated crop to be grown was relative to the water use of a "standard area and type" of pasture referred to as the 'reference crop'. This system operates on an estimation of the water use of the crop to be grown and is currently in use across the Upper South East of South Australia. The licence provides *no limit* on the volume of water than can be pumped from the aquifer to irrigate crops but only specifies the area upon which any volume of irrigation can be applied.

1.6.2 Water resource management framework

The Water Resource Act 1997 was created to permit specific water resource management where deemed necessary. Such management would have as its aim the sustainability of the water resource. The Tatiara Prescribed Wells Area is one of five management areas in the South East where the Act required a water allocation plan to be created. A State Government Select Committee Report on Water Allocations in the South East was released in August 1999 and created the framework for the South East Catchment Water Management Board (SEWCMB), which was formed under the Act, to be empowered in consultation with the community, to produce water allocation plans to replace existing water allocation policies.

1.6.3 Licence conversion

A significant aspect of the development of water allocation plans is the conversion of current area based licences to volumetric licences. Such licences will provide the irrigator with a set volume of water that will be permitted to be pumped from the aquifer in any given year. Consequently the irrigator will not be restricted in the area irrigated. This change in licensing will be implemented in 2007 and enhances the importance of the research for the specific South East region of South Australia. A quantified understanding of the volumes required will assist olive orchard development and management as well as fair licence conversions.

2. Objectives

2.1 Research Aims

The research aimed to quantify the water requirements of young olive trees in the period from planting to fruit bearing. Quantification of the water requirements will permit sustainable and efficient water use thereby assisting in securing the availability of the quantity and quality of the water resource for the future. Reduction of over irrigation would assist in minimising losses of nutrition beyond the olive root zone as well as conserving water. The olive industry will be able to promote the results of the research to community and government authorities and exhibit that olive growers have the information to irrigate their olives based on the known requirements of the trees and hence are managing the available water source in an ecologically sustainable manner.

In addition to quantifying the water requirements of young olives on varying soil types, the research will estimate the rate of development of the root zone and the depth of root zone water extraction. The research results will be published to compliment the existing information regarding the water requirements of established olive trees. The results will be available for irrigated olive growers to benchmark their current irrigation applications on olives from planting up until their initial harvest. Determination of crop factors (Kc values) for use in water use calculations involving modeling of evapotranspiration with such models as the modified Penman Monteith model would be calculated for use in irrigation scheduling.

2.2 Timing of research

The development of a new water allocation licence system in the research area to replace the current irrigation equivalent system is complex and emotive. Such a change in the licensing system will align water availability with the majority of Australia's irrigation districts, albeit the source of the water may be significantly different. Environmental, social, economic and agricultural factors need to be well researched and considered so a fair and equitable system of conversion can be created. Such a conversion needs to be based on solid quantified data collected through appropriate research. The research needs to determine what quantities are currently required by olive irrigators to maintain their current status quo. Unless the research determines significant sustainability issues any reductions in licences should not be part of the conversion process. The conversion process should simply change the type of licence without any major changes to current irrigation practices.

The creation of an accurate knowledge base would allow for refined allocation of the underground water for irrigation of olives and advancement in sustainable and efficient water use. This in turn assists in securing the availability of the quantity and quality of the water resource for the future.

3. Methodology

3.1 Location

The research site was positioned at Weeroona Park, Weeroona Pastoral Company (36^{o} 04.357' S & 140^{o} 29.974' E) and 60 m above sea level. The trellised grove was designed in 8m x 5m spacings with 250 trees/ha. Irrigation was supplied by Irritrol^{R} Waterbird V1-PC Olive sprinklers. 18 month old olives (var. Manzanello) were planted in September 2000 with the research focusing on two distinctly different soil types. One site was positioned on a deep "gutless" sandhill (15 m deep sand over clay) and the other site was on clay loam with minimal sand. Each site involved the monitoring of a single tree with the two trees being located in the same row that transgressed the sand rise and the clay flat. The sand section was irrigated in a valve section separate to the clay flat area, which enabled different irrigation patterns as required. The research row was able to be isolated from the irrigation of the entire grove and enabled comparisons between the commercial practices and the research activities. Two trees in a row adjacent to the research row and opposite the research trees had their growth monitored as per the research trees but did not have soil moisture monitoring devices installed. The following table outlines the age of the olives through the research project. For convenience the different irrigation seasons are classified in year brackets rather than age of trees.

Year	Age of trees
00/01	18-30 month (1.5-2.5 years old)
01/02	30-42 month (2.5-3.5 years old)
02/03	42-54 month (3.5-4.5 years old)
03/04	54-66 month (4.5-5.5 years old)

3.2 Site management

The general management of the olive trees such as pruning and weed control was the same for the research and the commercial trees. As fertiliser was applied mainly via fertigation management (apart from solid fertilising pre planting and in the first season after planting) the research trees were given two applications of a complete N-P-K and trace elements fertiliser because they were not being irrigated as regularly, and hence not receiving comparable amounts of fertiliser as the commercial trees. The entire research row was not fertilised and whilst the trees appeared no different, it may have had an insidious impact on their development and olive yield.

3.3 Soil moisture monitoring

A soil moisture monitoring site was established immediately at the base of each tree using an Agrilink C-probe^{R} . The soil moisture sensors measure soil moisture by capacitance and were placed at depths 10, 20, 30, 40 and 70 cm in the root zone. Irrigation was scheduled according to crop water demands as indicated by soil moisture availability depicted by the C-probe. As irrigation was applied only as the tree needed, actual tree water use requirements could confidently be calculated.

3.4 Weather station

A continual recording weather station was installed to record fundamental indices such as temperature, relative humidity, solar radiation, leaf wetness, rainfall and wind speed. This information was used in assisting the scheduling of irrigation and recording of weather through the production periods. The collected data would be used in a computer model of the modified Penman Monteith equation for calculating the evaporation potential of the atmosphere (ETo) through the irrigation period. Determination of the olive water requirements (ETc) and the ETo would permit calculation of the Kc factor for the olive growth stage which in turn, for the purposes of future irrigation scheduling of young olive trees, could be used in the predicting tree water requirements by multiplying the Kc factor by ETo (i.e. ETo x Kc = ETc). This methodology is outlined in *FAO Irrigation and Drainage Paper No.56 pp 95-97.*

3.5 Tree measurement

Periodic tree measurements were conducted on the research and commercial trees. Measurements included height, stem circumference and canopy. Canopy measurement was done by measuring the greatest width of foliage through the cross section of the tree. Stem circumference was measured consistently 5 cm up the stem from ground level. A measuring tape was wrapped around the stem and the circumference was recorded. General tree health was recorded such as frost impact, olive development and pest issues. On 21 May 2004 the first commercial harvest occurred and the yield of the research and commercial rows (hill and flat sections) were separately recorded to permit determination of yield per tree. This was compared to the average Manzanello yield from the grove. Harvest was done mechanically by a grape harvester.

4. Summary of results

4.1 Water application records

Tables 1-4 outline irrigation applications and rainfall on the research and commercial trees in the studied rows. The study of the commercial trees commenced halfway through the research due to significant differences in water regimes compared to the research rows. Such differences as evident in seasons 02/03 and 03/04 were worthy of tree and yield measurement comparisons. Applied irrigation is calculated in ML/ha and the effective rainfall (rain events in excess of 5 mm) is converted to ML/ha to permit calculation of total water received by the olives.

4.2 Olive yield

Table 5 outlines the average olive yield per tree in the research and commercial rows.

4.3 Tree measurements

Graphs 1-6 show the results of tree measurements. Once again measurement of the commercial rows commenced in season 02/03. Comparative tree height, stem circumference and canopy measurements are presented which map the trees' growth through the years.

4.4 Root zone development

The active root zone appeared to follow the irrigated area of just over 3.0 m^2, which was detected by digging around the edge of the trees to expose the root system. The depth of soil water extraction increased over the four irrigation seasons and is outlined in Table 6. These depths were determined from the soil water use data recorded by the C-Probes.

4.5 Climatic conditions and Crop coefficient (Kc) calculation

Average climatic conditions for the irrigation periods through the research are provided in Table 7. In addition in Table 8 the calculated crop coefficient (Kc values) are presented for each season of growth leading up to the first commercial harvest. Evapotranspiration (ETo) values were calculated using the recorded weather data via a computer model using the modified Penman Monteith model.

Table 1: Water application records for 'Hill' research rows.

Year	Irrigations	Flow rate (l/tree/hr)	Tree Application (l/tree)	Irrigation Hours	Trees/ha	Applied Irrigation (ML/ha)	Effective rainfall (mm)	Effective rainfall (ML/ha)	Total Water received (ML/ha)
00/01	21	46	700.7	15.2	250	0.18	70	0.7	0.88
01/02	16	46	787.05	17.11	250	0.2	116	1.16	1.36
02/03	9	46	357.19	7.77	250	0.09	160	1.6	1.69
03/04	10	46	1595.74	34.69	250	0.4	185.4	1.85	2.25

Table 2: Water application records for 'Flat' research rows.

Year	Irrigations	Flow rate (l/tree/hr)	Tree Application (l/tree)	Irrigation Hours	Trees/ha	Applied Irrigation (ML/ha)	Effective rainfall (mm)	Effective rainfall (ML/ha)	Total Water received (ML/ha)
00/01	19	56	650.72	11.62	250	0.16	70	0.7	0.86
01/02	13	56	667.69	11.92	250	0.17	116	1.16	1.33
02/03	6	56	325.74	5.82	250	0.08	160	1.6	1.68
03/04	12	56	1984.82	35.44	250	0.50	185.4	1.85	2.35

Table 3: Water application records for 'Hill' commercial rows.

Year	Irrigations	Flow rate (l/tree/hr)	Tree Application (l/tree)	Irrigation Hours	Trees/ha	Applied Irrigation (ML/ha)	Effective rainfall (mm)	Effective rainfall (ML/ha)	Total Water received (ML/ha)
02/03	46	46	2365.17	51.47	250	0.59	160	1.6	2.19
03/04	39	46	5451.0	118.5	250	1.36	185.4	1.85	3.21

Table 4: Water application records for 'Flat' commercial rows.

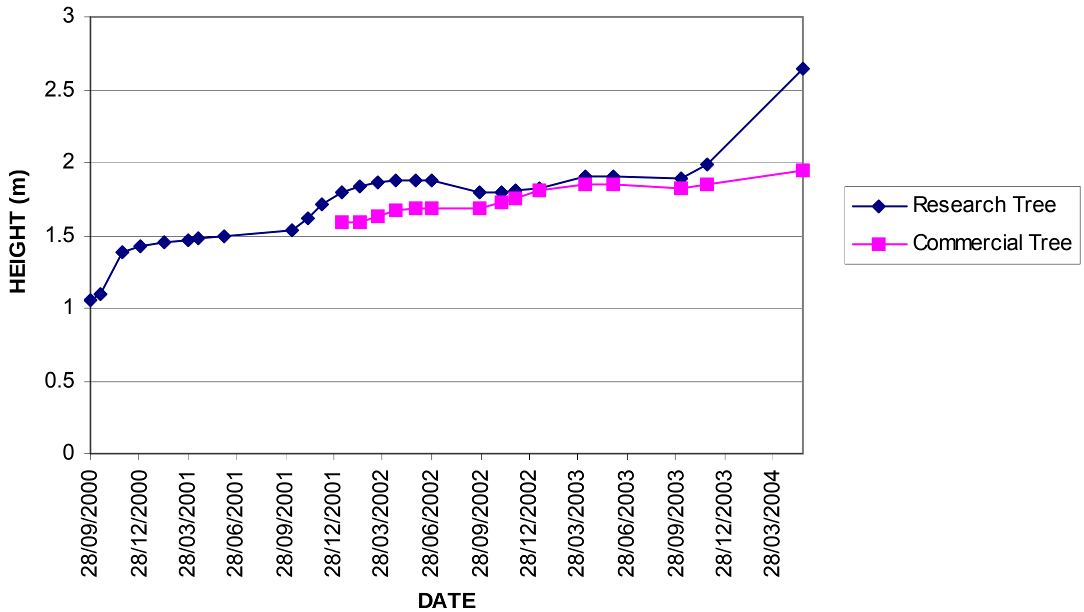
Table 5: Olive yield (21/5/04) for each monitored row.

Year	Irrigations	Flow rate (l/tree/hr)	Tree Application (l/tree)	Irrigation Hours	Trees/ha	Applied Irrigation (ML/ha)	Effective rainfall (mm)	Effective rainfall (ML/ha)	Total Water received (ML/ha)
02/03	35	56	1848.0	33	250	0.46	160	1.6	2.06
03/04	33	56	7177.3	33	250	1.79	185.4	1.85	3.64

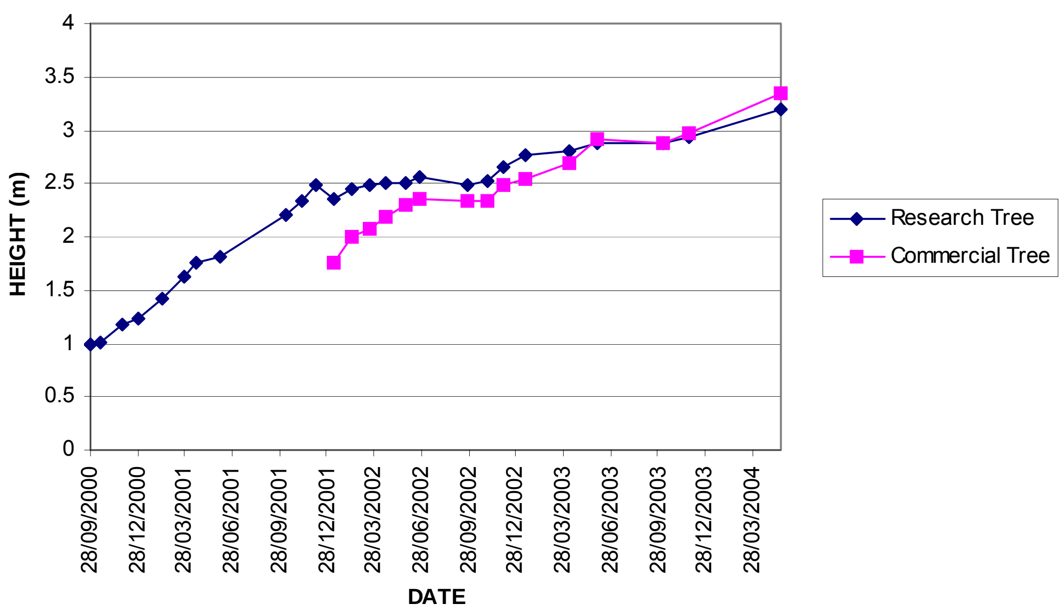
Average yield from 1045 Manzanello trees = 2.63 kg/tree

Row	Average Olive Yield (kg/tree)
Research row 'HILL'	0.65
Commercial row 'HILL'	0.65
Research row 'FLAT'	2.16
Commercial row 'FLAT'	3.71

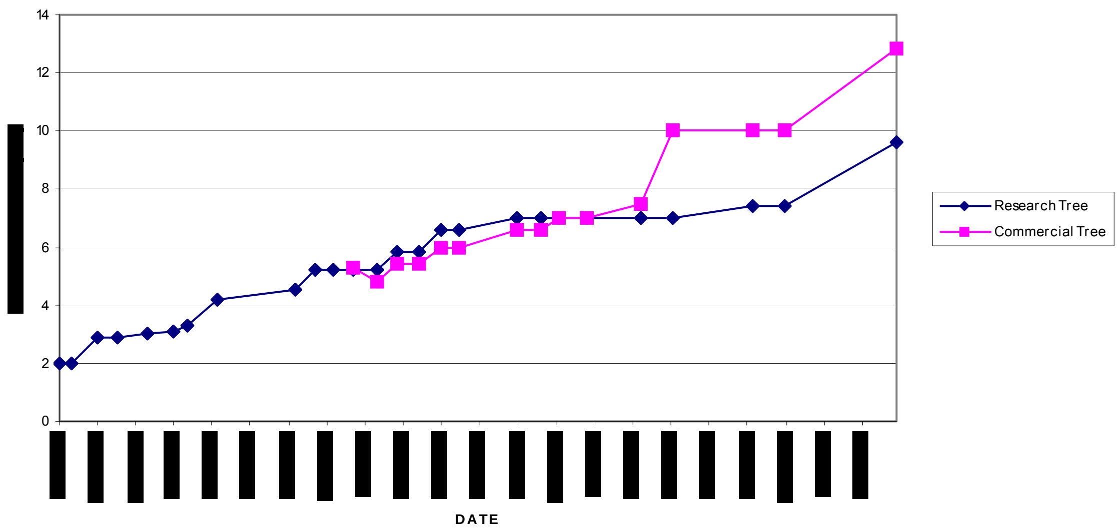
Graph 1: Research and Commercial 'Hill' tree height growth between 28/9/00 - 21/5/04



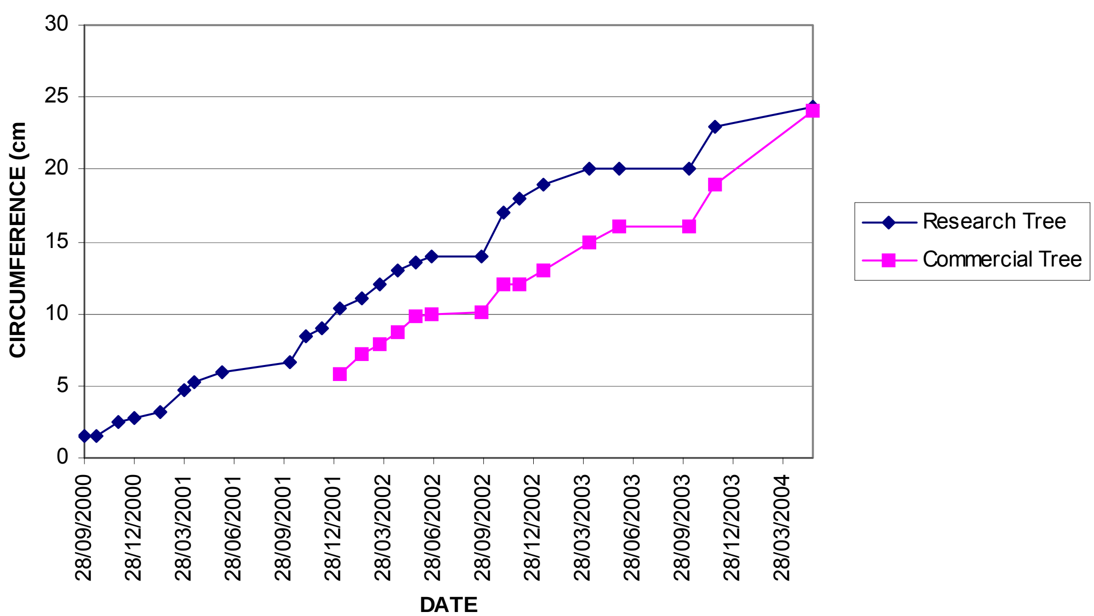
Graph 2: Research and Commercial 'Flat' tree height growth between 28/9/00 - 21/5/04



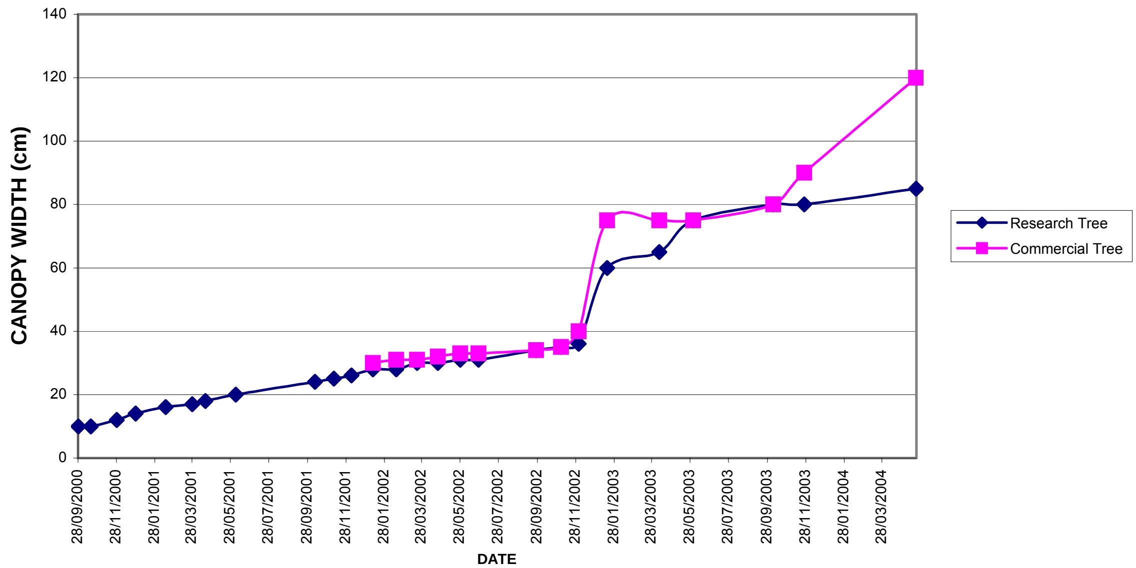
Graph 3: Research and Commercial 'Hill' tree, trunk base circumference between 28/9/00 - 21/5/04



Graph 4: Research and Commercial 'Flat' tree, trunk base circumference between 28/9/00-21/5/04



Graph 5: Research and Commercial 'Hill' tree canopy growth between 28/9/00 - 21/5/04



Graph 6: Research and Commercial 'Flat' tree canopy growth between 28/9/00 - 21/5/04

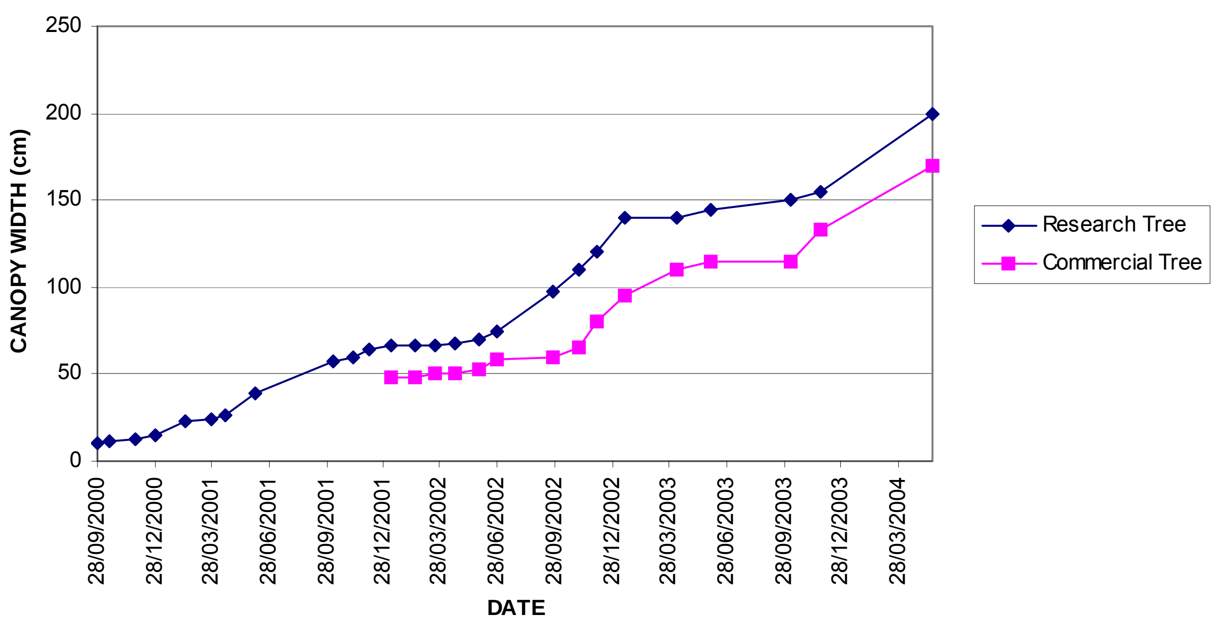


Table 6: Root depth development

Year	**'Hill' Tree root extraction depth**	**'Flat' Tree root extraction depth**
00/01	0-10 cm (not reliably at 20 cm)	0-20 cm
01/02	0-20 cm	0-30 cm
02/03	0-20 cm (slightly at 30 cm)	0-40 cm (only to 40 cm at end of irrigation season)
03/04	0-30 cm	0-60 cm (no detection of use at 70 cm)

Table 7: Average climatic conditions through the irrigation periods

Average maximum temperature (°C)	**Average minimum temperature (°C)**	**Overall average temperature (°C)**	**Average maximum relative humidity (%)**	**Average minimum relative humidity (%)**	**Overall average relative humidity (%)**	**Average wind speed (km/hr)**
25.23	8.22	16.58	88.93	31.91	61.43	7.85

Table 8: Calculation of crop coefficient (Kc values)

	00/01	**01/02**	**02/03**	**03/04**
Total water received (mm/ha)	88	133	169	235
Irrigation period (days)	154	190	109	159
Total ETo over irrigation period (mm)	662.2	817.0	497.15	696.83
Kc value	0.13	0.16	0.34	0.34

5. Discussion of results

From the outset it is necessary to make a qualified judgement of the growth and development of the commercial trees prior to the period of measurement. Analysis of Graphs 1-6 suggests strongly that the growth of the trees followed a similar pattern to the research trees and visual assessment of the commercial trees in the first two years of the research supports this judgement. Given acceptance of this, it is possible to reflect on the impact of the commercial irrigation practice in the first two seasons compared to the research trees. In the first two years, no records of irrigation applications were kept on a regular basis for the commercial trees. Changes of staff and other issues thwarted this from happening. What was apparent was that the growth of the research and commercial trees appeared no different yet the commercial trees were being irrigated more often and for longer periods of time. It was this observation that initiated the recording of growth measurements on the commercial trees. In 2002/03 the commercial trees received approximately six times more water from six times more irrigations and it is estimated that a similar trend would have been apparent in the first two irrigation seasons.

An interesting aspect of the results is that regardless of the trees being grown on deep sand (‘hill’) or clay (‘flat’) the total water received by the research trees per irrigation season was almost the same. The trees were supplied with irrigation that met their water use demands and the data indicates that an olive tree uses a set amount of water per season which is related to their growth stage and that the frequency of irrigation and volumes applied per irrigation vary only on the soil moisture holding capacity of the root zone and the weather driving plant water use. Not a surprising result given that crop and tree water requirements can be studied and modelled to assist in irrigation scheduling and studies of crop physiology. The research determined that young, growing olive trees require amounts of water through the spring, summer and early autumn period that are the same regardless of soil type. The comparison with the commercial trees in 02/03 and 03/04 highlights the negligible return for irrigating over this necessary volume in conjunction with effective rainfall.

If we accept that the research trees on the ‘hill’ and ‘flat’ (Tables 1 and 2) were provided with their water requirements and were not over or under watered, comparisons of the 02/03 and 03/04 total water received for the commercial trees (Tables 3 and 4) indicate that extra water received by the commercial trees was wasted. This extra water was irrigated water and ranged between 0.4-0.5 ML/ha in 02/03 and 1.0-1.3 ML/ha in 03/04. It can be suggested that this extra water applied per hectare wasted water, fertiliser and fuel/electricity and also added extra ‘wear and tear’ to pumps and infrastructure.

How can such a suggestion of waste be quantified? Examination of Graphs 1 and 2 show that in the period 28/9/02 and 28/5/03 there was no difference in the rate of height growth of the commercial and research trees on the ‘hill’ or ‘flat’ and the research tree was ostensibly the same size as the commercial tree. The same trend is apparent in Graphs 3, 4, 5 and 6. It is evident that the research tree was progressing as well as the commercial tree yet in the irrigation period of 02/03 the commercial trees had between 0.4 and 0.5 ML/ha more water applied via irrigation. Another way to express this is that the ‘hill’ commercial tree had approximately 2000 more litres (or >650% more water) in the irrigation season and the ‘flat’ commercial tree had approximately 1500 more litres (>550% more water). This data is a good example of the ‘law of diminishing returns’ in that for every extra litre applied to the commercial trees compared to the research trees there was no recorded or observable benefit.

A similar scenario is exhibited in season 03/04 but there are a few interesting features. From Tables 1 and 3 the ‘hill’ commercial tree had approximately 1.0 ML/ha more applied irrigation (3900 more litres of water/tree) than the research tree. From Tables 2 and 4, the ‘flat’ commercial tree had approximately 1.3 ML/ha more applied irrigation (5200 more litres of water/tree). In the period 28/6/03 to 28/3/04, Graph 1 shows that with the reduced irrigation application the height growth of the ‘hill’ tree was significantly more than the corresponding commercial tree. Yet in the same period the commercial ‘hill’ tree developed significantly more canopy than the corresponding research tree. It is unknown if these different growth patterns are due to irrigation or chance. Given the trees were both healthy and the research rows and tree rows looked very similar it is suggested that the differences are due to chance than any physiological factor.

From Graphs 2 and 6 the trees on the ‘flat’ showed the same growth pattern and rate of growth regardless of irrigation volume applied. Graph 4 indicates that the trunk of the commercial tree grew rapidly through the 03/04 irrigation season to match the size of the research tree. It is suggested that this is not a response to extra irrigation but rather a chance growth spurt of this particular tree. In general the trend of the data from the 03/04 season provides information to suggest that same outcome as season 02/03 with the extra applied irrigation water to the commercial trees on the ‘hill’ and ‘flat’ sites being wasted.

Table 5 suggests that the extra irrigation of ‘hill’ commercial trees in 03/04 (as well as the cumulative extra irrigation of the previous seasons) compared to the ‘hill’ research trees had no benefit to the gross yield of the trees. The hill trees on the deep sand were significantly smaller than the trees on the ‘flat’ and yielded well below the average yield of 2.63 kg/tree. Observation of olives on similar sand in nearby groves suggests that the trees will eventually grow to become solid trees that yield well. Visual observation of the trees in 2005 suggests they are steadily growing away and should follow the district trend. The variation of yield of the commercial and research ‘flat’ trees suggests a normal distribution around an average yield of 2.63 kg/tree from 1045 harvested trees. The two studied trees on the ‘flat’ ostensibly looked very much the same and the yield difference is likely due to chance than any management or environmental factor.

Depth of soil water extraction increased through the seasons (Table 6) and it is suggested that the rate of development would be similar to the growth above ground. The shallow root depth of young plants requires only irrigations to slightly below this depth as beyond the active root zone the soil is generally at full point due to no extraction of the moisture reserves. Irrigation needs only to just go beyond this depth to encourage root development and avoid moisture depletion by the developing root system.

The average weather data across all the irrigation periods reported in Table 7 was used in the determination of the ETo calculated and presented in Table 8. The estimated Kc values of 0.13 to 0.34 follow the progression of tree development and correlate well with other research calculating mature olives having Kc values of 0.65-0.7. These Kc values for young olives can confidently be used in calculating water requirements anywhere they are grown.

6. Implications for irrigators

An implication of the research results is that olives grown on varying soil types ranging from deep ‘gutless’ sand to high clay content use the same amount of water through the year to undergo seasonal growth and production from planting through to the first commercial harvest. The timing and quantity of delivery of the irrigation requirement in relation to the effective rainfall received is dependent on the irrigator’s management and soil moisture monitoring can assist in determining both.

It is suggested that over irrigation is common in young olive orchards and this is wasting both water and energy resources as well as increasing the irrigation structure workload. The indication of the research findings is that more olives could be irrigated due to over irrigation of the current grove, but an increase in grove size would be dependent on the predicted volumes required for established trees. Irrigators need to compare their irrigation applications to those recorded in this research and assess whether there is scope to reduce their irrigation output with no reduction in olive production. The great temptation with irrigation, and especially fine tuned irrigation delivery such as drippers and micro sprinklers is to over water due to the ease of watering and the desire to “make sure” all the effort and financing of the grove is rewarded with healthy, growing trees at the end of each irrigation season. Irrigators need to consider monitoring their soil water and the depth of olive water use and irrigate as required rather than using the calendar to time irrigation applications.

7. Recommendations

On the basis of the research results the following recommendations and comments are made to the Australian irrigated olive industry, Rural Industries Research and Development Corporation (RIRDC) and the Department of Water, Land and Biodiversity Conservation (DWLBC).

1) Utilise soil moisture monitoring devices. Irrespective of expense, ensure the most suitable device is used for the soil type and type of irrigation system used. Ensure the device is properly installed so that the device is operating in optimum conditions and that the soil water readings are accurate and reliable.

2) If the irrigator can not commit to regularly reading the results of the soil moisture monitoring device and scheduling irrigation in respect to prevailing weather and the devices data results, the irrigator should solicit advice and services from an appropriately qualified and experienced service provider.

3) In the prescribed wells areas of the south east of South Australia it is critical that for a fair conversion of licences from the current IE system to a quantified water volume (volumetric) licence this research should be utilised. It is suggested that this research is indicative of the irrigated olive water use in the region and there are likely to be irrigators whose irrigation enterprises will be better or worse off for the research findings. The aim of the licence changing process is to fairly convert based on quantified evidence from across the irrigation region.

4) In the prescribed wells areas of the south east of South Australia the conversion process is not an opportunity to reduce or increase water licence allocations, but it is a starting point for obtaining the baseline information for fair licence conversion.

5) This type of research should be well promoted to the irrigation communities of Australia to encourage all irrigators to assess their irrigation requirements and possibly improve their irrigation, and hence business, efficiencies and profits.

6) The development of Kc factors for young olive trees can be used to calculate olive water requirements from planting to the first commercial harvest and can aid the planning of grove development both from an initial development stage to expansion of existing groves.

7) Kc values for young olives can be used to assess the current efficiency of an irrigation practice by calculating the water requirements for the olive tree growth stage and comparing this to the known water application rates. This is a practice that should be encouraged for all olive irrigators and irrigators in general.