Proceedings of the 10th World Congress of EWRA 'Panta Rhei', 5-9 July 2017, Athens, Greece

Evaluation of the water footprint and water use efficiency in a high density olive (*Olea europea* L.) grove system

A.Gertsis[1], K. Zoukidis[1] and A. Mavridis[1]
Perrotis College, American Farm School, Marinou Antypa 54, str.. Thessaloniki , Greece
E-mail of corresponding author: agerts@afs.edu.gr

Abstract: Modern approaches in sustainable agricultural production management require holistic approaches and evaluation of the water use efficiency and water footprint. The irrigation water scarcity due to overuse and quality deterioration due to increased salinity levels, represent significant obstacles in sustainable agricultural systems. Systems that promote and evaluate less-inputs and more efficient production are strongly considered lately. This study presents results of two years from an olive grove, planted in high density linear systems adapted for mechanical harvesting. The grove was established in 2011 in Thessaloniki, Greece, for long term evaluation of the effects of major production inputs in olive yield and olive oil quantity and quality. The experimental design includes three planting densities (medium, high and super high density; 500, 1000 and 1670 trees/ha, correspondingly), two commonly used worldwide olive oil varieties/clones adapted for mechanical harvesting (Koroneiki and Arbequina), grown under two irrigation levels (conventional and 50% less) and two fertility levels (conventional and 50% less) with a foliar split application in the fertility treatments. Results from the two years (2015 & 2016) on water use efficiency (WUE) and water footprint (WF) are presented in this paper. The results indicated that increase in WUE and decrease in WF was achieved with management approaches such as planting density at least for the measured period and tree age. Additional efforts to minimize water use and increase WUE are in progress.

Key words: Olive grove, water footprint (WF), water use efficiency (WUE), high density olive

1. INTRODUCTION

1.1. Irrigation water utilization–an agronomic approach

The use of water in agriculture (both in crop and animal production systems) represents a very significant portion of the "fresh water" deposits in Earth and is under strong monitoring globally in the last decades. Particular use by crop species varies greatly and there are no common procedures to calculate crop water use and water use efficiencies. Water use efficiency (WUE) and water productivity (WP) are two different terms. However, they seem to cause some confusion and different interpretation among agronomists and engineers. WUE is the percent of water supplied to the plant that is effectively taken up by the plant, i.e., that was not lost to drainage, bare soil evaporation or runoff. In the general agronomic approach, the crop WUE is meant to be the ratio of total water used by crops over the total economic yield achieved at field conditions, which is very close to be considered as the WP. In the context of this study, the agronomic approach will be used, since the emphasis is on how much total water was provided to the field (total of rainfall and irrigation) and how much economic product was output. This is a simple but more realistic approach.

Physiological based Water-use efficiency (WUE) refers to the ratio of water used in plant metabolism to water lost by the plant through transpiration. Two types of water-use efficiency are referred to most frequently: photosynthetic water-use efficiency (also called intrinsic or instantaneous water-use efficiency), which is defined as the ratio of the rate of carbon assimilation (photosynthesis) to the rate of transpiration, and water-use efficiency of productivity (also called integrated water-use efficiency), which is typically defined as the ratio of biomass produced to the rate of transpiration.

Increases in water-use efficiency are commonly cited as a response mechanism of plants to moderate to severe soil water deficits, and has been the focus of many programs that seek to increase crop tolerance of drought e.g. project AZORT (http://www.cespevi.it/azort/azort.html). However, there is some question as to the benefit of increased water-use efficiency of plants in agricultural systems, as the processes of increased yield production and decreased transpiration water loss (that is, the main driver of increases in water-use efficiency) are fundamentally opposed (Bacon, 2004).If there existed a situation where water deficit induced lower transpiration rates without simultaneously decreasing photosynthetic rates and biomass production, then water-use efficiency would be both greatly improved and a desired trait in crop production.

Water productivity is the amount of beneficial output per unit of water depleted. In its broadest sense, it reflects the objectives of producing more food, and the associated income, livelihood and ecological benefits, at a lower social and environmental cost per unit of water used (Molden et al., 2007). Usually, water productivity is defined as a mass (kg), monetary ($) or energy (calorific) value of produce per unit of water evapotranspired (Kijne et al., 2003; Molden et al., 2010). They reported a range of WP for table olives of 1-3 kg/m^3.

1.2. Water footprint

Water is one of the most important commodities/natural goods on earth. However, continuous, multidisciplinary pressures through time, like climate change, water consumption and pollution, promote today, more than ever before, issues of sustainable water availability, use and management (Hoekstra et al., 2012). Although there are substantial water volumes consumed and polluted in the industrial and domestic sectors (WWAP, 2009), there are accumulated difficulties in the water-agriculture framework, such as the expected, increasing number of global population of more than 9 billion people by 2050 (Alexandratos et al., 2012). Additionally, the demanding needs for delivering successfully the four Fs (Food, Fibre, Fuel and Feed) of agriculture in the future, constitute a framework of establishing enhanced, holistic approaches to confront with these global challenges and to support better water balance (equilibrium) in nature as agriculture accounts for up to 70% of global water withdrawals (Calzadilla et al., 2010; FAO, 2015)

Towards that perspective, the combination of Water Footprint (Hoekstra, 2003) with GIS (Geographic Information Systems) applications can provide significant benefits. The concept of “Water Footprint-WF” defines the total volume of freshwater that is used to produce the product (Hoekstra et al., 2009). It provides a framework to analyse the link between human consumption and the appropriation of the globe’s freshwater. The water footprint of a product is defined by three components

i) the *blue water footprint* which refers to the volume of surface and groundwater consumed (evaporated) as a result of the production of a good;
ii) the *green water footprint* which is referred to the rainwater consumed, and,
iii) the *grey water footprint* of a product which refers to the volume of freshwater that can be associated with the production of a product over its full supply chain.

The blue water footprint refers to consumption of blue water resources (surface and ground water) along the supply chain of a product. The green water footprint refers to consumption of green water resources (rainwater stored in the soil as soil moisture). The grey water footprint is defined as the volume of freshwater that is required to assimilate the load of pollutants based on existing ambient water quality standards (Hoekstra et al., 2009).

The enhanced approach of geospatial analytics can provide extraction of information in multiple levels, while examining several aspects of crop-related parameters with water use at international, national and local scale.

It is important to comprehend that spatial analysis of large areas demonstrate a low spatial resolution and they limit the accuracy of the results (Hoekstra et al., 2011). Towards enhanced spatial resolution and better analysis of the spatial factors that influence the Water Footprint can be facilitated through the use of a Geographic Information System (GIS), providing a lot of benefits, such as the spatial factors related with climatic conditions, or/and precipitation (Fig. 1). Also, GIS gives us the capacity to easily calculate the WF of a case studied area (regional WF) by multiplying the WF of the specific crop by the aggregated size of the fields in the region of study. Additionally, GIS allows different approaches of geospatial modelling relating the impact of changes in agricultural practices with spatial distributions of different crops, with demographic data and estimated simulation of future climatic models affecting severely evapotranspiration ,e.g., model Prudence (Christensen et al., 2007) for 2070-2100 in relation to 1961-1990 period, enabling spatial time series analysis (Fig. 2) and helping significantly in cost-benefit analysis of the implementing practices, so as to reduce water consumption and increase efficiency (Thorp et al., 2015; Singh, 2016) .

Fig. 1. Total precipitation height (mm) in Greece for the period 1975-2004 provided by the Web-GIS portal of the project Geoclima (Source: www.geoclima.eu)

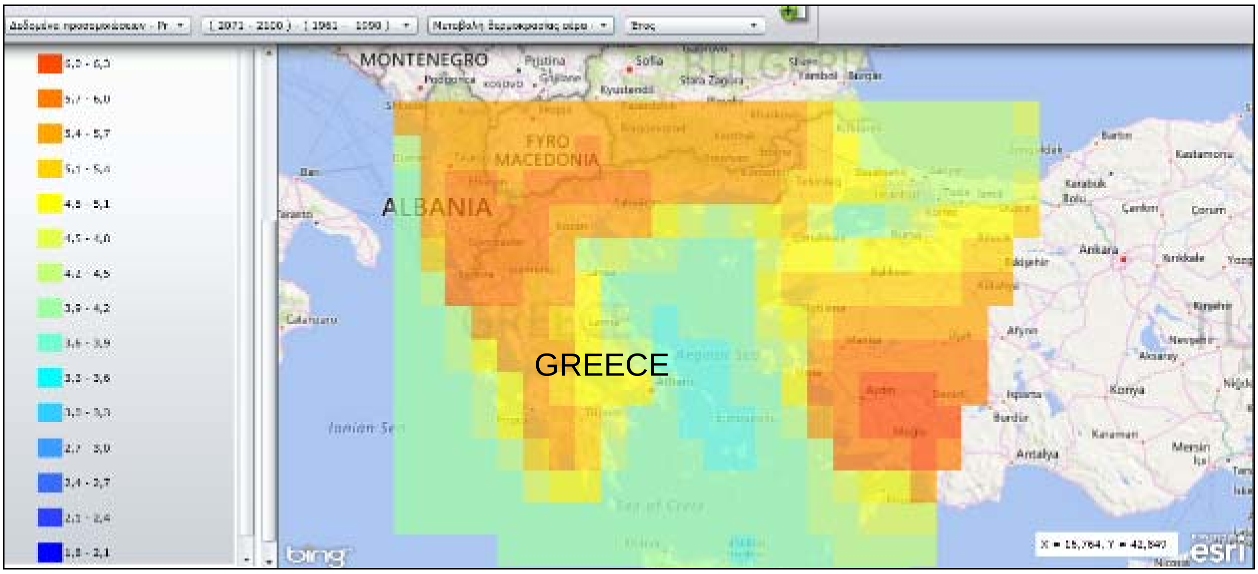

Fig. 2. Estimation of maximum temperature change (^{o}C) at 2 meters height in Greece for the period 2071-2100 in relation to the period 1961-1990, based on the climatic model PRUDENCE, provided by the Web-GIS portal of the project Geoclima (Source: www.geoclima.eu)

2. CHAPTER

2.1 New olive production systems

The worldwide trend in olive (*Olea europea* L.) production systems for olive oil, is in establishing high to super-high density systems adapted to mechanical harvesting and, is evident in all olive producing countries and in newcomers. These systems require higher levels of management and cautious use of major production inputs. One main advantage is the significantly lower harvesting cost due to modern technologies available in fully mechanical harvesting, since the main production cost (over 80-90% of the total cost) is the manual harvesting of olives.

2.2. Materials and methods

The Educational-Research-Demonstration olive grove (N40^{o} 34’ 13.42” and E22^{o} 59’ 12.25”) was established in late 2011 in Perrotis College, American Farm School of Thessaloniki, Greece (Fig. 3) and includes the following treatments: two varieties (Koroneiki and Arbequina), three planting densities acronym Super-High Density (SHD), High density (HD) and Medium (MD) density and included 1670, 1000 and 500 trees/ha, correspondingly, two irrigation levels (conventional irrigation and 50% less) and two fertilization levels (conventional fertilization and 50% less). The first year of mechanical and manual harvesting was in 2014. A number of trees from each treatment are harvested manually and the rest by a special olive harvester (Gregoire G120 model). The olive grove aims to evaluate in a long term all possible effects of the above treatments on olive production and olive oil, of the new high density systems.

The total amount of irrigation plus the rainfall in each growing season will be used to estimate WUE based on total water provided to the field and the olive yield produced. The climatic data were collected by a nearby located automatic weather station (Davis Vantage Vue, http://www.davisnet.com/solution/vantage-vue/). The average yield for each planting density across all within treatments values and varieties will be presented.

Fig. 3. The Educational-Research-Demonstration olive grove in Perrotis College, American Farm School of Thessaloniki, Greece

3. RESULTS AND DISCUSSION

3.1. Water Use Efficiency

Table 1 presents the calculated WUE for all three planting densities as an average across all other treatments. The trend shown is in close agreement but lower, when adjusted, with other conventional olive production systems. Since all the trees are young in age (< 6 years), the WUE was affected by the planting density and so, the SHD system produced the highest WUE as compared with the HD and the MD (Medium) density. A simple linear model used to extrapolate the expected WUE for the next 4 years and high yields observed in some treatments, produced the results shown in Table 2. It appears that WUE is increased yearly, under "average" weather conditions, that are considering the average of the three years used to measure the WUE. The variability in climate among the three years used was high enough to justify the rationale of using this "average" for modelling purposes.

Hijazi et al. (2014) reported from an olive grove in Syria, WUE values ranging from 0.4 to 2.1 kg/m^3 for a range of irrigation systems. Average production of fruits was 8.53 tons/ha or 48 kg/tree and a planting density of 180 trees/ha. Using drip irrigation, WUE increased from 1.3 kg/m^3 to 2.36 kg/m^3 compared with surface irrigation. These values are for conventional planting systems and older trees (18 years old) and are comparable to the high density systems of the presented study under drip irrigation, considering approximately similar tree age and yields/ha. Therios (2008) reports that the olive tree is very efficient in its use of water. It requires 312 g water to produce 1 g dry matter or converted to equivalent of 3, 2 kg/m^3, whereas other evergreen plants such as *Citrus* and *Prunus* species require 400 and 500 g, respectively. Nuberg and Yunusa (2003) reported for Australia the WUE range for two years ranged from 0.4 to 2.1 kg/m^3.

A statistical approach based on linear regression models with very high R^2 (0.95-0.98) and using "hypothesized future individual tree yields" resulted in simulated WUE for the three planting densities as shown in Table 2. The hypothesized yields were within the high range achieved in 2016 season. The WUE for the next 5 years, assuming three-year average total rain and irrigation levels, ranged from 0,65 to 3,58 kg/m^3. These values appear realistic but they may vary among the planting densities, not necessarily exhibiting a linear relationship. The SHD olive systems have an advantage during the first 4-8 years, due to higher population per unit area and, therefore, more efficient use of water and fertilizer inputs; however, the yield of the SHD systems was reported to level-off or slightly decreasing after 8-10 years. In this later period, the HD systems may have an overall advantage in WUE. This is a speculation not yet reported.

Table 1. Agronomic Water Use Efficiencies of the three planting densities (SHD-HD-MD).

YEAR	Average yield/ tree (kg)	Total RAIN (mm)	Total irrigation SHD (mm)	Total irrigation HD (mm)	Total irrigation MD (mm)	Average yield SHD (kg/ha)	Average yield HD (kg/ha)	Average yield MD (kg/ha)	WUE SHD (kg/m^3)	WUE HD (kg/m^3)	WUE MD (kg/m^3)
2016	4,5	353	65	39	20	7515	4500	2250	1,797	1,148	0,604
2015	3,2	458	40	24	12	5344	3200	1600	1,074	0,664	0,341
2014	1,6	418	32	19	10	2672	1602	800	0,594	0,366	0,187

Table 2. Simulated WUEs for the three planting densities (SHD-HD-MD for future yearly expected tree yields.

Yield kg/tree)	Total water SHD (mm)	Total water HD (mm)	Total water MD (mm)	YIELD SHD (kg/ha)	YIELD HD (kg/ha)	YIELD MD (kg/ha)	WUE SHD kg/m^3	WUE HD kg/m^3	WUE MD kg/m^3
4,5	418	392	373	7515	4500	2250	1,80	1,15	0,60
3,2	498	482	470	5344	3200	1600	1,07	0,66	0,34
1,6	450	437	428	2672	1602	800	0,59	0,37	0,19
5	455	437	424	8350	5000	2500	1,93	1,23	0,65
6	455	437	424	10020	6000	3000	2,35	1,50	0,79
7	455	437	424	11690	7000	3500	2,76	1,77	0,93
8	455	437	424	13360	8000	4000	3,17	2,03	1,07
9	455	437	424	15030	9000	4500	3,58	2,30	1,22

3.2. Water footprint (WF)

The calculations for the WF are shown in Table 3 for each of the three planting densities. The blue water footprint is considered as the amount of surface and groundwater consumed (evaporated and transpired) for the production of olives.

The green water footprint is considered as the effective rainwater amount consumed and is approximately equal to 80% of the seasonal rainfall. The grey water footprint of a product refers to the volume of freshwater that can be associated with the production of a product over its full supply chain. It the case of our study, the full supply chain is very near (<400 m) to the olive grove, in the facilities of the Krinos Olive Center of Perrotis College-AFS, where all production is processed, bottled and distributed to consumers. Since no pesticides and fungicide were used in all three years and only one herbicide application was used in the last two years in the lines only, the Grey water affect is considered negligible. Therefore, it is approximated as equal to zero. The Green WF is taken equal for each planting density, considering the rainfall factor.

Results from Salmoral et al. (2011) show more than 99.5% of the water footprint of one liter of bottled olive oil is related to the olive production, whereas less than 0.5% is due to the other components such as bottle, cap and label. Over the studied period, the green water footprint in absolute terms of Spanish olive oil production represents about 72% in rain fed systems and just 12% in irrigated olive orchards. Blue and grey water footprints represent 6% and 10% of the national water footprint, respectively. It is shown that olive production in Spain is concentrated in regions with the smallest water footprint per unit of product.

Table 3. The three components of the water footprint (WF) calculated for the average of the olive grove for each planting density.

WF component	**SHD**	**HD**	**MD**
Blue WF	273	262	254
Green WF	328	328	328
Grey WF	~0	~0	~0
Total WF	**601**	**590**	**582**

CONCLUSIONS

It appears that olive trees in super high density systems, utilized better than the lower density systems the total water in the field and have a higher WUE. This long-term study will produce in the next years, additional data to further evaluate the interaction of WUE and Total Fertilizer Use Efficiency (TFUE), in an effort to increase the WUE of the systems evaluated. The WF of olive is relative small, if production and processing units are close. The SHD systems did not have much higher WF from the lower density systems, proving again their highest overall water efficiency. This study reports only the average trend for the three planting densities across all other treatments.

REFERENCES

Alexandratos N., Bruinsma J., 2012. World agriculture towards 2030/2050: the 2012 revision. ESA Working paper No. 12-03. Rome, FAO.

Bacon, M. 2004. Water Use Efficiency in Plant Biology. Oxford: Blackwell Publishing Ltd.

Calzadilla A., Rehdanza K., Tol R. S. J., 2010. The economic impact of more sustainable water use in agriculture: a computable general equilibrium analysis. J. Hydrol. 384, 292–305. doi: 10.1016/j.jhydrol.2009.12.012.

Christensen, J.H. Christensen, O.B. 2007. Climatic Change 81(Suppl 1): 7. doi:10.1007/s10584-006-9210-7

Descheemaeker, K., Stuart W. Bunting, Prem Bindraban, Catherine Muthuri, David Molden, Malcolm Beveridge, Martin van Brakel, Mario Herrero, Floriane Clement, Eline Boelee, and Devra I. Jarvis. 2013. Chapetr 8. Increasing Water Productivity in Agriculture. IN © Managing Water and Agroecosystems for Food Security (ed. E. Boelee) CAB International 2013.

Hijazi, A., M. Doghoze, N. Jouni, V. Nangia, M. Karrou, and T. Oweis. 2014. Water requirement and water-use efficiency for olive trees under different irrigation systems. 7th International Conf. on Water Resources in the Mediterranean Basin, Oct 10-12, Marrakech, Morocco. They reported WUE ranging from 1.3 to 2.36 g/m^3 for a range of irrigation systems. Average production of fruits was 8.53 tons/ha or 48 kg/tree • Using drip irrigation, WUE increased from 1.3 kg/m3 to 2.36 kg/m3 compared with surface irrigation.

Hoekstra, A. Y., 2003. Virtual water trade. Proceedings of the International Expert Meeting on Virtual Water Trade, IHE Delft, ED : A.Y Hoekstra. Value of Water Research Report Series N°12 Delft, The Netherlands.

Hoekstra A. Y., Chapagain A. K., Aldaya M. M., Mekonnen M. M. 2011. The Water Footprint Assessment Manual: Setting the Global Standard. London: Earthscan

Hoekstra, A. Y., Mekonnen, M. M., 2012. The water footprint of humanity. PNAS 2012 109 (9) 3232-3237; doi:10.1073/pnas.1109936109.

Kijne, J.W., Barker, R., and Molden, D. (eds) (2003) Water Productivity in Agriculture: Limits and Opportunities for Improvement. Comprehensive Assessment of Water Management in Agriculture Series 1. CAB International, Wallingford, UK in association with International Water Management Institute (IWMI), Colombo.

Mekonnen, M.M., Hoekstra, A.Y., 2010. The green, blue and grey water footprint of crops and derived cropproducts. Value of Water Research Report Series No. 47, UNESCO-IHE, Delft, the Netherlands.

Molden D, Oweis T, Steduto P , Bindraban P, Hanjra MA , Kijne J. 2010a. Improving agricultural water productivity: Between optimism and caution. Agricultural Water Management 97: 528–535.

Nuberg, Ian and Isa Yunusa. 2003. Olive water use and yield – monitoring the relationship. RIRDC Publication No 03/048 RIRDC Project No UA-47A

Salmoral, G, M. M. Alday, D. Chico, A. Garrido and M. R. Llamas. 2011. The water footprint of olives and olive oil in Spain. Spanish Journal of Agricultural Research 2011 9(4), 1089-1104 [Available online at www.inia.es/sjar]

Singh A. 2016. Managing the water resources problems of irrigated agriculture through geospatial techniques : An overview. Agric. Water Management 174, 2–10. 10.1016/j.agwat.2016.04.021

Shtull-Trauring, E., Aviani, I., Avisar, D., & Bernstein, N. 2016. Integrating High Resolution Water Footprint and GIS for Promoting Water Efficiency in the Agricultural Sector: A Case Study of Plantation Crops in the Jordan Valley. Frontiers in Plant Science, 7, 1877. http://doi.org/10.3389/fpls.2016.01877

Thorp K. R., Hunsaker D. J., French A. N., Bautista E., Bronson K. F. 2015. Integrating geospatial data and cropping system to analyze spatial seed cotton yield, water use. Precision Agriculture 16, 532–557. 10.1007/s11119-015-9393-x

WWAP (World Water Assessment Programme), 2009. The United Nations World Water Development Report 3: Water in a Changing World. WWAP, UNESCO Publishing, Paris, and Earthscan, London.