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THE ENVIRONMENTAL IMPACT OF THE WATER HOLDING CAPACITY OF SOIL IN A MEDITERRANEAN OAK ECOSYSTEM

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Abstract: The main objective of this study is to focus on the importance of the available water holding capacity (AWHC) of the soil for forest growth. The study area is the oak ecosystems of central mountainous Halkidiki, which can play a significant role in the context of multi-purpose forestry and the promotion of sustainability in natural environment. Increased values of soil depth correspond to increased AWHC. We have found AWHC to be 71 mm for a soil depth of 45 cm, 90 mm for a soil depth of 60 cm, 103 mm for a soil depth of 75 cm and 115 mm for a depth of 90 cm. Soil samples at the same depths were examined in three treatment plots, namely, control, thinning and clearcut. Forest floor increases the total AWHC of soil to a range of 4-8 mm, depending on the impact of various treatments on the mass of the organic matter. Total available water surplus (TAWS) (in the form of run off or deeper infiltration) appeared in the shallower soils (AWHC of 70-80 mm) for a duration of two more months compared to the deeper soils (AWHC 115 mm). In these deeper soils, 47 mm/year more soil-water is retained and is available for tree growth. AWHC values higher than 100 mm extend the tree growing period for two more months. The TAWS differences between AWHC values of 103 mm and 90 mm compared to the lowest value of 71 mm, was found to be 33 mm/year and 17 mm/year respectively. Similar results were found in all plots. The thinning up to 15 %, practiced by the Forest Service, provides one more month of TAWS (extending the period in which TAWS appeared) compared to the untreated plots. The treatment was a 50 % thinning of total basal area, which provided two more months of water surplus availability (TAWS), to enhance water yield. In general, the best site quality is characterized by higher values of AWHC which is correlated to deeper soils. This is apparently reflected in tree growth. The tallest trees of the best site found to be five meters higher than those growing in shallower soils. For all soil depths and AWHC values, intense thinning (50 %) compared to the control treatment, supply the trees with an additional 32 mm/year of soil moisture and less thinning can increase soil moisture by 18 mm/year, which help trees withstand hot and dry summers. The limiting growth factors in Mediterranean oak ecosystems are soil depth and the seasonal change of soil moisture, especially during the dry summer period, so increasing the AWHC, even marginally, may prove crucial for tree sustainment. The role of these forests is of outmost importance for providing multi –purpose services (e.g. promoting health-fresh air, water, recreation, stabilizes the microclimate, supports biodiversity, tourism, economy, and enhance storing carbon).

Keywords: awareness on sustainable forest management, interactions and interconnections in ecosystems, available soils' water holding capacity, tree growth

1. INTRODUCTION

Soil, water and vegetation are strongly interconnected and interrelated (Ganatsios 2004). Vegetation cover exerts an important influence on soil (Grigal, 2000) and represents the main factor controlling the erosion process (Stefanescu et al., 2011). Interception is a very important term in the forest water balance (Gerrits et al., 2010). It can strongly influence preceding soil moisture conditions, which is a very important factor for the generation of floods (Savenije, 2004). Only a limited amount of rainfall reaches the forest litter layer -which can store -more water than its own dry weight up to its specific water holding capacity- and consequently significant amounts of water evaporate (Zagyvai-Kiss et al., 2019). Trees' canopy has a larger evaporative potential than litter due to its better exposure to winds and higher surface roughness being conducive to more effective transport of moisture into the air; and canopy interception capacity is relatively small compared to that of the forest floor (Baird & Wilby 1999).

Soil condition and characteristics also determine the condition of vegetation. Soil functions that support plant growth by means of controlling resources available to plants (Schoenholtz et al., 2000) can be altered by the impacts of harvesting activities such as increased biomass removal (Slesak et al., 2017) and soil compaction (Solgi et al., 2016). The Mediterranean area is particularly affected by erosion (Pereira et al., 2017) with topsoil being more susceptible to it. The loss of organic-rich topsoil is regarded to be the greatest degrader of soil quality and quantity and, in most cases, cannot be restored (Alewell et al., 2015). Undisturbed and adequate forest floor with favorable conditions for its decomposition is an important soil generating factor (Papaioannou 2013). Furthermore, forest litter layer can store water.

A large diversity of oak ecosystems can be found in Greece, varying from evergreen shrub lands along the coastline to productive forests in higher elevation areas. Oak ecosystems are important for forest management as they constitute 44% of the total forested area of the country (Ministry of Agriculture, 1992). The Greek Forest Service manages these oak ecosystems for both wood and non-wood services (recreation, erosion protection, water yield production, forage for livestock). The success of Forest management is assured by the knowledge about the appropriate water management of the forest soils, the knowledge of their resistance and adaptability on climate changes (Szendreine & Nemeskeri 2007). Oak is sensitive and it reacts in group, not individually to the disturbing factors (Nechita & Popa 2012). Additionally, the second pillar of sustainability is the humble recognition that modern societies should respect nature and promote the forests' known benefits, as well as those undiscovered yet, for the future generations.

There is an increasing interest in the management of forested areas for improving soil characteristics such as their water holding capacity (Startsev & McNabb 2001).

The water holding capacity is one of the most important variables for interception modelling (Zagyvai-Kiss et al., 2019). Available water holding capacity (AWHC) expresses the ability of soil to store water in a form available to plants. The remaining water in the soil at the end of a dry season depends on precipitation amount and intensity, land slope, and the soil type and depth. There is a relationship between the water potential of a given soil and the amount of water held in the soil at the field capacity and at the permanent wilting percentage. At field capacity, soil is holding the maximum amount of water useful to vegetation, where sufficient pore space is filled with air to allow optimal aeration for most aerobic microbial activity and plant growth. On the contrary, when permanent wilting of the plants occurs, there is still a limited quantity of water in the soil, which is held too tightly to permit its absorption by plant roots (Brady & Weil, 2008). These two boundary properties determine the available water holding capacity. The zone of interest, where plant needs are satisfied, lies within the range of available water values quantities contained between -0.033 MPa and -1.5 MPa.

Furthermore, there is a correlation between the higher vegetation growth (due to higher AWHC) and the forest environment capability of absorbing the negative environmental impacts of infrastructure works, such as, forest road construction. In particular, the introduction of specific environmental criteria concerning road construction environmental impacts in forest areas (Psilovikos & Giannoulas, 2017) showed that a high and dense vegetation and vegetation growth can "absorb" and diminish the harmful environmental effects of road construction. In this sense, AWHC may indicate whether a road construction may or may not have reversible environmental impacts and its degree of the environmental compatibility with the forest.

This study aims at enhancing the knowledge of interactions between soil, water and forest management of *Quercus frainetto* forest ecosystems in Northern

Greece. More specifically, it examines and analyzes AWHC under the broader objective of improving forest soil conditions in the context of sustainability.

2. MATERIALS AND METHODS

2.1 The study area

The study area is located in central mountainous Halkidiki, in Northern Greece and is dominated by hardwoods, mostly *Quercus frainetto* (Fig. 1). The forest ecosystems of the area are under sustainable management and have the chance and conditions to grow older and to become mature, self-dependent, capable of multi-purpose services. The importance of mature forests is gradually gaining interest and awareness. In terms of tree volume increase, old growth forests of most species excel, exhibiting considerable growth rates with increasing tree size (Stephenson et al., 2014). There are trees in the study plots (mean diameter 19 cm) and in the surrounding forest environment exceeding the diameter of 40 cm and up to more than 80 cm for a number of them. Forestry students learn that one of the pillars of sustainability is ethics including the recognition of the right of the trees to grow and mature. Oak trees live hundreds of years but unfortunately in Greece, oak wood is used to produce only fire wood, usually harvested in pre-mature state, before the age of 50 or 70 years at small diameters (less than 30 cm). Selective cutting can allow those trees -who have managed to reach diameters above 30 or 40 cm- to grow older. At least, for firewood, smaller diameters are more suitable, and easier to cut by lumberjacks. Coppicing is an old way of managing European forests that was introduced hundreds of years ago out of pure necessity. Timber was becoming increasingly scarce, because it was being used so heavily as fuel and building material, and people were not interested in letting trees grow old. Oaks and beeches were being cut down at the tender age of 20 to 40 (instead of 160 or 200), leading to the razing of forests (Wohlleben 2017).

The study area has a typical temperate mesothermal (subtype C_{Sb}) climate, according to the Köppen classification system. Moderate temperatures (average annual air temperature 11.4ºC) and rainy weather during the winters prevail, whereas summers are characterized by a short hot and dry period. Long-term mean annual precipitation is 756 mm, which mainly falls from October to March (for two out of the three years of the study period, precipitation was higher than the average values). All climatic data are collected at the TUF weather station (altitude of 860 m), located only 150 m away from the boundaries of the study plot at SE exposure. The study period was two years.

The forest floor has a mean depth of 4-5 cm that increases infiltration and decreases overland flow. For this reason, little soil erosion can be evidenced. The decomposition rate is adequate as a result of favorable temperature and moisture conditions (Ganatsios et al., 2021).

Soils' parent (bedrock) material is vertically stratified schist (mica and talk). The soil has subangular blocky structure. Topsoil is characterized by a high organic matter content and a sandy clay

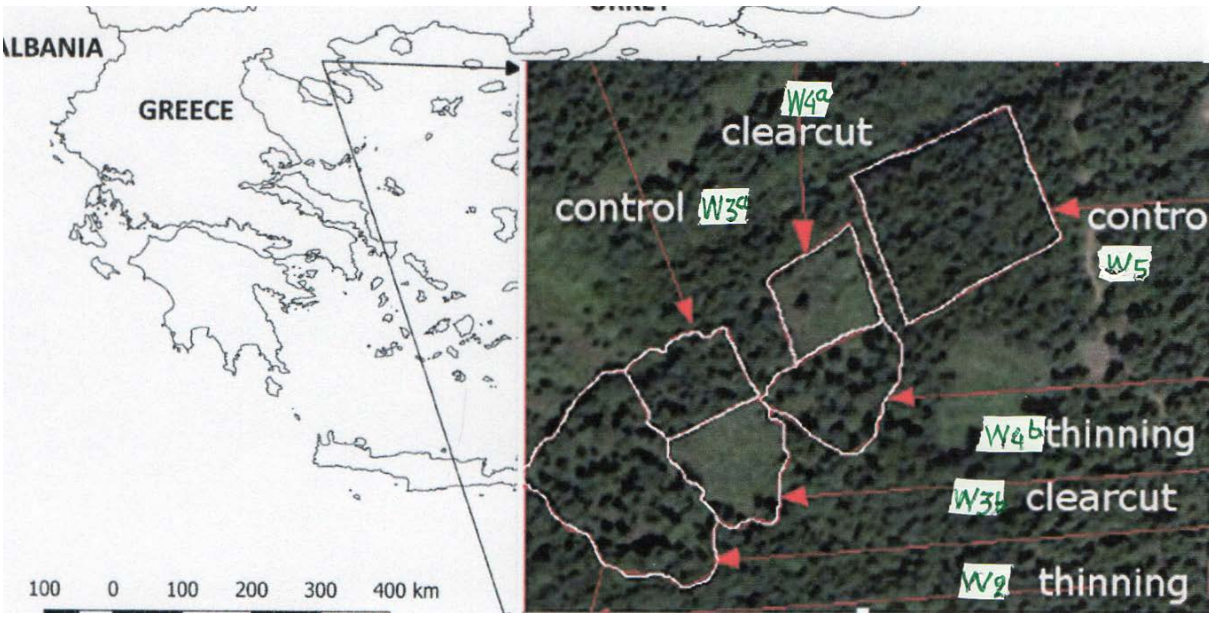


Figure 1. The study area

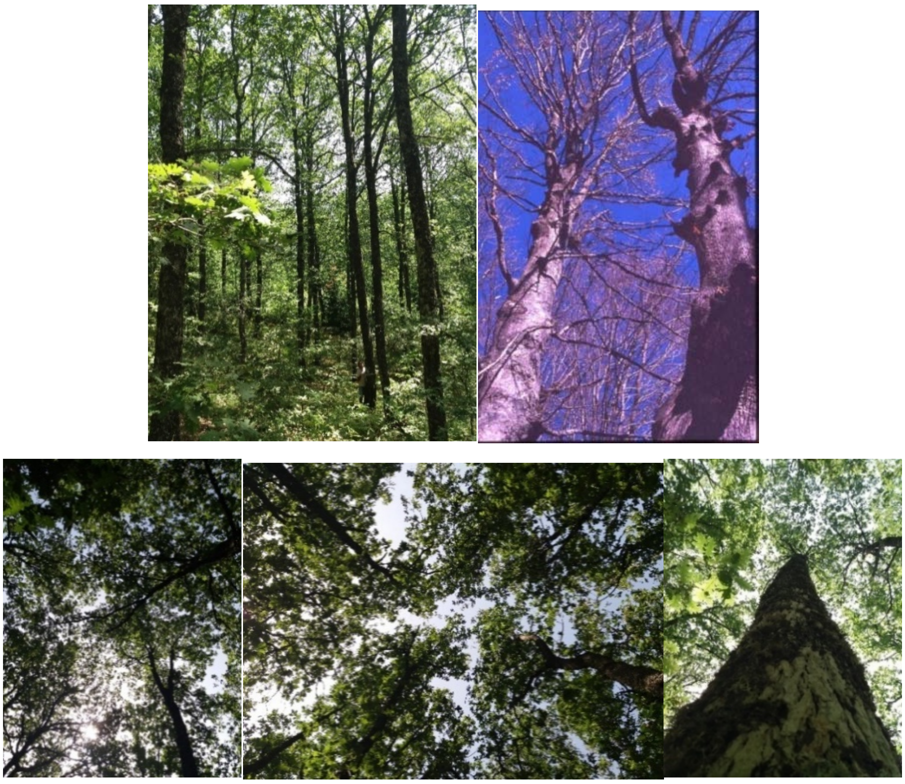


Figure 2. Canopy closure in the study area with rare precious trees over 80cm

loam texture (60%-20%-20%). The soil belongs to Chromic Luvisols (IUSS Working Group WRB, 2006) and could be described as immature due to a history of intense erosion. Xeralfs is the type of Luvisols of the study area. In our soil profiles there is no natric horizon (Natrixeralfs) or a duripanit, therefore there is no horizon firmly cemented and thus restricts soil management.

More specifically, the protective vegetation cover has been removed, as a result of alternating land uses in the past, including intensive wood harvesting, grazing and use of the area as agricultural land till the 50's. Today, the soils are well protected from erosion by the existing vegetation and forest floor. Soil has an average depth of 45-60 cm in the upper part of the plots and is deep (>90 cm) only at the lower part of one plot. The soil is fertile but under the prevailing stand conditions, the limiting factor for forest growth is its depth and seasonal change of soil moisture. Annually, these soils are dry for more than two months during the summer period. For a better understanding of the soil condition, soil profiles were taken from representative soil pits.

The predominant tree species in the study plots are the *Q. frainetto* and few *Fagus ssp (mainly in W1 plot)*. Tree age is 70-72 years (year 2020) and the forest stand is healthy. Dry tree tops can be witnessed only after very hot dry periods. During the summer, canopy closure can reach 100% (Fig. 2).

Detailed description of the study layout is included in Ganatsios et al., (2010). Four plots (W2, W3, W4, W5) –one next to the other- were used for data collection for various experiments in the past. Site quality ranged between medium and good (Fig. 1). The criteria for this classification included tree age and average height of the dominant trees. In particular, plots W4b and W2 are next to each other with the same characteristics. In 2001, thinning removed 50% of the tree stand basal area. A hypothesis can be made that the tree height differences between the plot W4b (the best site quality) and W2, are due to the deeper soils found in W4b. Even in terms of nutrients we haven't found significant differences between these plots.

2.2 Sampling and data collection

Bulk density was measured because of its relevance to the calculation of the AWHC. The widely used method of the volumetric ring was used for the soil bulk density measurement (Brady & Weil, 2008, Solgi et al., 2018). The volumetric ring was made of 1.5 mm thick stainless steel with an inside diameter of 5.5 cm and a height of 4 cm. The ring was driven into the soil by means of a drop hammer. The inner cylinder containing an undisturbed soil core was removed and trimmed on the bottom to yield a core of easily calculated volume. The weight of this soil was determined after being dried-out in an oven. Tree dimensions were measured with the help of a Haga relascope and a caliper.

2.3 Laboratory measurements -Available water holding capacity (AWHC)

2.3.1 Soils' AWHC measurements

Representative soil pits (13 in total) were constructed, 0.25 m^2 each, approx. 1m deep, down to the bedrock (3-4 per plot, 13 in total). Soil profiles were extracted from them (Fig. 3). From each profile, soil samples were collected (at 15 cm depth intervals down to the bedrock of each soil profile), brought to the laboratory and were oven-dried (104ºC) and sieved (2 mm). Then, the samples were saturated and put for 36 hours in a pressure membrane apparatus to be brought in moisture equilibrium at pressures of field capacity (-0.033 MPa) and permanent wilting (-1.5 MPa) (Brady & Weil, 2008).

Specimen mass (water content) was determined when in equilibrium at each applied pressure. The AWHC value was calculated as the difference of moisture (%) between the field capacity and permanent wilting percentage and was later converted to mm by taking into consideration the soil bulk density, the coarse fragment content and the thickness of each sampling interval (15 cm). The individual AWHC values of the soil horizons were summed to give the total AWHC of the soil-plant system within the rooting zone.

2.3.2 Litters' AWHC measurements

Litter samples (O_1 + O_2 horizons) were collected from nine sampling points, by pressing a square steel sheet sampling frame (25 cm x 25 cm) – three for each plot (control, thinned and clearcut), 19 years after the treatments` establishment. The weight values of the samples found to be in line with the respective values taken two years prior to this sampling (30 samples in each plot were taken for extensive nutrient content measurements, Ganatsios et al. 2021). Samples were brought to our university campus and placed properly (without disturbing their structure) in plastic containers, under similar forest conditions during the humid month of November (under an oak tree). For a week, they received artificial showers twice a day and they were weighed afterwards, to measure their max AWHC. Then, for three days, the samples were left to filter the excess moisture (there was no rain during this period) and weighed again. Then they were oven-dried to a constant weight at 75 °C for 24 hours and reweighed. The retained amount of water was determined as the difference between field weight and oven-dry weight.

2.3.3 Water balance method

Water balance models have been used as a means to analyze the allocation of water among the various components of the hydrologic cycle. The water balance model used in this study is the one developed by the Laboratory of Mountainous Water Management and Control at the Aristotle University of Thessaloniki (Papoulias, 1973, Pavlidis, 1997, 2005) and is based on the Thornwaite–Mather method (Thornwaite & Mather, 1955, 1957). It is a monthly accounting procedure, using precipitation, water interception, air temperature, potential evapotranspiration (PET) and the soil moisture storage capacity as inputs. The water balance equation used is:

$$PET = P - Q - S$$

where PET is the potential evapotranspiration, P is the total amount of precipitation, Q is the stream discharge (including surface and subsurface flow) and St is the change in soil moisture storage capacity in a month

$$DS = St_n - St_{n-1},$$

(DS is the difference of St between two sequential months, n is the month for which water balance is calculated and n−1 the previous month).

The value of St_n, which is inserted in the model, depends on the amount of soil moisture storage capacity (St_m) and its relationship to the Stmax=AWHC for the respective month:

$St_n = 0$	*if*	$St_m < 0$
$St_n = St_m$	*if*	$0 \leq St_m, \leq St_{max}$ (AWHC)
$St_n = St_{max}$	*if*	$St_m, > St_{max}$ (AWHC)

Also, for all months that $St_m \leq$ AWHC, we accept that there is no runoff. PET was calculated with the help of the Thornthwaite method (Thornthwaite, 1948). The following formula was used:

$$PET = 1.6 * (10*T/i)^a$$

where PET is the monthly potential evapotranspiration, T is the mean monthly temperature (◦C) and i is a heat index for a given area which is the sum of 12 monthly index values i_x. i is derived from mean monthly temperatures using the following formula (Thornthwaite, 1948):

$$i_x = (T/5)^{1.514}$$

Finally, a is an empirically derived exponent which is a function of i:

$$a = 6.75\times10^{-7} i^3 - 7.71\times10^{-5} i^2 + 1.79\times10^{-2} i + 0.492$$

The outputs of the method include the index of moisture adequacy (defined as the ratio AET/PET, where AET is the calculation of the actual evapotranspiration), as well as the amounts of total water surplus, available for runoff (including surface and subsurface flow) and infiltration.

3.RESULTS

3.1 Tree size results

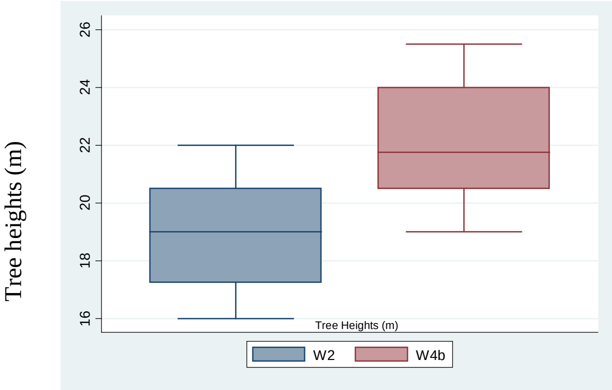
Maximum tree height for the control plot found to be 20 m with an average height 19.3 m. The respective maximum height value in the best site quality (W4b) was found to be 25.5 m and the average tree height 21.9 m (standard deviation=1.924) and average diameter 30,5 cm (st.d=5.784). For the plot W2, maximum height was found to be 21.5 m, the average tree height 18.9 m (st.d=1.837) and the average diameter 25 cm (st.d=4.241). The impact of soil depth on tree height and diameter is presented in Figure 4, in which there is a comparison of the tree heights, diameters and the variations between the two thinned plots (W4b and W2) of different soil depths, (W4b plot has deeper soils).

3.2 Soils' AWHC results

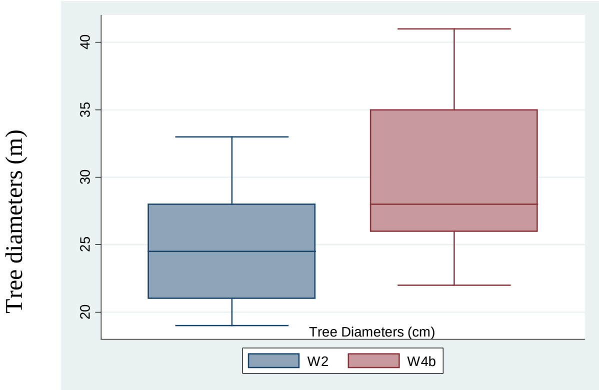
Soil horizon depths and coarse fragment content are presented in Table 1, Figure 4. Plot W4 is characterized by thicker horizons compared to the other plots. The coarse fragment content of the study plot was 18-20 % for the A11 horizons and slightly higher (range 20-24 %) for the A12 horizons. Coarse fragment content increased with increasing soil depth, ranging from 32-40 % in the Bt horizon to 65-75 % in the C horizon.

Soil bulk density increased from 0.95 to 1.40 g cm^{-3} with increasing soil depth. The field capacity was 26.7 % g g^{-1} at 0-15 cm and decreased to 21.75% g g^{-1} at 75-90 cm. Similarly, the wilting percentage decreased from 6.5 to 6% g g^{-1}. AWHC was found to be 71 mm in soils of depth of 45 cm, 90 mm in 60 cm, 103 mm in 75 cm and 115 mm in 90 cm depth, respectively (Table 2). This amount of available water could be stored by the soil for plant use all the time, including the crucial dry period. The deepest soils found in plot W4b were where the tallest trees are

Figure 3. Soil profiles of the study plots (from left to right): i) Plot W3, depth> 70 cm, ii) Plot W2, depth> 80 cm, iii) Plot W4, depth>1 m (roots found at a depth of 1.1 m)



The two thinned plots with similar characteristics but different soil depth (deeper soils in W4b)



The two thinned plots with similar characteristics but different soil depth (deeper soils in W4b)

Figure 4. The impact of soil depth on tree height and diameter. Boxplot comparing the tree heights and diameters and variations of 2 thinned plots (W4b and W2) of different soil depth (W4b plot has deeper soil).

located. Because all other characteristics were found to be similar, even in terms of nutrients, we attribute the tree growth differences between W4b and W2 to the differences in the soil depths. Table 3 presents -in brief- the water balance method results, related to four different AWHC values, within the plots and for each one of the three treatments.

Table 3 shows the variation of the values of total water surplus, which is available for the deeper bed rock infiltration or run off (surface and subterranean). This surplus indicates excess of moisture beyond the level of water holding capacity. As expected, lower values of AWHC (71 mm, 90 mm), related to the smaller depth of soils, drive the higher values of total available water surplus (TAWS) (284 mm, 267 mm). The smaller the reservoir of the soil, the sooner it gets filled and overflowed or filtered into deeper ground layers. During the study period, considering the three treatment plots and within each plot and for the shallower soils characterized by lower values of AWHC, TAWS appeared for two additional months, compared to the soils of the highest AWHC value. This amount of water in the deeper soils is utilized by the root system for the needs of the forest. In thinning treatments, the TAWS differences between lower and higher AWHC values appeared to extend to one additional month.

Figure 5. Forest floor samples collection and moisture contents measurements

Table 1. Soil horizon depth ranges and coarse fragment content (%) by soil horizon as determined from study plots two years after the harvest operations.

Plot	Soil profiles	Horizon Depth (cm)					Horizon Coarse fragment content (%)			
		A_{11}	A_{12}	B_t	C	R	A_{11}	A_{12}	B_t	C
W2	4	0-5	5-25	25-53	53-75	>75	19	23	38	67
W3	3	0-4	3-35	35-55	55-60	>60	21	22	40	75
W4	4	0-9	9-54	54-87	87-95	>95	18	20	32	65
W5*	2	0-7	7-25	25-54	54-60	>60	20	24	35	70

Table 2. Results of the available water holding capacity (AWHC) and total AWHC for various soil depths

Soil depth (cm)	Soil bulk density (g/cm^3)	Fine earth (%)	Field capacity (% g g^{-1})	Wilting percentage (%g g^{-1})	Available soil water for the plants (% g g^{-1})	AWHC (mm)	Total AWHC (mm)			
							Soil depth 45 cm	Soil depth 60 cm	Soil depth 75 cm	Soil depth 90 cm
(1)	(2)	(3)	(4)	(5)	(6)	(7)*				
0-15	0.95	88	26.70	6.50	20.20	25.33				
15-30	1.10	75	25.49	6.24	19.25	23.82				
30-45	1.25	70	24.12	7.32	16.80	22.06	71			
45-60	1.30	60	22.34	6.56	15.78	18.46		90		
60-75	1.40	40	21.85	6.01	15.84	13.31			103	
75-90	1.40	35	21.75	6.00	15.75	11.58				115

(7)= (1)(2)*(3)*(6)/100)*10 (page 245 Weil & Brandy 2017)

Table 3. Water Balance method results with four different AWHC values, within the plots and for each of the three treatments

Annual values /Treatments	**Control**				**Thinning (50%)**				**usual thinning (max 15%)**			
Average annual Precipitation, P (mm)					1008							
Interception, Lp (mm)	261				192				231			
Air temperature, T (°C)					11.8							
Potential Evapotranspiration (Thornthwaite), Etp, (mm)					695							
Total Water Surplus, (P-Lp-Etp)>0 (mm)	363				400				376			
Sum annual water deficit, (P-Lp-Etp)<0 (mm)	310				278				293			
Available Water Holding Capacity (AWHC) (mm)	**71**	**90**	**103**	**115**	**71**	**90**	**103**	**115**	**71**	**90**	**103**	**115**
Consumption of soil water, DSt (mm)-estimated	79	95	106	114	80	95	105	113	81	97	107	115
Calclulation of Real Evapotranspiration, Etr (mm)	464	480	490	499	496	512	521	530	482	498	508	516
Recorded water deficit RWD= Etp-Etr (mm)	231	215	204	196	199	183	173	165	213	197	187	179
RWD differences		16	27	35	**32**				**18**			
Total available water surplus **TAWS**, (mm)	284	267	251	237	320	304	291	277	295	280	264	250
TAWS differences		**17**	**33**	**47**								
Total months in which available water surplus was estimated	9	9	8	7	11	11	11	10	10	10	10	9

In table 3, showing TAWS differences within treatment plots, the lower TAWS value is related to the highest AWHC of 115 mm and indicates water availability and utilization (by the trees) of an additional 47 mm/year (st.d.= 1.796). The TAWS differences between AWHC values of 103 mm and 90 mm with the lowest value of 71 mm, found 33 mm/year, (st.d.=11.09) and 17 mm/year (st.d.=19.05) respectively. The standard deviation shows that an increase in soil depth significantly affects TAWS. This amount of soil moisture is used by the trees for growth. In thinning treatments, similar differences have been found. The best site quality is characterized by higher values of AWHC –deeper soils. This is apparently reflected in the tree growth. The tallest trees of the best site were found to be five meters higher than those growing in shallower soils. It is obvious that soil depth determines tree growth. Tree height is mainly influenced by the AWHC differences among trees of the same age and soil characteristics (Fig. 4).

Regarding the TAWS differences among the treatment plots (different interception values), the usual thinning, similar to the one applied by the Forest Service, provides one more month of TAWS compared to the untreated plots, while the treatment of 50% thinning of the total basal area, provides two more months of TAWS, available for water yield.

In Table 3, the lowest values of the recorded water deficit (RWD) appeared in soils of the highest AWHC. The deeper the soil, the higher the tree endurance in dry periods and the resilience of the forest to remain in good condition. The values of soil moisture consumption for different soil depths (different AWHC) indicate that the highest water consumption (ultimately turned into tree growth) (35 mm more than the value of the shallowest soil depth of 45 cm), were recorded in the highest AWHC value of 115 mm (at the soil depth of 90 cm). The respective values of the in-between soil depths (60 cm and 75 cm) – where found 27 mm (at 75 cm) and 16 mm (at 60 cm).

Among the three treatment plots, the highest values of RWD have been found in the control plots. The differences between the respective values of AWHC of the control and the 50% thinning plots, were found to be 32 mm/year. This means that irrespectively of the soil depth, intense thinning provides an additional 32 mm/year of soil moisture. Less thinning can increase soil moisture by 18 mm/year. Table 4 presents the average minimum value of the available moisture of the soil for the study period and prior to the beginning of the rainy season, expressed as a percentage (%) of AWHC. The shallower the soil, the less is the moisture, resulting in higher stress on the trees and the impact of the treatment is maximized. On the contrary, as expected, differences due to the treatment, are observed in the deeper soils in which the quantity of soil water during this dry period minimized tree stress. Figure 6 presents the fluctuations of soils' moisture content during the three-years study period in four different soil depths corresponding to four different AWHC.

3.3. Forest Litters' AWHC results

Table 5 presents the results of the AWHC of the litter. The average oven-dried sample litter weight (kg/m^2) for the control plot was found to be 3.36 kg/m^2 (st.d=0.577), for the thinned plot 1.84 kg/m^2 (st.d=0.080) and for the clearcut plot 2.24 kg/m^2 (st.d=0.733). The average AWHC in mm for the control plot, was found to be 7.95 mm of water (st.d=0.805), 4.05 mm for the thinned plot (st.d=1.726) and 4.95 mm for the clearcut plot (st.d=2.663). The respective values of AWHC in l/kg for the control plot were found to be 2.41 l/kg of water (st.d=0.430), 2.20 l/kg for the thinned plot (st.d=0.929) and 2.13 l/kg for the clearcut plot (st.d=0.869). According to our measurements, one kilogram of litter can store 2.13 to 2.41 liters of precipitation water with equal 216 % to 237 % of its own weight (216 % for thinning, 221 % for clearcut and 237 % for control plots). Table 6 presents the forest litters' contribution in increasing the AWHC of the soil and reducing the annual deficit of water in the soil, thus improving conditions for plant growth.

Table 4. Average minimum value of the available moisture of the soil for the study period and prior to the beginning of the rainy season, expressed as a percentage (%) of AWHC

AWHC	Control (%)	Common Thinning (%)	Intense Thinning (50%) (%)
71mm	2	2	2
90mm	4	5	5
103mm	6	7	8
115mm	8	9	10

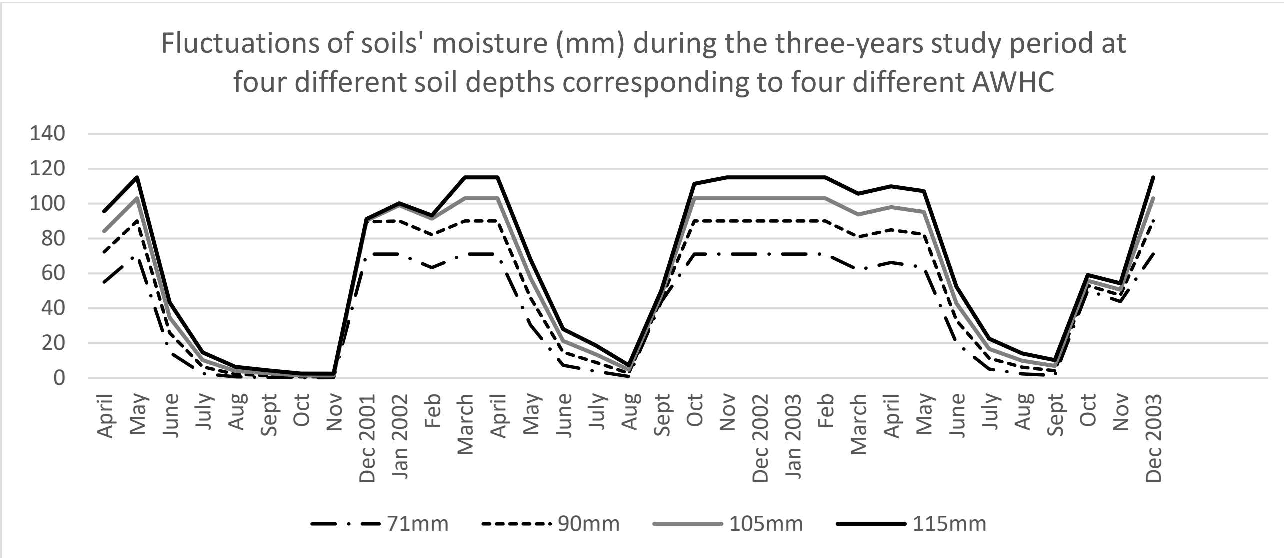


Figure 6. Fluctuations of soils' moisture (mm) during the three-years study period at four different soil depths corresponding to four different AWHC (control plot) The highest curve represents the highest (115 mm) AWHC

Table 5. AWHC results of forest litter

Treatment plots	Average liter weight values (Kg)	oven-dried liter weight (Kg/m^2)	st.d *	Average values of AWHC (litres)	Average AWHC (mm)	st.d*	Average AWHC (lt/Kg)	st.d*
Control	0.210	3.36	0.577	0.497	7.95	0.805	2.41	0.430
Thinning	0.117	1.84	0.080	0.253	4.05	1.726	2.20	0.929
Clearcut	0.140	2.24	0.733	0.310	4.95	2.663	2.13	0.869

*Standard Deviation

Table 6. Forest litters' contribution in increasing the AWHC of the soil and reducing the annual water deficit in the soil, thus improving conditions for plant growth.

AWHC	2001	2002	2003	sum of 3 years	average of 3 years	st.d.
71 ->79mm	8.7	7.4	6.6	22.7	7.6	1.078
90 ->98mm	8.2	6.8	5.4	20.4	6.8	1.391
103 ->111mm	7.8	6.4	5.7	19.4	6.6	1.080
115 ->123mm	7.5	5.6	5.3	18.4	6.1	2.171

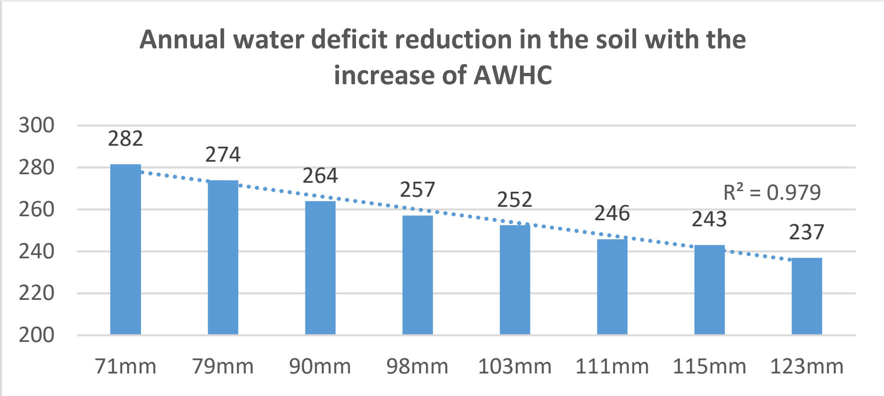


Figure 7. The annual reduction of the water deficit of the soil with the increase of AWHC

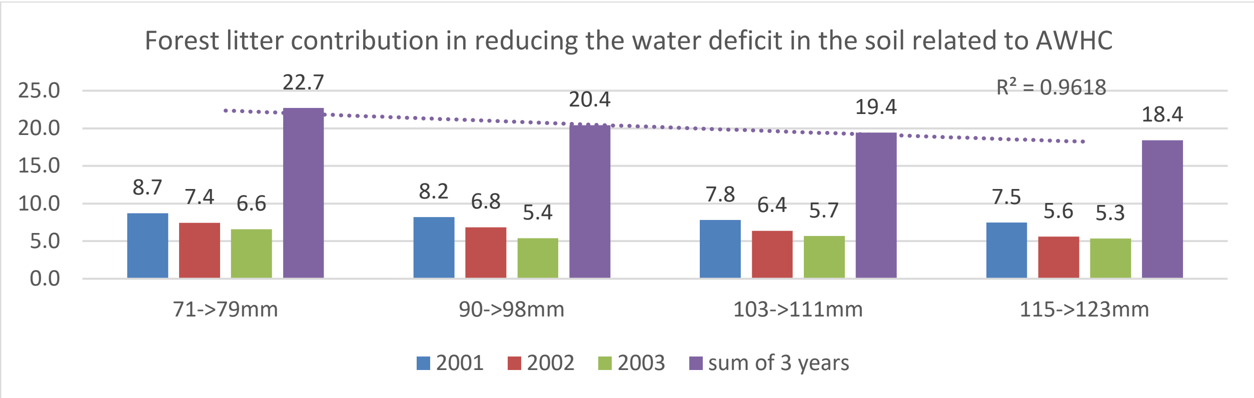


Figure 8. The contribution (mm of water) of the litter in reducing the annual water deficit in the soil related to AWHC

Figure 7 presents the annual reduction of deficit of water in the soil observed along with the increase of total AWHC including the contribution of the litter. According to statistical analysis, significant statistical differences (p value <0.01, F=2281,6) were observed between the different classes of AWHC. Figure 8 presents the contribution of the litter in reducing annual deficit of water in the soil which is related to AWHC. The lower the AWHC, the higher is the contribution of the litter in retaining soil moisture and improving the conditions for plant growth.

4. DISCUSSION

Soil moisture concerning the soils on which the common thinning treatments are practiced -based on the rotation period of the Forest Service management plan-increased by 18 mm/year due to the aforementioned treatments. This additional moisture (gained through interception reduction) is crucial for the tree growth because during the dry, hot summers and without adequate prior winter-spring precipitation, tree growth can stop and dry top branches can be observed (Ganatsios 2004, Nechita & Popa 2012). Forest ecosystems typically have a large leaf-area index both within the crown level and on the ground as litter, making interception a very important element of the forest water balance Zagyvai-Kiss et al., (2019). We have also found similar leaf-area index equal to six.

Thinning and foliage removal have been implemented as a means to increase soil water availability (Bruijnzeel & Vertessy, 2004). More specifically, thinning can improve soil characteristics by modifying the structure, composition and density of the forest stands as well as increasing water availability in areas with low precipitation. The study site and the wider area of the Halkidiki peninsula, face water scarcity, especially during the summer period. At the same time the area is a major tourist attraction of Southern Europe and thus the demand for water resources is high.

By improving the quality and quantity of forest soil, infiltration rate also improves. Ganatsios (2004) found increased infiltration rates in the area. Even during large rainfall events, forest soil minimized stormflow. Defining an optimum thinning degree is necessary as a means to address soil needs for a satisfactory forest growth and water yield. There is a limit, over which thinning may lead to ecosystem deterioration. Although, a removal of 50% of basal area has increased water yield (Ganatsios et al., 2010), lower degrees of thinning degrees are suggested as common practice for Greek oak forests, due to the important need to improve soil characteristics such as maintaining its properties through anti-erosion protective measures and increasing its depth. This increase can be partially achieved through ensuring the creation of good forest floor conditions to facilitate decomposition, provide soil nutrients. Sustainable forest management can increase the water surplus, which even in small quantities (e.g. 5 mm/year) can benefit Mediterranean ecosystems to a considerable degree. Guidelines on modification of the thinning rate along with the expected increase of water yield in the area, are described in Ganatsios et al., (2019). Various proposals for the minimum degree of thinning have been suggested (Serengil et al., 2007a and 2007b, Brown et al., (2005). However, it is important that in the long term, the impacts of forest operations should not exceed the capacity of soil to recover from natural processes (Vance et al., 2018; Worrell & Hampson, 1997). Hence, hydrological protection guidelines are available in the international literature (Cassells et al., 1984, Dykstra & Heinrich, 1996, FAO, 1999; Hamilton, 2005, Thang & Chappell, 2004)**.**

AWHC of forest litter (precipitation storage capacity) results in lt/kg varies between 2.13-2.41 lt/kg of oven-dry weight depending on the effect of the prior silvicultural treatment on the quantity of litter mass. These values are equal 216 % to 237 % of its own weight (216 % for thinning, 221% for clearcut and 237 % for control plots). For Sessile oak in the Alps, Zagyvai-Kiss et al., (2019) found the respective value to be 2.1 lt/kg (210 % of its own weight). According to these authors, the AWHC of forest litter varies between 2.0-2.1 lt/kg oven-dry weight, regardless of the tree species.

The sampled oak litter AWHC varies between 1.84 lt/m^2 (thinning plot), 2.24 lt/m^2 (clearcut plot) and 3.36 lt/m^2 (control plot), compared to the 1.66 lt/m^2 in the Alps report. This finding is supported by Helvey (1964), who characterized the maximum water content of forest litter as a percentage of dry weight and found it to be between 210–215 % for a mixed deciduous stand. Blow (1955) published a similar value (225 %) for the specific water holding capacity of litter for an oak forest.

AWHC of the leaf litter is independent of tree species, thus once the weight of the litter is known, the water holding capacity of the litter can be estimated immediately without further knowledge of the percentage composition of the litter by tree species. AWHC of the undisturbed control forest stand was found to be 7.95 mm compared to 1.68 mm from the study conducted in the Alps. The higher values of AWHC found in our study can be explained by the higher amounts of litter in our study area and the exclusion of mull humus from the study of Zagyvai-Kiss et al., (2019). Thinning reduced forest litter mass, thus reduced its own AWHC from 7.95 mm (control plot) to 4.05 mm (50% thinning plot). Considering that a 4 mm reduction might be crucial, less thinning is suggested. 15% and 50% thinning found to reduce the estimated real evapotranspiration by 18 mm and 32 mm respectively, compared to the untreated control plots.

According to Algayer et al. (2019), and their study conducted in France in deep soils, values of AWHC at maximum root depth were always lower than AWHC down to the bedrock, meaning that, on average, maximum root depth did not reach bedrock depth. In our case, roots were found penetrating the bedrock trying to provide trees with the vital moisture to resist the dry hot summer period. The aforementioned authors report that the AWHC (root density) exhibited mean values of 34% to 45% lower than AWHC (including the bedrock). They also report that total AWHC decreased gradually as fixed soils depth declined (with a mean of 51.7 mm, the lower AWHC were observed for the minimum fixed soil depth of 50 cm). This is in line with the findings of our study. The water retention capacity of coarse fragments based on the measurements was found to be important for explaining tree growth. The correlation coefficients increased significantly when deeper layers were considered, regardless of the considered soil volume (Algayer et al., 2019). According to these authors, this relationship is explained by the importance of coarse fragments, especially in the saprolite zone, but also by the substantial water retention of some of the pebbles Algayer et al., (2019), suggests that AWHC of forest soils should be assessed on a minimum of 200-cm deep soil volume. In our study we have measured AWHC and not total AWHC including bed rock (tree roots often penetrate it in search for water), because heavy machinery is prohibited in Greek forestry and furthermore, our intention is to cause the minimum disturbance in the study ecosystems where there is shallow soil.

The remaining soil water at the end of the dry season depends mainly on the AWHC and trees consumption. The AWHC values of 71 mm, 90 mm and 103 mm, refer to the soil depths of 45 cm, 60 cm and 75 cm, respectively (Table 3). Papoulias (1973) and Oikonomopoulos (1931), under similar soil conditions, found AWHC values of 50 mm, 100 mm and 150 mm referring to soil depths of 25-30 cm, 50-60 cm and 70-85 cm, respectively. Average minimum value of available soil moisture for the study period and before the beginning of the rainy season, expressed as a percentage (%) of AWHC (103 mm) was found to be 6%. Concerning the climate conditions of Pertouli University Forest, located in central Greece, Oikonomopoulos (1931) reported the same (6% of available soil moisture, for the value of AWHC of 100 mm), at the end of the dry season. According to Oikonomopoulos, this guarantees forest growth throughout the dry season. Thinning and intense thinning (50%) increase this value of soil moisture by one and two percentage units respectively.

On the contrary, lower AWHC values would put the plants into water stress prior to the beginning of the rainy season. Based on the tree height measurements, we consider that sufficient tree growth can be guaranteed by a minimum soil depth of 60 cm with an AWHC of 90 mm. Furthermore, for a healthy and productive forest, we consider a soil depth of 75 cm with an AWHC of 105 mm to be adequate. This is the main reason we have focused in the AWHC of both the soil and the litter.

The effect of AWHC, which is related to soil depth, is also a crucial parameter regarding road construction in forested areas. In practice, AWHC considerations can be applied during the earthworks stage of road construction. The excessive excavated fertile soil can be hauled to nearby locations for slope formation (at cross sections) and earth-fill volumes at the sides of the road (embankments), instead of dumped far away, saving costs and energy. In this manner, vegetation growth will be accelerated and in return it can "absorb" the negative environmental impacts of the road construction. Another benefits of vegetation regeneration are erosion protection of slopes or embankments formed by road construction, while the ability of vegetation to "hide" the area of removed vegetation due to construction works, satisfies the aesthetic considerations (e.g. view). The latter represents the type of the environmental criteria aiming at the absorption of the negative environmental impacts (Psilovikos & Giannoulas, 2017). Moving a step forward, AWHC may become a decision making parameter, for the approval of a proposed forest road construction, enhancing the tools of environmental protection.

5. CONCLUSIONS

This paper aspires to increase the awareness of the importance of sustainably managed Mediterranean oak ecosystems and the interconnections that characterize their functions and relationships, and the impact of soil water holding capacity on tree growth in particular. Although widely distributed and not extensively studied, these ecosystems play a significant role in a multi-purpose sustainable forestry.

The limiting factor for forest growth in these soils is the soil depth, the seasonal change of soil moisture and the water availability during summer drought. Maintaining the forest floor is essential in regulating temperature and moisture conditions –increased soil AWHC by 4-8 mm- and enriching the precious soil with nutrients from the plant remnants. The gain of a few additional mm of water surplus, through sustainable thinning treatments, can benefit the Mediterranean ecosystems. Similarly, by protecting or creating the conditions for increasing the soil depth by a few cm, the available water holding capacity (AWHC) can be improved. This might prove crucial for forest growth or even survival during the dry seasons.

The objectives of accelerating the rate of forest growth, improving soil properties (e.g. AWHC) and water yield production in the long term can be achieved with low intensity thinning treatments (increased through fall). Amongst other goals, sustainable forestry has to satisfy both the needs to increase water yield and improve soil characteristics which in some cases appear contradictory. Furthermore, this study illustrates the importance of AWHC for forest growth, rather than water yield production. We consider the contribution of AWHC to tree growth, to be of prime importance in the context of sustainable forest management. The higher the AWHC, the better the forest growth, the healthier and more stable the ecosystem. This is apparently reflected in tree growth. The study results show that the tallest trees of the best site were found to be five meters higher than the trees growing in shallower soils. For all soil depths and AWHC values, thinning compared to the control treatment, provided the trees with an additional 18 mm/year of soil moisture and thus helped them to endure hot and dry summers more easily.

Concluding, the prevention of loss of soil by erosion should be the first priority of forest management. At the same time, facilitating and accelerating soil genesis is the most worthwhile commitment to the strengthening of forest ecosystems and the greater natural environment.

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