Proceedings of the 10th World Congress of EWRA 'Panta Rhei', 5-9 July 2017, Athens, Greece

Daily transpiration of a single sessile oak measured by the tissue heat balance method

M.S. Ozcelik
Istanbul University, Faculty of Forestry, Department of Watershed Management, 34473, Istanbul, Turkey
e-mail: msaid.ozcelik@istanbul.edu.tr

Abstract: Transpiration is calculated as a component of evapotranspiration for planning water resources in watershed scale. Since the risk of water shortages is quite high for near future because of growing population, this information is important for water conservation and planning studies especially in sub-humid and semi-arid areas of Turkey where vegetation can take up significant amount of water. To present this fact, water consumption of a single full grown sessile oak (*Quercus petraea* (Matt.) Liebl.) was determined in daily basis by the tissue heat balance method in Belgrad Forest, Istanbul. Study period covered one growing season in 2016. The sample tree was 18.5 m in height, 34.5 cm in diameter at breast height. Mean air temperature, humidity, and precipitation were 17.4˚C, 76.6 (%) and 368 mm respectively, during the study period. The maximum transpiration was 162.4 kg day-1 in July and the minimum was 0.78 kg day-1 in the first day of April. Total amount of water consumption by this single tree in the whole growing season was 18325 kg. Results of this study revealed that water consumption of the vegetation cover should be taken into account for effective water management in addition to increasing water yield and improving water quality.

Key words: Transpiration, sessile oak, Belgrad Forest, tissue heat balance

1. INTRODUCTION

One of the main ecosystem services provided by forests is fresh water production with high quality for society. On the other hand; forest cover can consume enormous amount of water via transpiration. Since the water demand is increasing due to population growth, industrial developments and agricultural irrigation in Turkey, water resources management with sustainable approach in watershed scale is an important subject both for researchers and decision makers.

The amount of water in an area is directly related to climate, topography of the area and vegetation growing in the site. Vegetation cover is the only component that can be modified by humans in order to increase water yield in the watersheds. Therefore, the knowledge of water consumption rates of tree species and its relation to the atmospheric variables are the primary concerns in watershed management (Özçelik et al., 2016).

The water consumptions of trees via transpiration have been of special interest by researchers from mid-1800's and early studies were mostly conducted in laboratories under restricted conditions without reference to environmental factors (Weaver and Mogensen, 1919). A variety of methods have been put forth such as potometer, tent, lysimeter, watershed water balance, magnetic resonance imaging technics and sap flow methods for measuring transpiration (Özhan, 1982; Renninger and Schafer, 2012). After Huber's pioneer work in 1932, researchers focused on to develop different sap flow technics based on thermal transformation such as tissue heat balance, heat field deformation and heat dissipation. The technics which use heat as a tracer became the most preferred among the researchers interested in measuring tree transpiration in world-wide (Cermak et al., 2004). In fact; sap flow measurements provide interesting information about tree to tree variability within a forest stand and they are the only method in some cases e.g. on stands located on steep slopes, or on small sized plots (Granier et al., 1990, 1996). Moreover, xylem sap flow studies allow partitioning of the total flux to individual trees which may be consisted of different age, size, social position or species in the stand (Köstner et al., 1996).

Although transpiration of oak species has been examined by researches in a variety of habitats with different goals (Cermak et al., 1982; Breda et al., 1993, 1995; Granier and Breda, 1996; Fenyvesi et al., 1998; Schiller et al., 2003, David et al., 2004; Asbjornsen et al., 2007; Paço et al., 2009; Kanalas et al., 2010; Meszaros et al., 2011, Juice et al., 2015; Yan et al., 2016); transpiration data for oak species growing in Turkey has not examined yet. Therefore, the aim of this study was to investigate daily and total transpiration rates of a single full grown sessile oak (*Quercus petraea* (Matt.) Liebl.) which is one of the18 native oaks of Turkey.

2. MATERIAL AND METHOD

2.1 Study site and sample tree

The study was carried out in Belgrad Forest (41° 09' 48" - 41° 10' 55" N, 28° 57' 27" -28° 59' 27" E). Average annual precipitation was around 1129 mm and mean annual temperature was about 12.3 °C. Precipitation mostly falls between October and April in the site. The warmest month was August while the coldest was February. Snow fall is not common in the site. The climate is sub-humid Mediterranean with mild-rainy winter and hot-dry summer. Parent material was Neogene loamy, the texture was clay loam with medium-good permeability rates and high organic matter (Serengil et al., 2007). The stand was without any understory. The basal area of the stand was 57.78 m^2 and there were about 1500 stems ha^{-1}. Mean tree height was 16 m and mean diameter at breast height was 20.7 cm. One individual full grown sessile oak tree was selected as sample from the stand. The tree was a dominant one with 18.5 m in height and 34.5 cm in diameter at breast height. The highest leaf area index (LAI) of the tree was estimated as 1.42 m^2 m^{-2} in July. The study covered a growing season of 2016 from April 1st to November 15th.

2.2 Environmental data

Two meteorological stations were used for recording meteorological data. One of them was a mini automatic weather station equipped with pluviometer, solar radiation sensor, air humidity and air temperature sensors (EMS Minikin RTHI and EMS Minikin ERI, EMS Brno, Czech Republic) placed at an open field next to the study site while the other one was placed 5 km far away from the study area (GRWS 1000, Campbell Scientific, U.S.A). Air temperature, relative humidity and radiation were measured 5 minute intervals and precipitation was recorded by a tipping bucket rain gauge. Soil moisture was recorded as soil water potential (Ψ, bar) under the forest canopy using calibrated gypsum blocks (Delmhorst Inc, USA) and Microlog SP3 data logger (EMS Brno, CZ). Soil moisture was measured at 25 cm depth from three different points, with 60 minute intervals. Leaf area index (LAI) was estimated by CL-110 plant canopy imager (Bio-science.inc, USA).

2.3 Sap Flow Measurements

A sap flow kit (EMS 81, EMS Brno, CZ) working according to the tissue heat balance method (Cermak et al., 1973, 1982; Kucera et al., 1977) was installed on to tree trunk to determine water consumption of the sample tree. A section of a tree trunk was heated by using electrodes within the trunk with electric current passing through the tissues in the tissue heat balance method. The system consists of four electrodes and thermocouples placed into the tree trunk. The upper three electrodes were heated while the central electrode was not heated and positioned 10 cm below from the others. The temperature difference between the reference and heated part of the tree stem was set to 1 K. The temperature difference (dT) between upper heated electrodes and reference one was measured by needle type thermocouples. Method calculates the heat balance of a defined heated space according to the equation below (see Cermak et al., 2004):

$$P= QdTcw + dT\lambda \quad (1)$$

where P is input power (W), Q is the sap flow rate (kg s-1), dT is the temperature difference in the measuring points (K), cw is the specific heat of water (J kg-1 K-1) and λ is the coefficient of heat losses from the measuring point (W K-1). Tree trunk was packed with polyurethane foam after installation of the sensors to insulate the temperature field around the sensors from effects of the sun and convective heat loss. Microsoft EXCEL and EMS Mini32 softwares were used to data processing.

3. RESULTS

Results of sap flow measurements showed that the average daily transpiration rate of this single tree was 80.3 kg and varied between 0.78 kg in the first day of growing season and 162.4 kg in July. The total water loss through transpiration in one vegetation period by this tree was 18325 kg. The highest mean daily water consumption was 127.35 kg in July and the lowest was 19.48 kg in November because of the abscission of the foliage (Figure 1). According to the results 57% of the total transpiration occurred in summer months. The mean air temperature, mean air humidity and precipitation was recorded as 17.6 ˚C, 76.6 % and 368 mm respectively in the study period. The soil moisture was contented in April and May with mean -0.2 bar soil water potential (Ψ_{swp}), it started to decrease in June and the minimum Ψ_{swp} was recorded in July as mean -8.33 bar, but there was still available water in the soil. Maximum leaf area index (LAI) was 1.44 m^2 m^{-2} in July.

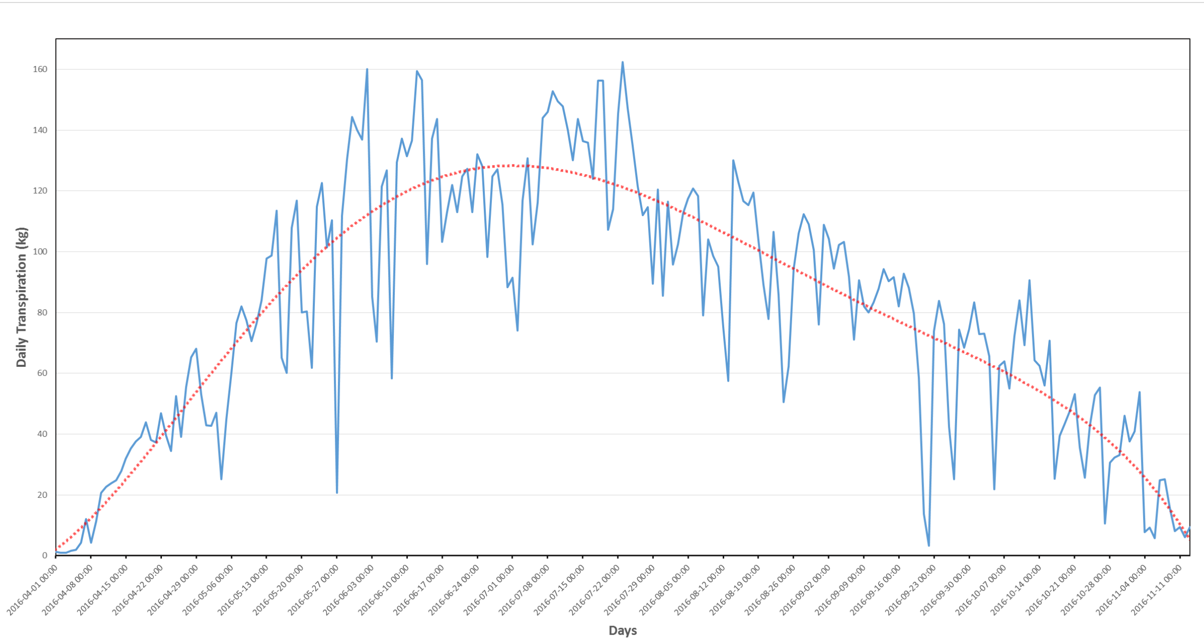

Figure 1. Transpiration trend of the tree in the whole growing season.

4. DISCUSSION AND CONCLUSION

Forest management in an appropriate way relies on maintaining sustainable water in a fresh water producing watershed. In fact, trees have important role on water cycle of terrestrial ecosystems through their effect on forest water use (Aranda et al., 2012). As a result, vegetation cover changes and forestry applications such as thinning and clear cutting can influence water yield in the watersheds (Bosch and Hewlett, 1982; Breda et al., 1995; Stednick, 1996; Lagergren et al., 2008). To understand this alteration, tree transpiration is monitored by researchers since it is one of the most important factors influencing water yield in the watersheds.

A wide-range of daily maximum tree transpiration rates can be found in literature from 10 kg day-1 to 1180 kg day-1, but it can be said that the general range is between 10 to 200 kg (Wullschleger et al., 1998). Meteorological variations, topography, soil water conditions, tree health, age and diameter, stand characteristics and tree physiology are some of the factors responsible for this variation (Aranda et al., 2012). When the subject is limited by oak species; it can be seen that daily transpiration rates of oak trees were between 10-12 kg and reached up to 400 kg. Breda et al. (1993) recorded 10 kg day-1 maximum transpiration for *Quercus robur* L. in France under water stress. On the other hand Cermak et al. (1982) found 400 kg daily maximum transpiration rate for the same species in a floodplain forest in Czech Republic. Renninger and Schafer (2012) reported 29.2 kg maximum transpiration day-1 for *Q. prinus* L. and 41.6 kg day-1 for *Q. velutina* Lam. According to Wullschleger et al. (2001) the maximum transpiration rates of *Q. alba* L. was 71 kg day-1 while it was only 46 kg day-1 for *Q. rubra* L. in the same site. Considering these studies conducted upon transpiration rates of oak species, it can be said that although the results of this study was compatible with the literature, daily average and maximum transpiration of the sessile oak growing in a sub-humid region of Turkey was higher than most of the other oak species growing under different conditions. This information can be taken as an indicator also for other oak species of Turkey which are covered more than 6.5 million hectares with 18 natural species (Yaltırık, 1984).

It can be concluded based on the transpiration rates of this single tree that water consumption of vegetation cover can reach significant amounts in hot-dry summer months in Turkey, so that this information should be taken in to account in watershed management practises especially conducted in fresh water producing watersheds of the country.

ACKNOWLEDGEMENTS

The author of the study is grateful to Prof. Dr. Kamil Sengonul and Prof. Dr. Ferhat Gokbulak from Istanbul University for their valuable discussions. He is also grateful to Prof. Dr. Jan Cermak from Mendel University and Mr. Jiri Kucera from Environmental Measuring Systems for their help and contribution in both obtaining the sensors and field studies with data evaluating. Financial support was provided by Istanbul University BAP coordination unit, from the projects number 52494 and 52831.

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