Soil water content and olive tree yield responses to soil management, irrigation, and precipitation in a hilly Mediterranean area

ABSTRACT
Olive trees constitute one of the most dynamic cultivations for Mediterranean countries, while their economic importance is high. As water constitutes a fundamental factor affecting olive tree production, soil water content is a most critical parameter that must be monitored to improve olive trees’ cultivation management. Effects of precipitation, irrigation, and soil management on water content in four soil depths (10, 20, 30, 40 cm), four periods of the year (February–March, April–May, June–July, August–September) and three successive years were determined in 12 Mediterranean olive groves (Trifiilia, southern Greece) as well as their respective fruit and olive oil yields. Significantly higher soil water content was recorded in the first (+16.8%) and third (+27.4%) year compared to the second year. Higher (+6.8%) water content was observed in irrigated olive groves compared to rainfed fields. Higher (+5.6%) water content was observed in sustainable olive groves compared to intensively managed fields. Significantly, higher soil moisture was recorded at 40 and 30 cm depth compared to 10 cm depth while intermediate values were observed at 20 cm. Marked increase in fruit yield was achieved through sustainable management (+39%) compared to intensive olive groves. The potential to improve irrigation practices in the area was also indicated by results of the present study.

Key words | climate change, drought, soil depth, water

INTRODUCTION
The value of olive tree cultivation is of high importance for the Mediterranean basin both from the economic and the ecological perspective (Loumou & Giourga 2005). More than 70% of olive trees around the world are cultivated in the European Union’s (EU) Mediterranean countries (Greece, Italy, Portugal, and Spain) (Camarsa et al. 2010), and therefore, the EU constitutes globally the major olive oil producer. Greece holds about 9% of the EU olive production, while olive products are of high significance for the national economy. Olive oil and table olives produced in Greece not only serve domestic needs, but a significant volume of olive oil is exported inside and outside of the EU. Despite the fact that olive trees have limited water requirements and can grow in soils of shallow depth, of low fertility and high salt content soils, the intensification of their cultivation combined with climate variability and increased cultivation costs are causing strong pressures on olive cultivation in Greece. More specifically, some of the most important factors that contribute to low olive fruit yields or total barrenness are insufficiently covered water needs, lack of low temperature during winter, various pests and diseases, and inefficient plant nutrition.

Although favorable for olive tree cultivation, Mediterranean climate conditions are characterized by limited water
availability, which according to Fereres et al. (2003) reduces the potential to increase irrigated areas in the olive industry, taking into account also the competitive non-agricultural uses. Moreover, considering the fact that (a) climate change projections are indicating a decrement in water availability and increment in droughts and extreme climate events in the Mediterranean and (b) the major factor limiting crop production in Mediterranean-type climate conditions is soil water availability (Zuazo et al. 2009), it is easily deduced that understanding of soil water dynamics in olive groves is of major importance both for olive cultivation sustainability and agricultural water management at the basin scale. The reason is that soil water reflects the very critical water availability for olive trees and therefore can be directly related to cultivation-irrigation practices’ efficiency and olive fruit yields.

The present paper aims to determine the effects of precipitation, irrigation, and soil management on soil water content in four soil depths (10, 20, 30, 40 cm), four periods of the year (February–March, April–May, June–July, August–September) and three successive years in 12 Mediterranean olive groves (Triφilia, south Greece) as well as their respective fruit and olive oil yields.

MATERIALS AND METHODS

Study sites and field measurements

The present study was implemented in the Triφilia area, which is located in the southwest Peloponnese (Greece) and characterized by wet Mediterranean climate (Csa) (Figure 1). Six rainfed and six irrigated olive fields were chosen in order to systematically monitor soil water content at monthly intervals for three years (2014–2016). Also, half of the olive groves were discriminated by the management system (three irrigated and three rainfed sustainable: recycling of organic materials without soil tillage; and three irrigated and three rainfed intensive: no organic materials, only chemical fertilizers and soil tillage). The trees in every field were mature (20–50 years old) and drip irrigation was applied to the six irrigated fields. Soil water content monitoring was performed with PR2 sensors produced by DELTA-T Devices Ltd, accompanied by an HH2 readout unit. PR2 sensor gives the ability to monitor soil water profile at fixed depth with minimal influence from salinity and temperature depths by installing an access tube in each monitoring point. For the purposes of our study, three access tubes were installed in each monitored field and soil water content was measured at four depths, namely, 10, 20, 30, and 40 cm. There are two reasons why soil water content was monitored up to 40 cm depth: (a) soils in the study area are relatively shallow and therefore their depths do not exceed 50–60 cm; and (b) more than 70% of tree water requirements are satisfied from the upper 50% of root depth, which in our case means that the major volume of tree water requirements are satisfied from depths down to 50 cm (Thakur et al. 1981; Besharat et al. 2010). Slope of the fields was 0–6% and the three access tubes in each monitoring field were installed under the canopy of trees, at 3/4 of the canopy radius from the trunk and at representative points of the field in terms of crop growth. Four bimonthly periods were identified for the results’ representation and analysis, namely, February–March (period 1), April–May (period 2), June–July (period 3), and August–September (period 4).

Apart from soil water content, soil texture was also determined in soil samples from every field using the Bouyoucos hydrometer method (Bouyoucos 1962) before

Figure 1 | Location map of experimental groves in Triφilia area (satellite imagery: ESRI).
the onset of the experiment in November 2013, and soil

texture classification was performed according to the scheme

proposed by the United States Department of Agriculture
(USDA) (Soil Science Division Staff 2017). Soils of clay

loam texture were determined in four olive groves, while

three olive groves were found to have soils of loam texture.

Another three olive groves were found to have soils of silty

clay loam texture. For the remaining two olive groves, sandy

clay loam and silty loam texture were determined.

Based on the above, all olive groves are classified as

having medium textured soils; for such kind of soils an

indicative range of plant available water capacity is

0.15–0.22 cm H2O/cm of soil.

In each of the three growing seasons of the experiment,

fruit yield was determined in each olive grove as kg fruit per

tree and kg of olive oil per tree.

Statistical analysis

Data were analyzed using SPSS software (SPSS Inc., Chi-

cago, IL, USA) and were subjected to analysis of variance

(ANOVA) using the GLM procedure (General Linear

Model) including different years, season of the year, soil

management treatment, irrigation regime, and soil depth

as factors. Subsequently, due to significant complex inter-

actions observed, data were analyzed separately for each

soil depth and season. In the figures, significantly different

means between control and treatments were statistically

analyzed by the Tukey HSD test. The number of replicates

(n) for each measured parameter is specified in the figure

captions. Precipitation and soil moisture results are pre-

sented in four periods: February–March (period 1), April–

May (period 2), June–July (period 3), and August–September

(period 4).

RESULTS AND DISCUSSION

The effects of precipitation, irrigation, and soil manage-

ment on soil water content in four soil depths (10, 20, 30, 40 cm),

four periods of the year (February–March, April–May, June–

July, August–September) and three successive years were
determined in 12 Mediterranean olive groves as well as

their respective fruit and olive oil yields. Different years,
different periods, irrigation, soil depth, and soil manage-

ment had significant (P < 0.001) effects on soil moisture (Table 1). Significantly higher soil water content was recorded in the

first (+16.8%) and third (+27.4%) year compared to the

second year. Higher (+6.8% but not statistically significant) water content was observed in irrigated olive groves com-

pared to rainfed fields, taking into account the overall
dataset of the experiment. Similarly, higher (+5.6% but not

statistically significant) water content was observed in

sustainable olive groves compared to intensively managed

fields.

Overall, significantly higher soil moisture was recorded

at 40 and 30 cm depth compared to 10 cm depth, while

intermediate values were observed at 20 cm (Table 1). A

similar trend was observed in a more drought affected

area in Crete, southern Greece (Kourgialas et al. 2017). The

highest soil moisture was recorded in February–March, fol-

lowed by April–May and the lowest in June–July with no

statistical difference from August–September. Precipitation

was also the highest in February–March, declined sharply

from April to July and recovered during the last period
due to September rainfall incidents (Figure 2). Soil water

content is, as expected, linked to precipitation and declines
during summer in Mediterranean areas as also observed pre-

viously in southwestern Spain (Egea et al. 2016). Significant

interactions between factors were observed for year ×

period, year × management, year × soil depth, period × irri-

gation, period × depth, management × irrigation (Table S1,
available with the online version of this paper). Also, signifi-
cant triple interactions were recorded for year × period ×

depth and year × management × irrigation (Table S1).

In all four periods, a clear increasing trend in soil water

content was observed with soil depth (Figure 3), as also

observed in a previous relevant study (Kourgialas et al.

2016). During the first period, soil was saturated with

water due to abundant winter rainfall and only the super-

ficial soil layer had lower soil moisture (Figure 3(a)). In

the second period, the trend was identical for irrigated

olive groves, while for rainfed fields water content started
to decrease also in the intermediate soil depths (Figure

3(b)). A dramatic decrease in soil water content was

observed during the June–July period, when deep soil

water reserves seem to have depleted to levels similar to

surface soil layers (Figure 3(c)). Finally, soil water content
started to recover during the August–September period. This result seems to be linked partially to September rainfall, but mainly to water supplied by farmers since higher levels were recorded in irrigated fields (Figure 3(d)). Significant differences were observed neither between intensive and sustainable olive orchards nor between rainfed and irrigated fields of the same soil depth and the same period in the majority of the cases (Tables S2–S5, available online). Only one exception was recorded for irrigated intensive showing significantly higher soil water content than rainfed intensive at 30 cm soil depth during the period August–September (Table S5). Noteworthy is that evidence of water extraction by olive tree roots even below the first meter of soil has been reported (Chebbi et al. 2014), implying that olive trees have developed strategies to cope with water stress.

Sustainable management with recycling of olive grove biomass increased soil water content in an experimental field, where all other factors were identical (Kourgialas et al. 2011). In the present study, natural variation between the 12 olive groves may have masked the effect of soil

Table 1

<table>
<thead>
<tr>
<th>Source of variance</th>
<th>Soil moisture</th>
<th>Olive fruit yield</th>
<th>Olive oil yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>26.4 ± 0.8a</td>
<td>35.6 ± 1.8b</td>
<td>6.3 ± 0.3ns</td>
</tr>
<tr>
<td>2</td>
<td>22.6 ± 1.2b</td>
<td>35.5 ± 1.7b</td>
<td>6.2 ± 0.3</td>
</tr>
<tr>
<td>3</td>
<td>28.8 ± 0.7a</td>
<td>44.4 ± 1.7a</td>
<td>7.0 ± 0.3</td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigated</td>
<td>26.8 ± 0.8ns</td>
<td>38.8 ± 1.4ns</td>
<td>6.4 ± 0.2b</td>
</tr>
<tr>
<td>Rainfed</td>
<td>25.1 ± 0.8</td>
<td>38.2 ± 1.5</td>
<td>6.6 ± 0.3a</td>
</tr>
<tr>
<td>Soil management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sustainable</td>
<td>26.6 ± 0.8ns</td>
<td>44.8 ± 1.3a</td>
<td>7.6 ± 0.2a</td>
</tr>
<tr>
<td>Intensive</td>
<td>25.2 ± 0.7</td>
<td>32.3 ± 1.5b</td>
<td>5.4 ± 0.2b</td>
</tr>
<tr>
<td>Soil depth</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 cm</td>
<td>20.6 ± 0.9c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 cm</td>
<td>24.9 ± 1.0b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30 cm</td>
<td>27.5 ± 1.0a,b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40 cm</td>
<td>30.6 ± 1.1a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>February–March</td>
<td>38.4 ± 0.5a</td>
<td></td>
<td></td>
</tr>
<tr>
<td>April–May</td>
<td>33.6 ± 0.6b</td>
<td></td>
<td></td>
</tr>
<tr>
<td>June–July</td>
<td>14.8 ± 1.0c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>August–September</td>
<td>16.9 ± 0.4c</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F(Year)</td>
<td>151.548***</td>
<td>7.941***</td>
<td>2.458**ns</td>
</tr>
<tr>
<td>F(Irrigation)</td>
<td>32.958***</td>
<td>0.073ns</td>
<td>0.391**ns</td>
</tr>
<tr>
<td>F(Soil management)</td>
<td>21.571***</td>
<td>36.010***</td>
<td>42.215***</td>
</tr>
<tr>
<td>F(Soil depth)</td>
<td>205.149***</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F(Period)</td>
<td>1609.496***</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*aGLM model. Values of F: *P < 0.05; **P < 0.01; ***P < 0.001; ns: no significant differences.
*bSoil moisture in %, olive fruit yield and olive oil yield kg tree⁻¹.
*cMean values for each measured parameter within factors, with the same letter are not significantly different (P < 0.05) Tukey HSD test.
management on water content. Significant seasonal and spatial variation in soil moisture was observed even in the same olive grove and is dependent on tree canopy and soil properties (Espejo-Pérez et al. 2016). In addition, organic materials were applied in higher quantities in a previous study (Kourgialas et al. 2017), possibly contributing to a more pronounced effect. Increased soil organic matter plays a significant role in water storage and retention in olive groves (Kavvadias et al. 2017; Koubouris et al. 2017).

Olive fruit yield was significantly affected by year, irrigation, and soil management (Table 1). Significant interactions between factors were observed for year × soil management and irrigation × soil management (Table S6, available online). Significantly higher (+25%) fruit yield was recorded in the third year compared to the first two (Table 1). Also, a marked increase in fruit yield was achieved through sustainable management (+39%) compared to intensive olive groves (Table 1). However, irrigation caused no change in fruit yield and this result is reasonable taking into account that irrigation had no effect on soil moisture. Research should be focused on defining the level of irrigation water deficit that maintains fruit yield, and beyond, which water saving is punished with yield losses (Ahumada-Orellana et al. 2016). Also, the irrigation technique employed may have a significant effect on olive yields and therefore should be carefully selected (Dbara et al. 2016). The positive influence of sustainable management on fruit yield was more stable in rainfed olive groves throughout the three years, while it varied yearly in irrigated fields (Figure 4). Irrigation had a positive effect on fruit yield in intensive olive groves in all three years, while the trend was reversed in sustainable fields. To achieve highest efficiency, special attention should be paid to customized irrigation scheduling rather than only to the total amount of water applied (Padilla-Díaz et al. 2018). In addition, fruit yield is largely determined by leaf area (Hernandez-Santana et al. 2017), therefore tree pruning can be modified to achieve the optimized balance between water availability and yield.

In the study area, as common around the Mediterranean, olives are mainly cultivated for olive oil production. Olive oil yield was stable among the three years, which is impressive in terms of applying optimized
orchard management to alternate bearing. Sustainable management also increased olive oil yield (+41%) compared to intensively managed olive groves (Table 1). Surprisingly, olive oil yield was slightly higher in rainfed olive groves compared to irrigated fields. This finding could be interpreted by higher fruit water content in irrigated fields resulting in less olive oil extracted by the same amount of fruit. In addition, summer rainfall incidents in the study area may have eliminated the drought stress of rainfed olive trees and masked the beneficial effect of irrigation. Irrigation should also be scheduled taking into consideration olive oil quality since it was demonstrated that trees with high water status yielded oils with lower concentrations of total phenols (Caruso et al. 2014). Significant interactions between factors were observed for year × soil management, year × irrigation and irrigation × soil management (Table S7, available online). Sustainable management had a positive effect on fruit yield in most cases in all three years with only one exception in irrigated groves during the first year (Figure 4). Irrigation had a positive effect in intensive farms, but not in sustainable groves.

CONCLUSIONS

The results of the present study demonstrate that soil water content and fruit yield variation were significant both for rainfed and irrigated fields, mainly because of the complex interference of several factors that contribute to this variation, such as tree size and leaf area, weed cover, overall tree health, and nutrition. Higher (+6.8%) water content was observed in irrigated olive groves compared to rainfed fields. Similarly, higher (+5.6%) water content was observed in sustainable olive groves compared to intensively managed fields. Significantly higher soil moisture was recorded at 40 and 30 cm depth compared to 10 cm depth while intermediate values were observed at 20 cm. A marked increase in fruit yield was achieved through sustainable management (+39%) compared to intensive olive groves. Use of meteorological data, soil moisture, and plant water status sensors as well as modern irrigation systems in the framework of a holistic water management strategy would contribute to optimized crop performance, water use efficiency, and natural resources conservation in the era of climate change.

ACKNOWLEDGEMENTS

The authors are grateful for the contribution of the LIFE+ financial instrument of the European Union, for the project LIFE11 ENV/GR/942/oLIVECLIMA.

REFERENCES


First received 15 May 2018; accepted in revised form 26 July 2018. Available online 3 September 2018.