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Water use by Tabor and Kermes oaks growing in their respective habitats in the Lower Galilee region of Israel

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ABSTRACT

We estimated water use by the two main oak species of the Lower Galilee region of Israel—Tabor (*Quercus ithaburensis*) and Kermes (*Quercus calliprinos*)—to develop management options for climate-change scenarios. The trees were studied in their typical phytosociological associations on different bedrock formations at two sites with the same climatic conditions. Using the heat-pulse method, sap flow velocity was measured in eight trunks (trees) of each species during a number of periods in 2001, 2002 and 2003. Hourly sap flux was integrated to daily transpiration per tree and up-scaled to transpiration at the forest canopy level. The annual courses of daytime transpiration rate were estimated using fitted functions, and annual totals were calculated. Sap flow velocity was higher in Tabor than in Kermes oak, and it was highest in the youngest xylem, declining with depth into the older xylem. Average daytime transpiration rate was 67.9 ± 4.9 l tree^{-1} d^{-1}, or 0.95 ± 0.07 mm d^{-1}, for Tabor oak, and 22.0 ± 1.7 l tree^{-1}d^{-1}, or 0.73 ± 0.05 mm d^{-1}, for Kermes oak. Differences between the two oak species in their forest canopy transpiration rates occurred mainly between the end of April and the beginning of October. Annual daytime transpiration was estimated to be 244 mm year^{-1} for Tabor oak and 213 mm year^{-1} for Kermes oak. Adding nocturnal water fluxes, estimated to be 20% of the daytime transpiration, resulted in total annual transpiration of 293 and 256 mm year^{-1} by Tabor and Kermes oaks, respectively. These amounts constituted 51% and 44%, respectively, of the 578 mm year^{-1} average annual rainfall in the region. The two species differed in their root morphology. Tabor oak roots did not penetrate the bedrock but were concentrated along the soil–rock interface within soil pockets. In contrast, the root system of Kermes oak grew deeper via fissures and crevices in the bedrock system and achieved direct contact with the deeper bedrock layers. Despite differences between the two sites in soil–bedrock lithological properties, and differences in the woody structure, annual water use by the two forest types was fairly similar. Because stocking density of the Tabor oak forests is strongly related to bedrock characteristics, thinning as a management tool will not change partitioning of the rainfall between different soil pockets, and hence soil water availability to the trees. In contrast, thinning of Kermes oak forests is expected to raise water availability to the remaining trees.

1. Introduction

Climate forecasts for the eastern Mediterranean region in the coming decades predict increased aridity with longer spells of droughty winters (Ben-Gai et al., 1998; Paz, 2004), higher air temperature, and less rainfall caused by fewer, albeit more intense, storm events. Conditions in Mediterranean regions that are currently sub-humid may become semi-arid, with obvious implications for the water balance, and possibly profound effects on the biota, which is presently adapted to a more humid climate (Pereira and Chaves, 1995; Petit et al., 2005). In order to prepare for such a contingency in terms of management plans for natural woodland ecosystems, more information is required on the current status of soil water contents, the balance between rainfall and transpiration, and physiological activity related to water availability. This should place us in a better position to develop silvicultural approaches to tackle the increasingly pressing problem of reduced water availability.

Two eastern Mediterranean oak species predominate in the Mediterranean climatic zone of Israel, which receives 400–1000 mm of annual rainfall: Tabor oak (*Quercus aegilops* L. ssp. *ithaburensis* [Decne] Boiss) and Kermes oak (*Quercus coccifera* ssp. *calliprinos* Webb.) (Eig, 1933; Zohary, 1961, 1962). Tabor oak is a deciduous tree species that has a ring- to semi-ring-porous wood anatomy (Fahn et al., 1986). It creates park-like forests of single-stemmed trees with

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broad canopies. Kermes oak is a sclerophyllous evergreen species that has a diffuse-porous wood anatomy (Fahn et al., 1986). Its recovery after disturbances such as fire, cutting and grazing generally results in a dense and stunted scrub composed of many sprouts per stool that, under favorable site conditions, develops into a low- to medium-sized tree stand.

Ecological site conditions, such as bedrock lithological properties, soil–bedrock water content, and root system morphology, affect the distribution of natural Tabor and Kermes oak forests in the lower Galilee region and elsewhere. These species tend to be found in habitats that differ in soil–bedrock characteristics, with the Tabor oak occupying soil pockets in areas with relatively soft, porous bedrock, and the Kermes oak growing mainly on outcrops of relatively hard limestone or dolomite bedrock with deep fissures (Zohary, 1962; Aloni and Orshan, 1972; Herr, 2000). Previous studies have estimated the daily and annual course of transpiration (water use) by typical stands of these species in relation to annual rainfall (Schiller et al., 2003, 2007); however, those studies were conducted under different climatic conditions, preventing any meaningful comparisons between the species.

The objectives of this research were: (1) to characterize the daily and annual course of transpiration by Tabor and Kermes oak stands growing under similar climatic conditions and (2) to relate water withdrawal by the trees to available soil water content and patterns of root distribution in the soil–bedrock complex. The results are expected to facilitate decision-making on silvicultural management of oak forests.

2. Materials and methods

2.1. Study sites

The study was conducted at two sites, each representing a typical plant association. The Tabor oak site, representing the *Q. ithaburensis–Styrax officinalis* association (Zohary, 1962), is located within the forest reserve adjacent to Alon HaGalil (32°45′N, 35°13′E, 225 m a.s.l.). The Kermes oak site, representing the *Q. calliprinos–Phillyrea latifolia* association (Rabinovitz-Vin, 1986), is located within the Shimron national park, adjacent to Timrat village (32°42′N, 35°14′E, 240 m a.s.l.) in the hills bordering the Yizre'el valley from the north, 6.3 km south of Alon HaGalil. The two forest sites differ mainly in their bedrock formation and lithological properties (Geological Survey of Israel, 1998), which influence the water-retaining characteristics of the soil–bedrock complex (Herr, 1998, 2000). The Tabor oak site is of the Timrat and Adulam formations, characterized by chalk covered by calcrete hardpan with intermediate layers of limestone and alternate hard and soft chalk and marl. The Kermes oak site is of the Maresha formation, characterized by soft chalk. Further details on the two sites are provided in Table 1.

Table 1
Ecological parameters and tree size at the two research sites. Values are means and, where applicable, standard deviations.

Ecological parameters	Site	
	Tabor oak	Kermes oak
Bedrock formation	Timrat and Adulam	Maresha
Soil type	Brown to red-brown rendzina	Brown rendzina
Height (m)	7.1 ± 1.0	4.5 ± 0.8
Breast height circumference (cm)	85.2 ± 19.8	54.2 ± 6.4
Number of trees per 0.1 ha	14	–
Canopy projection area (m^2)	34.4 ± 13.6	16.6 ± 2.7
Canopy projection (% of area)	48.2	53.4
Canopy projection area ratio[a]	–	32.4

[a] See text for explanation.

The climate at the two sites is Thermo-Mediterranean (UNESCO-FAO, 1963), with rainfall occurring during the winter months only. Average annual rainfall (October to October basis), recorded at the Newe Ya'ar regional research center, not far from the two study sites, was 578 ± 135 mm (mean ± S.D.) during the period 1931–2003, and 572 ± 128 mm during the period 1995–2003. In several years rainfall was recorded in as early as September and as late as May; the wettest months were between December and March. Annual rainfall in the three seasons of the study was 433, 710 and 801 mm $year^{-1}$ in 2000/1, 2001/2 and 2002/3, respectively.

2.2. Experimental plots and tree selection

At the Tabor oak site, a 0.1-ha plot was selected which contained 14 oak trees, of which eight single-stemmed trees representative of the trunk-circumference distribution within the forest were selected for transpiration measurements. Average height, trunk circumference and canopy-projection area of these eight trees are presented in Table 1. At the Kermes oak site, a 0.1-ha plot was selected which contained a thicket of 23 oak stools and sparse representation of *Pistacia lentiscus* and *P. latifolia*. Each oak stool comprised several trunks differing in height and diameter. The canopy-projection area of each trunk was determined by measuring four radii of the canopy. Eight trunks, each from a different stool, were selected to be representative of the canopy-projection area of the trunks in the plot. Their average dimensions are presented in Table 1. The height, trunk circumference and stocking density of the trees at each site were representative of forests of these species in the lower Galilee region.

2.3. Soil–bedrock water

Holes were drilled into the soil–bedrock complex at the two study sites for the installation of 8-m-long neutron probe access tubes. 24 and seven tubes were installed in the Tabor and Kermes oak sites, respectively. Monthly measurements with a calibrated neutron probe (model 4301, Troxler Electronic Laboratories, NC, USA) were taken from February or March to November or December of each year of the study. Readings were taken at 25-cm intervals to a depth of 8 m and transformed to soil water content (SWC, $m^3\ m^{-3}$) using calibration coefficients established in the laboratory (Herr, 2008).

The water content of the soil–bedrock complex at each 25-cm horizon in February or March was taken as the initial value for the calculation of the dynamics of water content throughout the season. The calculation method distinguished between loss of water from a horizon by downward percolation and plant extraction (Herr, 2008).

2.4. Sap flow velocity and transpiration

Sap flow velocity (ν, cm h^{-1}) was determined by means of the heat-pulse method (Cohen, 1994), using the same configurations as in earlier studies (Schiller et al., 2003, 2007). In each plot, a measurement system was used that comprised a battery-powered data logger (21X, Campbell Sci., Logan, UT, USA) connected to a custom multiplexer (model TJB 818, Ariel, Tel Aviv, Israel) and eight heaters and probes (produced in-house), each 60 mm length. Each probe contained six thermistors, placed 8 mm apart along the axis. Heaters and probes were inserted radially into the trunks, the probe 15 mm above the heater, at 1.30 m above ground as in earlier studies. Each system enabled measurements of sap flow velocity in the trunk sapwood of eight oak trees by cycling through the group every hour and measuring ν in each for 7.5 min $cycle^{-1}$.

Measurements were conducted as a series of campaigns, each comprising a number of consecutive days during which the