

Consideration of Soil Water Consumption of *Juniperus macrocarpa* in Semi-Arid Ecosystem in Western Crete, Greece.

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Abstract

This study aimed at determining the transpiration water use of *Juniperus macrocarpa* in a closely to 40 year-old even-aged stand categorized into three classes based on canopy size, over a two-year period (2011-2012) located in Palaiochora, 77 km south of Chania, Crete. Sap flow techniques (Granier-type) were used to determine water use. Annual trends in sap flow were generally bell-shaped, and varying significantly between seasons and canopy classes. Winter sap flow was minimal but trees were active when temperatures were above freezing point and trees depended on deep water (below 60 cm) for transpiration. Rates increased from 1.46Ld⁻¹ in winter to 3.32 Ld⁻¹ in the spring, irrespective of tree canopy class, because of improvement in weather conditions. Maximum transpiration rates were observed during the growing season with an average of 134.42 Ld⁻¹ for dominant trees and 8.68Ld⁻¹ for suppressed ones. The daily variations in photosynthetically active radiation, vapor pressure deficit, air temperature, and surface soil water were the principal drivers for transpiration during the growing season. The findings have shown that climate in Crete does not limit the expansion of *J. macrocarpa* and that this expansion will have potential significant impacts on the ecohydrology of the system.

Keywords: *Juniperus macrocarpa*, Sap flow, Semi-arid ecosystems, Soil water content, Transpiration rates.

1. Introduction

Juniperus macrocarpa as an evergreen coniferous species has a predominantly large potential for accommodating precipitation. Water losses estimation from the collective intervention of juniper canopies and underlying litter layers may reach 70% to 80% depending on the species and site conditions (Thurow and Hester 1997). The authors estimated that for a densely-covered Ashe juniper forest, closely to 250 mm precipitation would be intervened annually. Owens and Ansley (1997) resolved that the potential transpiration rate of a mature Ashe juniper may reach to 125 L of water per day, which would be equivalent to 300 to 450 mm water annually on a landscape scale, depending on the forest dense cover.

Other studies on water use by *Juniperus* species have shown that stand level transpiration rates range from 0.23 to 1.13 mm day⁻¹ in Utah juniper (*Juniperus osteosperma*) in Arizona and New Mexico, 1.21 mm in alligator juniper (*J. daydepeana*) in Arizona, and 1.90 mm day⁻¹ in Ashe juniper (*J. ashei*) in Texas. These comparatively low transpiration rates reflect juniper's conservative water use which allows it to survive in dry areas (Heilman *et al.* 2009). Although several studies have examined the water use in *Juniperus* species, but very few have been conducted on *J. macrocarpa* especially in semi-arid plains (van Auken and McKinley 2008), where soil water has been testified to be the plant growth and bionetwork efficiency key limiting factor (Chaves *et al.* 2003, Duursma *et al.* 2008). Moreover, it's also the vegetation type determinant that comprises the relative grasses and woody species abundance in semi-arid ecosystems (Darrrouzet-Nardi *et al.* 2006, Bradley and Fleishman, 2008). Moreover, scenarios of future climatic change predict increasing air temperatures with increases in water vapor pressure deficits experienced by plants (Harmsen *et al.* 2009). The frequency, intensity, timing, and distribution of precipitation will also be altered (IPCC 2007). Such vicissitudes will influence vegetation function (especially water vapor flux) and will alter the consequences of the climate and vegetation interaction. Consequently, it is imperative to comprehend the means underlying the plant function and climate interactions in term of efficient water resources management and vegetation (Porporato *et al.* 2004). The goal of the study is to estimate the whole-tree water use in term of transpiration of the woody species *Juniperus macrocarpa* in semi-arid ecosystems of Western Crete and the transpiration rate significances on the water balance, soil water availability, and consequently groundwater recharge in the ecosystem.

2. Materials and Method

2.1. Study area

The study area located in Southern west of Crete and covers an area of about 4,317.21 hectares, 35° 25' 51" N and 35° 09'47" N latitudes, 24° 32'07" E and 24° 54' 42" E longitudes. The recognized stand history and the relatively unvarying age of the *Juniperus macrocarpa* grown in the study area make it distinctively accommodated to address

the issue of tree expansion in the arid ecosystems. The climate is recognized as semi-arid continental, mean annual precipitation is closely to 750 mm, falling mainly in the winter season. Soils are loamy clay which is covered mostly by pastoral forest areas of maquis vegetation (Turland *et al.*, 1993; Elhag and Bahrawi, 2016).

2.2. Experimental design

The site selected for the study is a dense canopy of *J. macrocarpa* stand. A 50 m x 50 m area was fenced and basic inventory measurements were conducted. Tree density was recorded as 520 trees ha⁻¹. Tree height averaged 7.7 ± 1.4m with 63.3 ± 13.5 % foliage cover, and Diameter at Breast Height (DBH) averaged 12.3 ± 3.9 cm. From this site, 22 trees were selected for sap flow measurement. All the trees were even-aged around 40 years old. Three different classes were selected based on the canopy and growth of the trees. The dominant class included trees with an average of 17.44 cm DBH and 8.49 cm in tree height. The co-dominant class included trees with an average of 12.85 cm DBH and 6.96 cm in height. The suppressed class averaged 8.5 cm DBH, and 5.1 m in height. Soil moisture determination was carried out using ML2 Theta Probe installed at different soil depth of 20, 40 and 60 cm respectively. Collected data stored in 15 seconds' interval using CR10X, Campbell Scientific Inc., UT data logger.

2.3. Sap flow and sapwood measurements

The quantification of the *J. macrocarpa* transpiration rate was carried out following Granier (1987). Based on the heat differences between the heated probe (implanted in the tree trunk) and the referenced probe (2 cm apart) at time t the temperature difference ΔT_M (°C) were constantly recorded for sap flux estimation. Based on the experiential association of Granier (1987), the density of the sap flux was conducted in term of J_s , g m⁻² s⁻¹ as following:

$$J_s = 119 \left(\frac{\Delta T_M - \Delta T}{\Delta T} \right)^{1.231}$$

Clearwater *et al.* (1999) suggested an empirical correction for sap flux estimation when the sap wood depth is less than 2 cm:

$$J_s = 119 \left(\frac{\Delta T_M - \frac{\Delta T - b\Delta T_M}{a}}{\Delta T - \frac{b\Delta T_M}{a}} \right)^{1.231}$$

a is the probe proportion in sapwood

b is the probe proportion in heartwood, where b = 1 - a.

Transpiration rates determination in term of (L day⁻¹) was conducted as a multiplication of the sap wood area by J_s . Annual transpiration rate of *J. macrocarpa* canopies in term of (E_c , mm yr⁻¹) was conducted by multiplying J_s with sapwood area (A_s) per unit ground area (A_G) following Oren *et al.* (1998):

$$E_c = J_s \frac{A_s}{A_G}$$

3. Results and Discussion

Trends in air temperature were reliable with the archived metrological data (22-year average), with maximum temperature recorded in August (>32 °C), and minimum temperature recorded in January (< -6 °C). Recorded precipitation data in 2011 was significantly exceeding the average (780 mm), while that of 2012 was average (590 mm). The seasonal soil volumetric water content was highly variable at the 20cm depth, reflecting recent precipitation events. In contrast, the water content at the 40 and 60 cm depths was less responsive to precipitation events. The site received a total of 229.8 mmol m⁻²s⁻¹ of photosynthetically active radiation in 2011 and 213.9 mmol m⁻²s⁻¹ in 2012. The cloudier days observed throughout the growing spell of 2012 could be recognized as a lower PAR in 2012 relative to 2011 as it shown in Figure 1. Annual transpiration trends were generally bell-shaped. Transpiration rates varied significantly between seasons (Table 1). Maximum transpiration rates were observed during the growing season with an average of 134.42 Ld⁻¹for dominant trees and 8.68 Ld⁻¹for suppressed ones. The highest daily rates for the largest tree measured was more than 30-fold that of the smallest tree. This was probably a result of the greater leaf area (green canopy), vigor, and exposure to radiation in larger trees relative to the suppressed ones (Table 2).

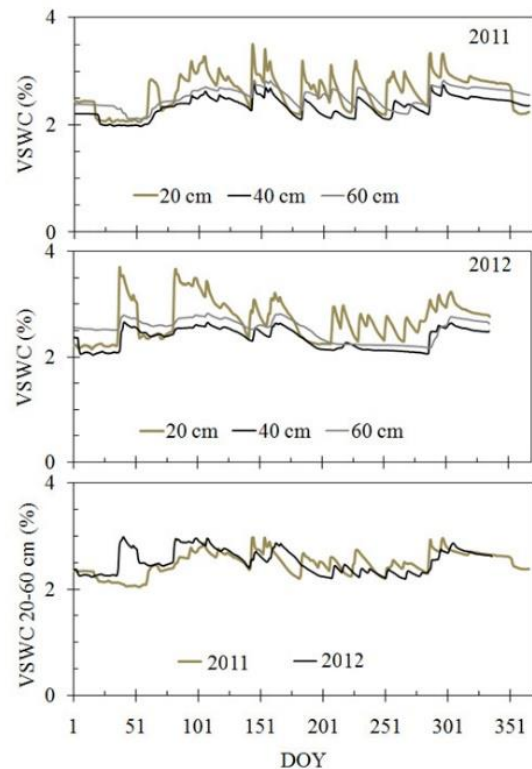


Figure 1. Daily average of soil volumetric water content (VSWC) different depths.

With the onset of the spring season, the average daily air temperatures increased from 1.2 °C to 16.3 °C (in both years), and light levels increased significantly from 101 $\mu\text{mol m}^{-2}\text{s}^{-1}$ to 1298 $\mu\text{mol m}^{-2}\text{s}^{-1}$ in 2011 and 50.9 $\mu\text{mol m}^{-2}\text{s}^{-1}$ to 1301 $\mu\text{mol m}^{-2}\text{s}^{-1}$ in 2012. These higher PAR levels and warmer temperatures, in conjunction with increased cell and photosynthetic activities, resulted in

increased transpiration rates. The transpiration rate increased from 1.55 ± 0.08 Ld⁻¹ in the winter period to 3.29 ± 0.15 Ld⁻¹ in the spring, irrespective of tree canopy class (Table 1). Variations in air temperature and light levels were shown to have the greatest influence on the transpiration of *Juniperus macrocarpa*. Soil water content limitation varied with depth and depended on the season. Figure 2 showed the daily maximum and average sap flow in correspondence to the minimum and maximum air temperatures.

Table 1. Sap flow in Lday-1 descriptive data analysis

Season	Mean	Std. Error
Winter	1.46 d	0.10
Spring	3.32 cd	0.20
Summer	16.62 a	0.31
Autumn	10.77 b	0.43

Table 2. Tree class description in the designated study area

Canopy class	Average DBH (cm)	Average tree height (m)	Average height of live branches from the ground (m)	Average green canopy (%)
Dominant	16.44	8.39	1.91	75.51
Co-dominant	11.85	6.86	1.78	73.68
Suppressed	8.4	5.3	3.2	10.57

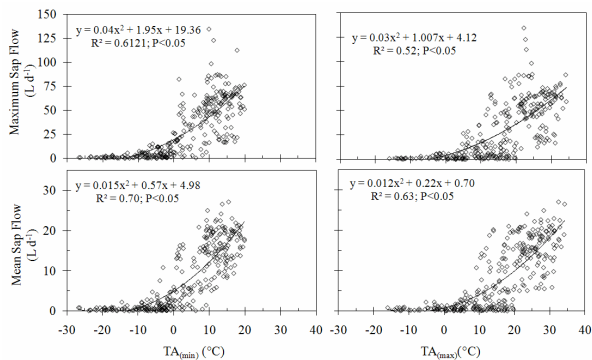


Figure 2. Daily maximum and average sap flow as a function of minimum air temperature (TA_{min}) and maximum air temperature (TA_{max}).

The values obtained are comparable to the water use values measured on other *Juniperus* sp. (Table 1). Transpiration rates of *Juniperus macrocarpa* trees in the designated study area varied among canopy classes, with highest values observed in the dominant canopy, followed by the co-dominant and finally the suppressed canopy. This is in covenant with the outcomes of Granier *et al.* (1996), Andrade *et al.* (1998) and Meinzer *et al.* (2001), who

reported that canopy status (dominant, co-dominant, and suppressed) is the key feature defining sap flow rates. According to Lassoie *et al.* (1983), photosynthetically active radiation is the most important environmental factor regulating photosynthesis in understory eastern red cedar. Hence, transpiration in understory eastern red cedar (for the suppressed stands) is in great part light-limited throughout the 5-month period when fully expanded overstory leaves are present. Sap flow tendencies were commonly plotted as bell-shaped curves over the daily sampling time of 24 hours, with the peak sap flow occurring near noon in spring and summer and around 1400 hour in the fall. Significant diurnal variability in sap flow rates were observed, and were related to variations in air temperature. In the fall, sap flow for dominant, co-dominant and suppressed trees increased from 0800 to 1400 hours, peaked just after 1400 hours, and then began decreasing after 1600 hours (Figure 3). Daily, whole-tree transpiration (sap flow estimations) reacted significantly to the sun light. Diurnal sap flow as a precipitation and soil moisture function was not substantial. However, within-day variability is highly connected to light levels (PAR). Figure 5 shows how sensitive the flow to sudden changes is in light (example: a cloud passing). When PAR showed an increase, or decrease, the sap flow increased or decreased instantly.

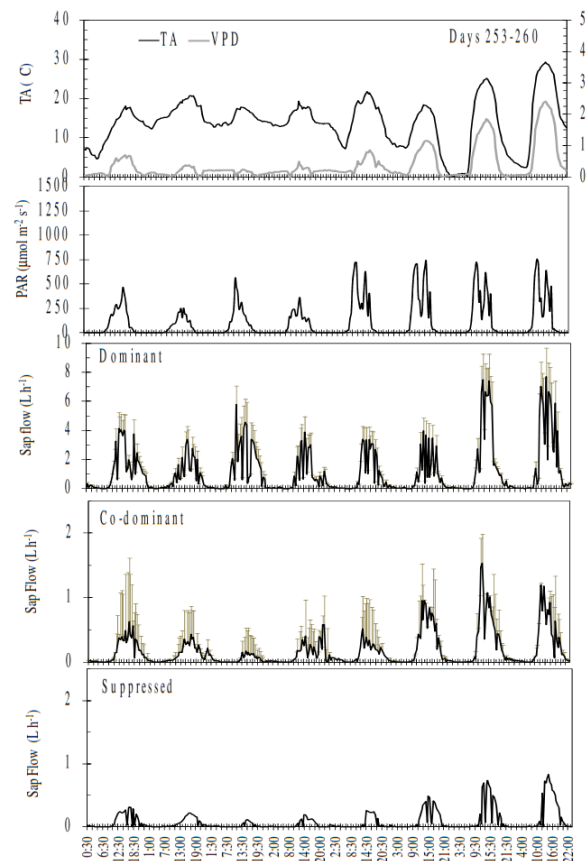


Figure 3. Temperature, VPD, PAR and Sap flow (Lh⁻¹) daily curves for the three canopy classes of *J. macrocarpa*.

Transpiration declined in fall and winter but continued progressive when temperatures were > 0 °C. Results agreed to those observed by Briggs *et al.* (2002) and explained by the fact that *Juniperus macrocarpa* trees maintain positive

photosynthesis and stomatal conductance at temperatures above 0 °C and they efficiently utilize water from the deeper rescinded soil horizons (Brümmer *et al.* 2012). This might contribute to the accumulation of biomass and might result in decreased soil water content, which otherwise will be used to recharge the groundwater in grassland-dominated areas. Transpiration rates increased with the improvement in weather conditions, reaching their maximum during the growing season. The absence of a drought period during our study (2011-2012) didn't show the response of *Juniperus macrocarpa* to drought stress. However, according to Brümmer *et al.*, (2012), even under drought stress, *Juniperus macrocarpa* has the capacity to preserve stomatal opening at low water potentials, and utilize deeper soil water. The annual transpiration rate per unit ground area (mm yr⁻¹) was estimated for 2011 through scaling up mean flux density by multiplying it with sapwood area per unit ground area (Oren *et al.* 1998). Results showed that trees utilized on average between 0.18 and 1.79 mm d⁻¹ and averaged 376 mm yr⁻¹, which represented 52 % of the annual precipitation, leading to drier soils under forested cover compared to open grasslands. In winter, fall and early spring, while grasses are dormant, trees were effectively consuming water that otherwise would go to charge the groundwater (Briggs *et al.*, 2002).

4. Conclusions.

Results indicated that diurnal air temperatures determined the overall stomatal status, whereas inconstant light levels accounted for stomatal activities during the daylight, thus regulating the jeopardy of severe water discrepancies. Soil moisture, while very important, did not seem to limit the expansion of the red cedar trees. Therefore, this species can continue invading and displace the dominant native grasses and potentially impacting the groundwater recharge. In conclusion, appropriate management must be designed to control *Juniperus macrocarpa* expansion, and more realistic and attainable goals and management regimes for the current site conditions should be adopted to minimize the impacts of this continuous invasion of *Juniperus macrocarpa* on long-term ecosystem processes and services including groundwater.

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