DOI: 10.26650/ forestist.2018.344844
Forestist 2018, 68(2): 101-105

Original Article

Annual water consumption of an Anatolian black pine in a sub-humid region

Yarı-nemli koşullarda yetişen bir Anadolu karaçamının yıllık su tüketimi

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ABSTRACT

The primary aim of this study was to investigate the annual water consumption of an individual Anatolian black pine [*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe] growing in Belgrad Forest, İstanbul. The sample tree was 56 years old, measuring a height of 17 m and a diameter at breast height of 40 cm. The study was conducted over a period of 1 year from January 1, 2016, to January 1, 2017. The minimum and maximum air temperatures were −11°C and 32°C, respectively. The precipitation during this period was recorded as 1,083 mm. Tree water consumption measurements were carried out using the tissue heat balance method. Results showed that water uptake of the tree varied between 0.007 and 71.54 kg day^{-1}, while the average daily and annual water consumptions of the tree were about 27.06 and 9,851 kg, respectively. The daily water consumption varied between 59 kg in July and 3.37 kg in January. These values can be considered as guidance for an effective management of forested watersheds in terms of both water quality and water production.

Keywords: Anatolian black pine, sap flow, tissue heat balance, transpiration, water consumption

ÖZ

Bu çalışmanın amacı İstanbul Belgrad Ormanı'nda yetişen bir Anadolu karaçamının [*Pinus nigra* Arn. subsp. *pallasiana* (Lamb.) Holmboe] yıllık su tüketimini ortaya koymaktır. Örnek ağaç 56 yaşında, 17 metre (m) yüksekliğinde olup göğüs yüksekliğindeki çapı 40 santimetre (cm)'dir. Çalışma 1 Ocak 2016 ile 1 Ocak 2017 tarihleri arasını kapsamaktadır. Çalışma süresi boyunca yağış 1083 milimetre (mm), en düşük sıcaklık -11˚C ve en yüksek sıcaklık 32˚C olarak kaydedilmiştir. Ağacın su tüketimi ölçümleri gövde/doku ısı dengesi yöntemi kullanılarak yapılmıştır. Sonuçlara göre, örnek ağacın günlük ortalama su tüketimi 27,06 kilogram (kg) olup günlük tüketim 0,007 kg ile 71,54 kg arasında değişiklik göstermektedir. Bu ağacın yıllık toplam su tüketimi 9851 kg'dır. Aylara göre bakıldığında ise en yüksek günlük ortalama tüketim 59 kg ile Temmuz ayında, en düşük günlük ortalama tüketim ise 3,37 kg ile Ocak ayında gerçekleşmiştir. Elde edilen bu veriler ormanlık havzaların yalnızca su kalitesi anlamında değil su üretimi anlamında da verimli yönetilebilmesi için yol gösterici olarak alınabilir.

Anahtar Kelimeler: Anadolu karaçamı, bitki özsuyu akış ölçümleri, gövde ısı dengesi, transpirasyon, su tüketimi

Cite this paper as:
Özçelik, M.S., 2018. Annual water consumption of an Anatolian black pine in a sub-humid region. *Forestist* 68(2): 101-105.

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Received Date:
17.10.2017
Accepted Date:
21.12.2017

INTRODUCTION

Water is one of the vital necessities for all living organisms and it directly affects the quality of life. Turkey's water distribution per year per capita is around 1519 cubic meter (m^3) today. Countries having less water than 1000 m^3/per year/per capita are classified as "water poor country" (DSI, 2016). According to population growth projections by the Turkish Statistical Institute (TUIK, 2016), the population of Turkey will reach 90 million by 2030. Therefore, water scarcity will become a critical issue and watershed management and water budget plans will be more important.

The amount of precipitation, topography of the area and vegetation cover of the site are the main factors affecting the water yield of a watershed. While the amount of precipitation cannot be increased by humans continuously, vegetation management practices can be applied to increase water yield in the watersheds. Hence, it is important to know the water consumption rates of tree species, its relation to the atmospheric variables (i.e. air temperature, air humidity, solar radiation) and its trend according to the seasons for vegetation management and plantations in these watersheds (Özçelik et al., 2016).

Several methods including lysimeter, transpirometer, watershed water balance, potometer, tent, and sap flow methods are available for measuring transpiration from plants (Özhan, 1982). Sap flow method was developed after the pioneer work of Huber in 1932 and several methods have been added based on different principals (thermodynamic, electric, magnetic resonance) ever since (Cermak et al., 2004). These methods have been used in world-wide especially after the development of chip technology with smaller and mobile sensors and less energy consuming data loggers. Thermal sap flow methods are commonly used in forest hydrology and ecophysiology due to their simplicity, cheapness and potential of separate estimation for the transpiration component (Poyatos et al., 2005). Sap flow measurements are also useful in harsh environments such as those that have complex terrain and variable topography (Renninger and Schafer, 2012).

Although sap flow method has a long history in forest hydrology, this method has not been used in Turkey so far. Therefore, the information about exact water consumption of vegetation cover and its seasonal trend are still being objectives of concern in Turkey. Besides, while there are several researches focused on transpiration rates of pine species such as Scots pine (Köstner et al., 1996; Lagergren and Lindroth, 2002; Cienciala et al., 2002; Moore et al., 2004; Poyatos et al., 2005; Wang et al., 2005; Tor-ngern et al., 2017), Maritime pine (Grainer et al., 1990; Loustau et al., 1996), ponderosa pine (Ryan et al., 2000; Small et al., 2008), slash pine (Martin, 2000), loblolly pine (Martin, 2000; Torngern et al., 2017), Canarian pine (Luis et al., 2005), shortleaf pine (Renninger and Schafer, 2012) and radiata pine (Jackson et al., 1972); data about the water consumption of Anatolian black pine, which is one of the most widespread pine species in Turkey covering more than 2,2 million hectares (ha) (Karadağ, 1999), is not available in the literature.

Figure 1. Study site: Atatürk Arboretum in Belgrad Forest


Figure 2. Electrodes, needle type thermocouples, isolator band and electric supplier hooks on the tree trunk

Therefore, the main objective of this study was to determine the annual water consumption of an individual Anatolian black pine tree growing in İstanbul.

MATERIALS AND METHODS

Study Site and Sample Tree

The study was carried out in the Atatürk Arboretum in Belgrad Forest (Figure 1) on the European side of İstanbul (41° 09′ 48″ - 41° 10′ 55″ N, 28° 57′ 27″ -28° 59′ 27″ E). Mean annual precipitation is around 1120 mm and mean annual temperature is 13°C at the site. August is the warmest month and January is the coldest. In general, the soil at the site is shallow with high organic matter, the texture is clay loam and the permeability rates are medium-good. Parent material is characterized Neocene loamy (Serengil et al., 2007). The stand was established in 1960. The basal area of the stand is 54.8 m^2 and the tree density is about 975 stems per hectare. Mean tree height is 14.5 meter (m) and mean diameter at breast height is 24.2 centimeter (cm). The overall topography of the stands is flat. The understory vegetation is scarce and mainly consists of *Erica arborea* L. and *Pteridium aquilinum* (L.) Kuhn. For the study, one individual Anatolian black pine tree was selected as the sample tree from the stand. The tree was 56 years old with a height of 17 m and a diameter of 40 cm at breast height. The study period covered one year between January 1st 2016 and January 1st 2017.

Environmental Data

The meteorological data were recorded using two automatic meteorological stations. One of them was placed in an open field next to the study site measuring solar radiation, air temperature, air humidity and precipitation (EMS Minikin RTHI and EMS Minikin ERI, Environmental Measuring Systems, Brno, Czechia). The other one was a fully equipped automatic weather station 5 km far away from the study area (GRWS 1000, Campbell Scientific, Logan, USA) measuring solar radiation, air humidity, air temperature, wind direction, wind speed, sunshine duration, and precipitation. Air temperature, relative humidity and radiation were measured at 5 minute intervals and precipitation was recorded using a tipping bucket rain gauge type. Soil moisture was recorded at three soil depths (10 cm, 25 cm, and 50 cm) under the forest canopy using calibrated gypsum blocks (Delmhorst Inc, New York, USA) and Microlog SP3 data logger (Environmental Measuring Systems Brno, Czechia) as soil water potential (Ψ, bar) at 60 minute intervals.

Table 1. Meteorological data, soil water potential and transpiration values according to the months

Months	Mean air temperature (°C)	Mean air humidity (%)	Maximum Global radiation (W m^{-2})	Soil water potential (bar)	Precipitation (mm)	Transpiration of the tree (daily mean) (kg)
January	4.4	79.55	533	-0.23	167	3.37
February	9.4	77.05	638	-0.20	114.8	9.87
March	9.1	75.86	820	-0.17	88.3	17.40
April	13.6	63.9	1034	-0.28	26.8	36.9
May	16.2	82.69	1149	-1.55	59.0	34.93
June	21.3	81.46	1115	-4.5	73.6	50.45
July	23.0	81.68	1142	-5.83	35.2	59.0
August	23.7	86.82	1054	-9.4	43.8	42.58
September	19.5	82.10	983	-7.93	52.4	33.91
October	14.3	88.75	828	-5.41	50.2	16.49
November	13.1	82.23	568	-5.01	119.4	13.16
December	3.3	90.32	342	-1.35	213.6	5.46

Sap Flow Measurements

A sap flow sensor (EMS 81, Environmental Measuring Systems, Brno, Czechia) working according to the tissue heat balance method was used to determine water consumption of the sample tree (Cermak et al., 1973, 1982; Kucera et al., 1977).

In the tissue heat balance method, a part of a tree trunk was heated with electrodes using an electric current passing through the tissues. Four electrodes and thermocouples were placed into the tree trunk according to the system (Figure 2). The central electrode was positioned 10 cm down from the other three upper electrodes and only the upper electrodes were heated (Cermak et al., 2004). Needle type thermocouples were used to determine the temperature difference (dT) between upper heated electrodes and the reference one. The method calculates the heat balance of a defined heated space according to the equation below (Cermak et al., 2004):

$$P = QdTcw + dT\lambda$$

Where P is the input power (W), Q is the sap flow rate (kg s^{-1}), dT is the temperature difference between the heated and unheated electrodes (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}). A pack of polyurethane foam was used to insulate the temperature field around the sensors from the effects of the sun and convective heat loss. The data were evaluated by EMS Mini32 and Microsoft EXCEL software.

RESULTS AND DISCUSSION

During the study period, the total amount of precipitation was 1083.6 milimeter (mm), and mean daily temperature was 11.8°C with a minimum of -11°C and maximum of 32°C. The results showed that the average daily water consumption was 27.06 kilogram (kg) and varied between 0.007 kg and 71.54 kg. Annual total water consumption of the tree was 9851 kg. The highest water consumption was in July with daily average of 59 kg while the lowest was in January of 3.37 kg. Due to the winter precipitations, soil moisture was high until June but it dramatically decreased after this month, especially at 25 cm depth. Soil water potentials at 10 cm and 50 cm depths were higher than at the 25 cm depth, (-10, -9 and -13 bars for 10 cm, 50 cm and 25 cm soil depths respectively). The understory (*Erica arborea* L. and *Pteridium aquilinum* (L.) Kuhn) could be responsible for this difference because their roots mostly expand to 25 cm soil depth. Although the soil moisture decreased after June, the water uptake of the tree increased. This could have been an indication of the tree roots expanding into deeper soil depth.

Some data about climate, soil water potential and transpiration values are given in Table 1. It can be seen that seasonal transpiration percentages were 5.5%, 27.5%, 47.5% and 19.5% for winter, spring, summer and autumn respectively. The table shows that the water consumption of the tree in summer is equal to the sum of the other three seasons. Water consumption of the tree in June was about 17 times greater than that in January. Higher transpiration values can be expected if soil moisture is high enough during the summer months. Other parameters measured in the study site can be seen on Table 1.

The literature includes high daily water consumption rates such as 400 kg per day^{-1} by a 100 years old *Quercus robur* L. growing in a floodplain forest (Cermak et al., 1982) and 1180 kg per day^{-1} by a *Eperua purpurea* Bth. tree growing in the Amazonian rainforest (Jordan and Kline, 1977). However, Wullschleger et al. (1998) reviewed the studies of 67 species from 35 genera and reported that the daily water use of individual trees generally varied between 10 and 200 kg per day^{-1}. Therefore, it can be concluded that the results of this study were consistent with those of previous studies conducted in different regions.

Considering only pine species, the water consumption of the Anatolian black pine was within the range of results from other studies. For instance, Wieser et al. (2014) measured an average 14.5 kg daily water consumption with maximum daily values of 25.4 kg in a dry valley of Austria for Scots pine (*P. sylvetsris* L.). Cienciala et al. (2002) reported similar results with a maximum of 25 kg per day^{-1} in Sweden. Köstner et al. (1996) found 4.4-24 kg per day^{-1} sap flow rates for the same tree species. Renninger and Schafer (2012) applied two different sap flow methods on the same tree species in USA and they found that transpiration rates varied from 1 to117.9 kg per day^{-1} for shortleaf pine (*P. echinata* Mill.). Loustau et al. (1996) examined the transpiration rates of Maritime pine (*P. pinaster* Ait.) in Portugal, and reported a water consumption rate of between 75 and 270 kg per day^{-1} for this species. Luis et al. (2005) determined that the Canarian pine (*P. canariensis* C. Sm.) consumed 18.24 to 47.52 kg per day^{-1} in the Canary Islands and the annual total transpiration of this species was 2-3 times lower than the transpiration rates of Mediterranean forest ecosystems. Martin (2000) focused on the transpiration of intensively managed slash pine (*P. elliottii* Engelm.) and loblolly pine (*P. taeda* L.) in the winter season and reported that the daily maximum water consumption of these two species were 75.1 and 71.6 kg per day^{-1} respectively in winter.

CONCLUSION

It can be seen from the literature that the water consumption of pine trees has been investigated by many researchers under different climate conditions for different purposes. The results of the present study revealed that the water consumption of a single pine tree under sub-humid climate conditions can be high especially in the summer months when the precipitation is minimum and water demand for evapotranspiration is maximum. It is obvious that the knowledge of water consumption of trees and its seasonal variation are necessary for forest hydrology and management. In the forested watersheds of Turkey, only limited data on water consumption of stands and trees are available. Therefore, further work is needed to investigate the potential water consumption of forest stands and plant species of Turkey in order to make reliable projections and plans for water budget on watershed scale.

Ethics Committee Approval: No approval has been obtained from the ethics committee in this study, approval of the ethics committee is not required in studies conducted on plants.

Peer-review: Externally peer-reviewed.

Acknowledgements: The author of the study is grateful to Prof. Dr. Kamil Sengonul and Prof. Dr. Ferhat Gokbulak from İstanbul University for their valuable suggestions and comments. 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.

Conflict of Interest: The author have no conflicts of interest to declare.

Financial Disclosure: The author declared that this study has received no financial support.

REFERENCES

- Cermak, J., Deml, M., Penka, M., 1973. A new method of sap flow rate determination in trees. *Biologia Plantarum* 15(3): 171-178. [CrossRef]
- Cermak, J., Ukehla, J., Kucera, J., Penka, M., 1982. Sap flow rate and transpiration dynamics in the full-grown oak (*Quercus robur* L.) in the floodplain forest exposed to seasonal floods as related to potential evapotranspiration and tree dimensions. *Biologia Plantarum* 24(6): 446-460. [CrossRef]
- Cermak, J., Kucera, J., Nadezhdina, N., 2004. Sap flow measurements with some thermodynamic methods, flow integration within trees and scaling up from sample trees to entire forest stands. *Trees* 18: 529-546. [CrossRef]
- Cienciala, E., Mellander, P.E., Kucera, J., Oplustilova, M., Ottoson-Löfvenius, M., Bishop, K., 2002. The effect of a north-facing forest edge on tree water use in a boreal Scots pine stand. *Canadian Journal of Forest Research* 32: 693-702. [CrossRef]
- DSI, 2016. Devlet Su İşleri. Toprak ve su kaynakları. http://www.dsi.gov.tr/toprak-ve-su-kaynaklari (acessed: 04.01.2017).
- Grainer, A., Bobay, V., Gash, J.H.C., Saugier, B., Shuttleworth, W.J., 1990. Vapour flux density and transpiration rate comparisons in stand of Maritime pine (*Pinus pinaster* Ait.) in Les Landes forest. *Agricultural and Forest Meteorology* 51: 309-319. [CrossRef]
- Jackson, D.S., Gifford, H.H., Hobbs, I.W., 1972. Daily transpiration rates of radiate pine. *New Zealand Journal of Forestry Science* 3(1): 70-81.
- Jordan, C.F., Kline, J.R., 1977. Transpiration of trees in a tropical rainforest. *Journal of Applied Ecology* 14: 853-860. [CrossRef]
- Karadağ, M., 1999. Batı Karadeniz Bölgesinde Karaçam (Pinus nigra Arnold ssp. Pallasiana (lamb) Holmboe), Doğal Gençleştirme Koşulları Üzerine Araştırmalar, Orman Bakanlığı Batı Akdeniz Araştırma Enstitüsü Müdürlüğü, Teknik Bülten No:4, Orman Bakanlığı Yayın No: 067, Müdürlük Yayın No:6, Bolu, Türkiye.
- Köstner, B., Biron, P., Siegwolf, R,, Grainer, A., 1996. Estimates of water vapor flux and canopy conductance of Scots pine at the tree level utilizing different xylem sap flow methods. *Theorotical and Applied Climatology* 53: 105-113. [CrossRef]
- Kucera, J., Cermak, J., Penka, M., 1977. Improved thermal method of continual recording the transpiration flow rate dynamics. *Biologia Plantarum* 19: 413-420. [CrossRef]
- Lagergren, F., Lindroth, A., 2002. Transpiration response to soil moisture in pine and spruce trees in Sweden. *Agricultural and Forest Meteorology* 112: 67-85 [CrossRef]
- Loustau, D., Berbigier, P., Roumagnae, P., Arruda-Pacheco, C., David, J.S., Ferreira, M.I., Pereira, J.S., Tavares, R., 1996. Transpiration of a 64-year-old maritime pine stand in Portugal. *Oecologia* 107: 33-42. [CrossRef]
- Luis, V.C., Jimenez, M.S., Morales, D., Kucera, J., Weiser, G., 2005. Canopy transpiration of a Canary Islands pine forest. *Agricultural and Forest Meteorology* 135: 117-123. [CrossRef]
- Martin, T.A., 2000. Winter season tree sap flow and stand transpiration in an intensively-managed loblolly and slash pine plantation. *Journal of Sustainable Forestry* 10(1-2): 155-163. [CrossRef]

- Moore, G.W., Bond, B.J., Jones, J.A., Phillips, N, Meinzer, F., 2004. Structural and compositional controls on transpiration in 40-and 450-year-old riparian forests in western Oregon, USA. *Tree Physiology* 24: 481-491. [CrossRef]
- Özçelik, M.S., Şengönül, K., Gökbulak, F., 2016. Sap flow measurement methods for determining transpiration of forest trees and its importance for watershed management. *Turkish Journal of Forestry* 17(2): 208-214.
- Özhan, S., 1982. Belgrad Ormanındaki Bazı Meşcerelerde Evapotranspirasyonun Deneysel Olarak Saptanması ve Sonuçların Ampirik Modellerle Karşılaştırılması. İstanbul Üniversitesi Orman Fakültesi Yayınları, Yayın No: 311, İstanbul, Turkiye.
- Poyatos, R., Llorens, P., Gallart, F., 2005. Transpiration of montane *Pinus sylvestris* L. and *Quercus pubescens* Willd. forest stands measured with sap flow sensors in NE Spain. *Hydrology and Earth System Sciences* 9: 493-505. [CrossRef]
- Renninger, H.J., Schafer, K.V.R., 2012. Comparison of tissue heat balance and thermal dissipation derived sap flow measurements in ring porous oak and a pine. *Frontiers in Plant Science* 3: 103. [CrossRef]
- Ryan, M.G., Bond, B.J., Law, B.E., Hubbard, R.M., Woodruff, D., Cienciala, E., Kucera, J., 2000. Transpiration and whole-tree conductance in ponderosa pine trees of different heights. *Oecologia* 124: 553-560. [CrossRef]
- Serengil, Y., Gökbulak, F., Özhan, S., Hızal, A., Şengönül, K., 2007. Alteration of stream nutrient discharge with increased sedimentation due to thinning of a deciduous forest in İstanbul. *Forest Ecology and Management* 246: 264-272. [CrossRef]
- Small, E.E., McConell, J.R., 2008. Comparison of soil moisture and meteorological control on pine and spruce transpiration. *Ecohydrology* 1: 205-214. [CrossRef]
- Tor-ngern, P., Oren, R., Oishi, A.C., Uebelherr, J.M., Palmroth, S., Tarvainen, L., Ottoson-Löfvenius, M., Linder, S., Domec, J.C., Nasholm, T., 2017. Ecophysiological variation of transpiration of pine forests: synthesis of new and published results. *Ecological Applications* 27(1): 118-133. [CrossRef]
- TUIK., 2016. Türkiye İstatistik Kurumu. Nüfus projeksiyonları, 2013-2075.
- Wang, K., Kellomaki, S., Zha, T., Peltola, H. 2005. Annual and seasonal variation of sap flow and conductance of pine trees grown in elevated carbon dioxide and temperature. *Journal of Experimental Botany* 56(409): 155-165.
- Wieser, G., Leo, M., Oberhuber, W., 2014. Transpiration and canopy conductance in an inner alpine Scots pine (*Pinus sylverstris* L.) forest. *Flora* 209: 49-498 [CrossRef]
- Wullschleger, S.D., Meinzer, F.C., Vertessy, R.A., 1998. A review of whole plant water use studies in trees. *Tree Physiology* 18: 499-512.[CrossRef]