Nutrients, trace elements and water deficit in Greek soils cultivated with olive trees

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ABSTRACT

The studied soils consist of alluvial and/or colluvial deposits and are located in the Prefecture of Messinia, Western Peloponnese (Greece). A number of 263 surface soil layers were selected and analysed for the main properties. Minimum and maximum values as well as the distribution of soil properties varied greatly and can be attributed mainly to various fertilization practices adopted by the farmers, inputs of nutrients by irrigation water and differences due to inherent soil conditions. Lower variability was recorded for the parameters pH, Cation Exchange Capacity (CEC), total soil nitrogen and soil organic matter (SOM), while coefficients of variation for properties that can be affected easily by human activities such as available phosphorus and micronutrients, are much higher. Minor content for trace elements was observed in the following order: Zn>Mn>B>Fe. During the dry period, irrigation of olive trees is recommended and the appropriate irrigation demands were defined taking into account the rainfall and the water requirements.

Riassunto

I suoli studiati si sono formati da depositi alluvionali e/o colluviali e si trovano nella prefettura di Messinia, Peloponneso occidentale (Grecia). Un numero di 263 orizzonti di superficie sono stati selezionati e analizzato per le proprietà principali. I valori minimi e massimi, nonché la distribuzione delle proprietà del suolo, variano notevolmente e possono essere attribuiti principalmente a varie pratiche di fertilizzazione adottate dagli agricoltori, apporti di nutrienti da parte dell'acqua di irrigazione e a differenze causate delle condizioni intrinseche del suolo. Variabilità più bassa è stata registrata per il pH, la capacità di scambio cationico (CEC),l'azoto totale del suolo e la materia organica del suolo (SOM), mentre i coefficienti di variazione per le proprietà che possono essere influenzati facilmente da attività umane, come fosforo disponibile e micronutrienti, sono molto superiori. Contenuti minori in oligoelementi sono stati osservati nel seguente ordine: Zn> Mn> B> Fe. Durante il periodo secco, l'irrigazione degli ulivi è raccomandata e le appropriate richieste irrigue sono stati definite tenendo conto della pioggia e del fabbisogno di acqua.

INTRODUCTION

Olive-tree tolerates a wide range of soil acidity and is characterised by high resistance to drought, lime content and salinity. Greece holds third place in world olive production with more than 130 million trees, which produce approximately 350,000- 400,000 tons of olive oil per year. Most olive trees in Greece are grown for oil in Peloponnese, as well as in Crete, Chalkidiki, the Aegean and Ionian Islands.

In areas of annual rainfall higher than 600 mm (like Western Peloponnese), production can be profitable under rain fed conditions in soils with adequate water-holding capacity. However, in the last two decades very high density, hedgerow type, olive orchards (from 1,000 to 2,000 tree ha) have been introduced to reduce harvesting costs using over-the tree harvesting machines. Because of the higher crop evapotranspiration (Etc) demand of the dense canopies and the low soil volume available for each tree, irrigation during the summer period is needed (Steduto et al., 2012).

In general, soils in Greece cultivated with olive trees are characterized by medium or low fertility. Olive-trees tolerate a wide range of soil pH, but the neutral, slightly alkaline values assure their best development (Martinez, 1984). The presence of $CaCO_3$ may reduce the availability of phosphorus and Zn, Cu Mn, Fe and B via different mechanisms (Galvez et al., 2004; Benitez et al., 2002). Soil organic matter content (SOM) decreases the soil erosion risk and can enhance soil water holding capacity, so the trees can better resist under dry conditions. Soyergin et al. (2002), have reported that olive trees grow well on soils containing more than 1% of organic matter even if a threshold of 1.5% is considered low in other conditions (Freeman and Carlson, 1994). In research works carried out in Tunisia a critical value 8 ppm for P was suggested (Gargouri and Mhiri, 2002). The optimal values for plant available potassium in soils varied greatly and ranged between 40 and 400 ppm (Gonzalez and Troncoso, 1972; Recalde, 1975), while the minimal threshold for available K content in the soil is correlated to clay content. The spatial variation of the components of soil fertility has been studied for the olive groves in the area of Western Messinia. The main aim of this work was the improvement of agricultural practices applied in olive groves taking into account the environmental impacts and parcel production capacity.

METHODS

Site description, obrothermic diagram

The studied area is located in the prefecture of Messinia, Western Peloponnese (Greece). The land is used for high-income agriculture, mainly olives and vineyards. The climate of the region is temperate with wide temperature and rainfall fluctuations (Table 1). According to data provided by the National Meteorological Service in Kalamata, the mean annual temperature was 17.8°C, the mean annual relative humidity was 66.5% and the mean annual precipitation was 780.3 mm.

The estimated monthly mean values of precipitation and air temperature were used for the compilation of the obrothermic diagram of Kalamata meteorological station. Gaussen (1956) defines a month as dry, when $P < 2T$

where: P and T are the monthly mean values of precipitation (mm) and air temperature (°C)

Based on the study of the ombrothermic diagram, the soil moisture deficit occurs from mid April to October (Figure 1).

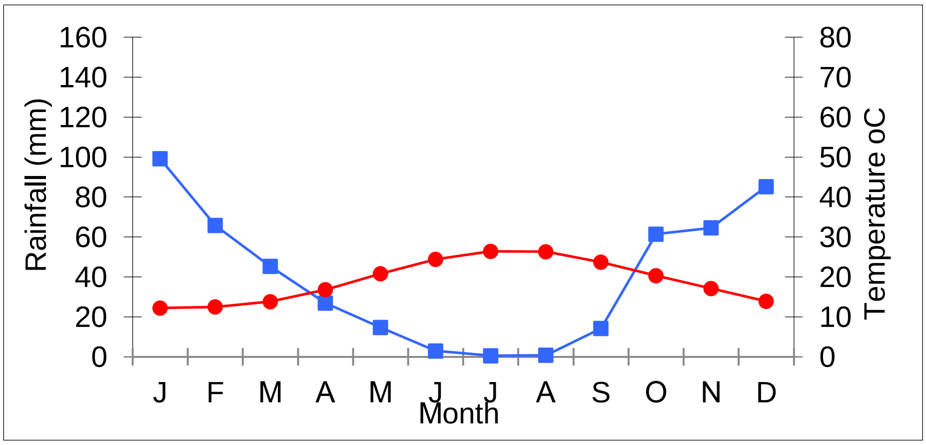

Figure 1 Ombrothermic diagram for Kalamata meteo station

Sampling and chemical determinations

Surface samples were selected from a depth 0-30 cm for 263 points, from soils cultivated with olive trees. Soil samples were taken after removing the fresh plant debris and five replicates per soil sample were conducted. The samples were air–dried and the fraction (<2 mm) was used for laboratory determinations. Particle size distribution was determined by the Bouyoucos hydrometer method (Gee and Bauder, 1986). The pH was measured in a 1:1 soil–H_2O suspension (McLean, 1982). Soil carbonates were determined by the volumetric calcimeter method (Allison and Moodie, 1965). The method of ammonium acetate (1N at pH 7) was used for exchangeable cations (Thomas, 1982). Cation exchange capacity (CEC) was determined by the ammonium acetate method (Rhoades, 1982). A modified wet digestion Walkley and Black method (Nelson, and Sommers, 1982) was used for the organic matter determination and plant available P was determined by the Olsen method (Olsen, 1982). The azomethine-hydrogen method (Keren, 1996) was used to determine the plant available boron (B). The available form of Fe, Cu, Zn and Mn was determined by extraction with 0.005 M diethylene-triamine-penta-acetic acid (Lindsay and Norvell, 1976).

Water samples were collected and stored in portable thermally insulated containers to avoid mineralization before the analyses. All samples were analyzed for pH with the standard glass electrode method, and electrical conductivity was measured in the field by a portable conductivity bridge. Heavy metals were analysed after filtration and preservation in concentrated HNO_3. NO_3^- -N and NH_4^+ -N were measured in UV-VIS spectrophotometer. The colorimetric titration method was used for Cl^-, atomic absorption for Ca^{2+} and Mg^{2+}, flame photometry for K^+ and Na^+, and spectrum photometry for SO_4^{2-}.

RESULTS AND DISCUSSION

The studied soils consist of alluvial or colluvial deposits and are located in the Prefecture of Messinia, Western Peloponnese. Field survey indicated that soils in the lowland of Messinia consist of alluvial deposits and the dominant parent materials of the hilly soils are carbonate conglomerates or neogene marls.

Stratification of soil horizons differentiates the physical and chemical properties. Minimum and maximum values as well as the distribution of soil properties varied greatly and can be attributed mainly to different fertilization practices of crops by farmers, inputs of nutrients by irrigation water and differences due to inherent soil conditions. Most soils have a loamy or clay loamy texture (62.8%) and 37.2% of them are heavy (clay). Statistical analysis has shown that CV for $CaCO_3$ was highest (Table 1) followed by SOM, CEC and pH. High variability of $CaCO_3$ can be attributed to soil genesis factors, degree of soil erosion, climate and human activities such as soil leveling.

Table 1 Statistical analysis of selected surface soil properties (N=263)

	CEC cmol/kg	**pH (1:1)**	**SOM**	**$CaCO_3$**
			%	
AVER	16.9	6.8	2.7	14.3
MAX	34.2	7.9	5.7	61.6
MIN	5.2	3.8	0.5	0
STD	5.1821	1.0769	0.9275	16.7730
CV %	30.6	15.8	33.8	117.5

Table 2 shows the content and variation of total nitrogen, exchangeable K^+ and Mg^{++} and plant available phosphorus. The highest CV was recorded in P content (Table 2) and can be attributed mainly to annual fertilization with phosphate fertilizers. The values for K^+, Mg^{++} and plant available P varied greatly, and rational application of nutrients is required, according to olive trees demands. Total nitrogen also varies, but most of N is bounded to the SOM and can be available after mineralization via soil microorganisms.

The average exchangeable K^+ content of the soils is found to be 0.48 cmol/kg and the average changeable Mg^{++} is 1.3 cmol/kg.

Table 2 Statistics for soil nutrients in surface horizons

	N_{total}	K+	Mg+	P-Olsen
	mg/kg	cmol/kg		mg/kg
AVER	1266.8	0.48	1.3	23.1
MAX	2605.5	1.7	6.6	162.9
MIN	208.4	0.1	0.4	1.1
STD	408.0515	0.2609	0.9435	26.3832
CV %	32.2	54.4	72.6	114.2

The average available phosphorus content of the soil samples is determined as 23.1 mg/kg although P content in certain samples was under the threshold value of 15 mg/kg with the presence of very low content in one sample, i.e. 1.1 mg/kg. Similar trends were recorded in the case of potassium, hence this situation raises the necessity of P and K fertilization.

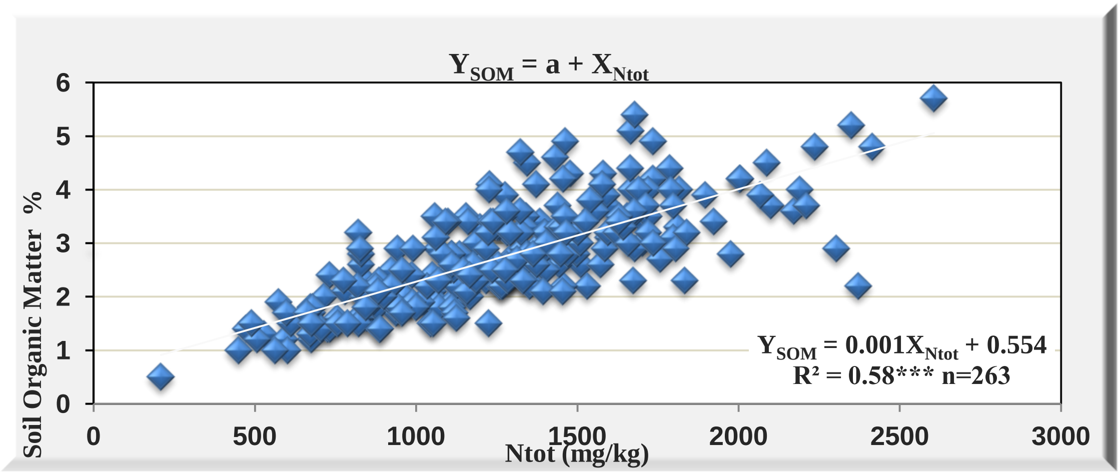

Figure 2 Relation between SOM and total soil nitrogen

Total nitrogen content varied between 208.4 and 2605.5 mg kg^{-1}, much lower than the mean content observed in soils rich in organic matter (Karyotis et al., 2005). Statistical analysis shows soil organic matter correlates (Figure 2) with total soil N, indicating that this element is mainly bound in the organic matter fraction of soils.

The variation of trace elements is very high (Table 3) and can be assumed that 82.9% for Zn and 46.0% for P are at deficiency levels (Table 4).

Boron deficiency is very common in olive trees and the most practical way to mitigate this problem is to apply borax or boric acid to the soil. To correct B deficient in olive trees, Greek farmers use to apply borax in the soil at rates of 220 to 450 g per tree. Regarding Zn deficiency, this was observed in calcareous soils and may be attributed to low content of parent material in Zn.

Table 3 Statistics for soil trace elements in surface horizons

	Cu	Fe	Zn	B	Mn
			mg/kg		
AVER	6.8	23.2	0.7	0.6	16.0
MAX	53.8	175	3.8	3.5	124.9
MIN	0.4	1.5	0.2	0	1.2
STD	9.7267	25.5653	0.5143	0.5287	18.6897
CV %	143.0	110.2	73.5	88.1	116.8

Table 4 Limiting factors for soil nutrients and trace elements

	Fe	Zn	B	Mn	N_{total}	K^+	P-Olsen
	mg/kg					cmol/kg	mg/kg
samples	10	218	41	45	71	50	121
%	3.8	82.9	15.6	17.1	27.0	19.0	46.0

Decreasing trends were recorded in the content of available phosphorus in the study area (Figure 3) between the years 2011 and 2013, due to reduction of P fertilization.

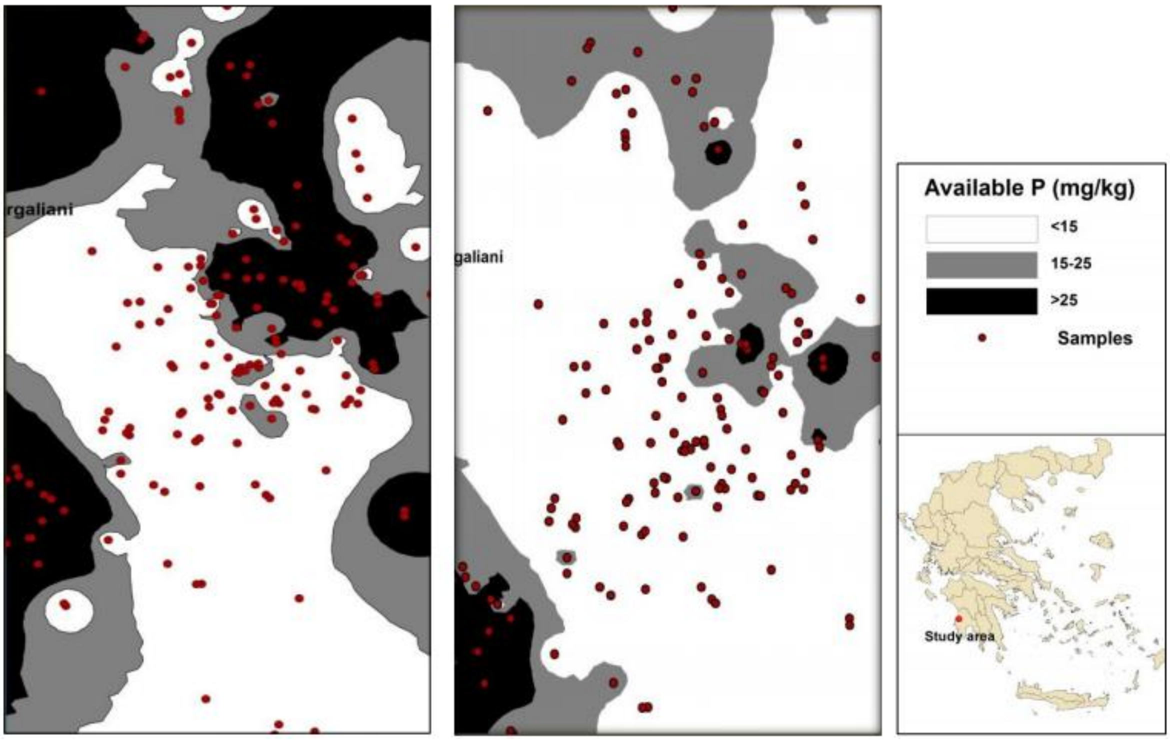

Figure 3 Differences of plant available phosphorus in the study area for the years 2011 (left) and 2013 (right)

To diagnose nutrient status in olive trees, research has indicated that soil analysis must be combined with plant analysis. This is considered the most reliable tool for detecting the nutritional status of an olive plantation.

Fourteen samples were collected from groundwaters in the study area of Messinia at the end of August 2012 and the main chemical properties were performed. It was observed that water properties varied significantly among water samples (Table 6).

However, irrigation water also contains elements that are essential for plant growth, such as nitrates, phosphates, potassium, sulphur, calcium, magnesium, iron, zinc, copper, manganese and boron. Proper crop nutrient management often includes fertilization of some of these nutrients. Most farmers in Greece do not consider irrigation water nutrient concentrations when applying a fertilization plan. This source of plant nutrients is important, production cost can be decreased and prevent addition of non-essential quantities of nutrients to the agricultural ecosystem.

Maximum nitrates concentration varied from 0.7 to 54.4 mg/l and this means that a farmer who irrigates olive trees with water rich in nitrates, has to take into consideration the inputs of nitrates into the soils according to Table 7.

Table 6 Chemical determinations in groundwaters used for irrigation

Code	pH	K	Na	Ca	Mg	Cl	SO_4	NO_3	NH_4
		mg/l							
B01S003	7.0	1.8	32.9	161.1	17.4	47.7	56.3	38.4	0.3
B01S004	7.2	0.5	10.1	125.5	5.9	15.9	0.1	4.1	0.4
B01S005	7.2	1.5	31.4	129.2	17.4	35.6	21.1	13.6	0.8
B01S007	7.1	1.9	36.9	154.0	16.7	58.0	82.2	23.5	0.5
B01S008	7.1	4.2	45.7	149.0	18.0	71.6	68.2	47.3	1.0
B01S009	7.2	1.5	18.9	162.8	7.8	28.3	27.3	54.4	0.8
B01S010	7.4	1.7	25.1	119.9	12.5	31.4	13.1	21.2	0.6
B01S012	7.4	3.0	58.0	112.4	26.5	81.0	67.3	2.6	1.0
B01S013	7.0	1.0	73.7	233.0	45.6	123.6	349.6	7.0	0.4
B01S014	7.2	4.6	82.5	92.9	13.1	71.4	33.4	10.8	0.1
B01S015	7.1	1.6	30.5	161.0	12.3	59.3	54.0	13.5	0.7
L01S001	6.6	0.8	30.0	37.7	7.7	27.5	18.2	0.7	1.0
L01S006	7.1	2.2	32.9	150.1	23.1	32.0	45.0	20.4	0.5
W01S00	7.0	1.3	92.4	194.4	40.6	292.8	87.0	3.1	1.7

Water nitrates' concentration has received much "negative" attention over the last decades. However, nitrates contained in irrigation water provide crops with part of the required nitrogen. Hence, farmers have been advised to reduce the quantity of applied nitrogenous fertilizers accordingly if water used for irrigation is high in nitrates content.

Table 7 Theoretical nitrogen inputs from irrigation

Nitrates (mg/l)	**Quantity of irrigation water** (m^3/ha)			
	2000	**3000**	**4000**	**5000**
	Nitrogen inputs (kg/ha)			
5	2.26	3.39	4.52	5.65
10	4.52	6.78	9.04	11.30
20	9.04	13.56	18.08	22.60
30	13.56	20.34	27.12	33.90
40	18.08	27.12	36.16	45.20
50	22.60	33.90	45.20	56.50

It has been also observed that SOM content was >2% in 86.5% of the soil samples in 2011 and was reduced in 2013 (Table 8). This decrease can be attributed to improper tillage practices which increased the erosion risk. Nitrates values higher than 20 mg/kg were also decreased in 2013 due to more rational application of nitrogenous fertilizers. The enhancement of total soil nitrogen (>2.000 mg/kg) can be explained by the increasing of organic form of nitrogen in soils with gentle slopes originated from plant residues.

Table 8 Variation of SOM, nitrates and total soil nitrogen

SOM %	**2011**	**2013**
<1	1.0%	3%
1-2	12.5%	37%
>2	86.5%	60%
pH	**2011**	**2013**
<5.5-6.5	29.5	19.0
6.5-7.5	31.0	23.0
>7.5	39.5	58.0
NO_3 (mg/kg)	**2011**	**2013**

<10	47.5%	75.0%
10-20	36.5%	16.0%
>20	16.0%	9.0%
Ntot (mg/kg)	**2011**	**2013**
<1.000	23.0%	16.0%
1.000-2.000	73.0%	72.0%
>2.000	4.0%	12.0%

The application of a more rational fertilization plan has affected the available phosphorus and potassium (Table 9) and maximum contents were decreased.

Table 9 Variation of available phosphorus and potassium

P (mg/kg)	**2011**	**2013**
<15	**57%**	**72.0%**
15-25	**11%**	**12%**
>25	**32%**	**16%**
K(mg/kg)	**2011**	**2013**
<100	**18.5%**	**32.5%**
100-250	**59.5%**	**58.0%**
>250	**22.0%**	**9.5%**

Climatic conditions

Climate in the study area varies greatly due to variation of altitude, slope, orientation of cultivated soils, geomorphology e.t.c. Climate data provided by the meteorological station of Kalamata (years 1975-2006) show very high maximum temperature, which is higher than 42 ^oC in July and implies the need for irrigation of olive trees taking into account the very low height of rainfall especially for the period from June to August (Table 10).

Table 10 Climate data from Kalamata meteorological station

Month	**Mean temp.** ^{o}**C**	**Abs. Max. Temp.** ^oC	**Abs. Min. Temp.** ^oC	**RH** %	**Rainfall** mm
J	10.2	23	-5	72.6	111.7
F	10.6	23.8	-4.4	71.7	94.1
M	12.3	26	-3.6	71.2	73
A	15.2	29.8	-0.4	70.4	48.5
M	19.7	37	5.4	66.3	25.6
J	24.1	41.8	9	58.6	7.5
J	26.4	42.6	12	58	4.2
A	26.3	42	12.4	61.1	11.3
S	23.2	38.8	9.6	65.2	29.1
O	18.9	37.4	4.2	69.3	85.3
N	14.8	29	-0.4	74.8	137.4
D	11.7	26	-2	75	152.6
Mean	**17.8**	**30.5**	**3.5**	**66.5**	**780.3**

Aridity is the degree to which a climate lacks effective, life-promoting moisture; a measure of aridity of a region, proposed by De Martonne (1925), is given by the following relationship:

$$I_{DM} = \frac{P}{T+10}$$

where P is the annual mean precipitation (mm) and T (°C) the annual mean air temperature.

The De Martonne index based on the values of I_{DM} and P is shown in Table 11. The monthly value of the De Martonne Aridity Index is calculated by the following equation:

$$Im = \frac{12P'}{T'+10}$$

where P΄ and T΄ are the monthly mean values of precipitation and air temperature for the considered month. When the value of Im is lower than 20 then the land in this month needs to be irrigated (Zambakas, 1992).

Table 11 De Martonne index of climatic classification

Climate	**Values of I_{DM}**	**Values of P** (mm)
Dry	$I_{DM} < 10$	P < 200
Semi-dry	$10 < I_{DM} < 20$	200 <P <400
Mediterranean	$20 < I_{DM} < 24$	400 <P <500
Semi-humid	$24 < I_{DM} < 28$	500 <P <600
Humid	$28 < I_{DM} < 35$	600 <P <700
Very humid	a. $35 < I_{DM} < 55$ b. $I_{DM} > 55$	700 <P <800 P > 800

According to our calculations, the De Martonne aridity index was found 45.4, and the climate has been classified as very humid (Table 11). In the reviewed literature estimations of applied irrigation quantities for olive trees in the Mediterranean region were found. These range from 181 mm/yr (Fernández, et al., 2006) to 403 mm/yr (Palomo, et al., 2002). Olive trees are irrigated in Greece approximately once every second week during the warm and dry season June-September. Small trees would need less water and according to rough estimations an irrigation amount of around 100-150 mm/yr is needed. In shallow wells with a water table depth between 20-30 m, there have been signs of declining water levels and increasing salinity of up to 2500-2700 μS/cm.

The Joint Ministerial Decision F16/6631/1.6.1989 issued by the Ministers of Internal Affairs, National Economy, Agriculture, Environment, Industry and Energy and Technology (Government Gazette B΄ 428), suggests the lowest and highest limits of the necessary volumes for rational water use with regard to irrigation. The high mean monthly temperature reduces water availability due to increased evapotranspiration. Taking into consideration the duration of dry period (Figure 1), the recommended volume of irrigation water (Table 12) for the olive trees is 386.8 mm as calculated on the basis of values provided in the aforementioned Joint Ministerial Decision 6631on the minimum olive tree water requirements and the average rainfall per month.

Table 12 Water requirements for irrigation of olive groves in Peloponnese

Month	**Minimum requirements (MR)** (mm)	**Rainfall (R)** (mm)	**MR – R = Irrigation** (mm)
April	63	48.5	14.5
May	82	25.6	56.4
June	93	7.5	85.5
July	102	4.2	97.8
August	96	11.3	84.7
September	77	29.1	47.9
	513	126.2	386.8

Olive trees can be adapted to grow as a rain fed or irrigated crop. Due to water scarcity from April to mid of October, drip irrigation is the most widely used system for irrigation in olive groves, and an efficient irrigation can be achieved. Different measures and agricultural practices must be applied by farmers in each soil type. It is well known that irrigation increases yield and profitability, if water quality is not impaired by natural causes or by excessive abstraction.

CONCLUSIONS

The elaboration of climate data has shown that the main problem is rather related to the seasonal fluctuation of rainfall and not to the amount of annual rainfall. Phosphrous and potassium deficiencies were recorded in certain soil samples, while problems were observed related to Zn B and Mn. A close relationship was found between soil organic matter and total soil N, indicating that this element is mainly bound in the organic matter fraction of soils. Differences in CV can be attributed mainly to the following factors such as: degree of soil nutrients mobility, soil genesis factors, erosion, SOM content of soil horizons, soil slope and applied agricultural practices. Coefficients of variation for properties which are affected easily by human activities, are much higher such as available P and micronutrients. It must be mentioned that certain soil properties have been changed. Soil acidity was corrected by application of lime material, while N, P, K and B content were reduced in 2013 due to decreased application of fertilizers. The duration of very dry period is more than three months and the recommended amount of irrigation water for the olive trees was defined taking into account the rainfall per dry month, rainfall and the water requirements for the olive groves. The nutrients management in olive trees is a complicated issue, dependent on several factors which include: tree variety, age, density of trees and whether the groves are irrigated or rainfed.

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