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Throughfall, stemflow, and interception characteristics of coniferous forest ecosystems in the western black sea region of Turkey (Daday example)

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Abstract This study aims to identify precipitation, throughfall, stemflow, precipitation, and interception processes in pure black pine, pure Scots pine, and mixed black pine–Scots pine forest ecosystems and present the precipitation partitioning according to different stand types. Throughfall and stemflow measurements were performed using five standard precipitation gauges in a pilot area established to represent pure black pine, pure Scots pine, and mixed black pine–Scots pine stands in the Bezirgan Basin. The total precipitation was measured in an open field close to the study area. Throughfall values were calculated as the percentage of precipitation measured in an open field. According to the results of the study, the throughfall values were 69.8% in black pine, 73.9% in Scots pine, and 77.7% in the mixed black pine–Scots pine stands; the stemflow values were 2.6% in black pine, 5.9% in Scots pine, and 3.1% in the mixed black pine–Scots pine stands; the amounts of precipitation reaching the forest floor were 72.3% in black pine, 79.8% in Scots pine, and 80.7% in the mixed black pine–Scots pine stands; and the interception values were found to be 27.7% in black pine, 20.2% in Scots pine, and 19.2% in the mixed black pine–Scots pine stands.

Keywords Hydrological cycle · Throughfall · Stemflow · Interception · Kastamonu · Turkey

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Introduction

Although three-fourths of the Earth's surface is covered with water, the amount suitable for human use is rather limited (WWAP 2003). Water resources are significantly affected by global changes, and only few surface and groundwater systems are currently unexploited by human activities around the world. Therefore, water scarcity will be one of the major problems in the future (WWAP 2012). This will further increase the pressures on the quantity and quality of water resources. The global water demand, currently 4500 km^3, is estimated to increase to 6900 km^3 by 2030 according to recent studies. This quantity is 40% more than the amount of accessible and reliable water supply (2030 Water Resources Group 2009).

According to the Falkenmark index, which is used to define water scarcity or water stress, Turkey is now a water stressed country and is at a risk of being a water scarce country in the near future (Falkenmark and Lindh 1974). Based on the analyses performed in a previous study, the amount of water that will be required in the next 25 years may be assumed to be three times that of the current water demand (Muluk et al. 2013). Turkey aims to fully benefit its total usable water potential (112 km^3) by 2023 (DSI 2009).

Turkey hydrologically comprises 25 major basins, where the mean annual precipitation, evaporation, surface water flows, and amount and distribution of annual precipitation vary greatly (Akkemik et al. 2005). As the importance of water and degree of climate change has increased in recent years, the Mediterranean Basin, where Turkey is located, is one of the places where the effects of climate change are and will be felt the most intensely in the future. Due to the decrease in temperature and the lack of rainfall, many river basins in the Mediterranean will face water stress in the near future when drought will be more likely, and by 2030 in Turkey, the water stress at a rate exceeding 40% in the interior and western regions is expected to experience (DSI-State Hydraulic Works 2009). This situation shows increasing the pressure on water resources to meet the needs of Turkey's rising water. Dam reservoirs, which are built to increase river water use, may cause huge amounts of water loss due to evaporation, leading to effects that further increase this pressure (UNESCO 1999; Muluk et al. 2009). Owing to the available data and assessment results, the importance of preserving existing water resources and structures producing high-quality clean water is realized more in recent years. In this context, forest ecosystems, in particular, have a special significance. Beside the fact that forests are an effective means of protecting soil, they have positive hydrological and hydrochemical influences such as storage of water, regulation of flow regime and water quality, and prevention of floods and overflows (Özhan 2004). Therefore, understanding the hydrological function of forests and the structure of the elements in the system and examining their place in this cycle in detail will be very useful to increase the amount of clean and high-quality water in the future.

The partitioning of rainfall amounts reaching the Earth's surface in the water cycle, i.e., disposition of precipitation, can be used to determine the silvicultural intervention techniques to be performed on basins for water production (Özyuvacı et al. 2004). The most important factor in such basins is interception, which prevents precipitation from reaching the soil and thus determines the amount of water collected in a basin. Interception is considered as an important hydrological process in water resource management and adaptation to climate change (Arnell 2002). Interception refers to precipitation (rain, snow, dew, etc.) that does not reach the forest floor but instead intercepted by the leaves, branches, and stems of plants and returns to the atmosphere via evaporation (Zhang et al. 2005). The interception rate depends on the duration and density of precipitation, structure of vegetation, and meteorological conditions controlling evaporation during and after precipitation (Rutter et al. 1975; Ward and Robinson 1990; Dingman 2002; Brutsaert 2005; Muzylo et al. 2009). To measure the amount of interception, the amounts of throughfall and stemflow must be known in addition to precipitation falling above the canopy (Lewis 2003). The amount of interception in forest ecosystems varies depending on the degree of crown closure of the stand, type of stand, age of stand, type of trees, and seasons (Çepel 1986). The portion of the precipitation that returns to the atmosphere from the forest canopy by interception plays an important role in the water balance of forest ecosystems by evaporating a significant portion of precipitation (Horton 1919; Navar 2017) and affects hydrological processes and ecosystem productivity (Acharya et al. 2016).

Measurements of throughfall, stemflow, and interception, which constitute the disposition of precipitation in the hydrological cycle, were first conducted in the mid-nineteenth century in Europe (Molchanov 1963) and in the early twentieth century in the USA (Zinke 1967; Janik and Pichler 2008; Pérez-Suárez et al. 2008; Konishi et al. 2006; Devlaeminck et al. 2005; Maloney et al. 2002). The first attempt at modeling interception loss was made by Horton in 1919, also reproduced by Gash and Shuttleworth (2007). However, interception loss was estimated using empirically derived relations with gross precipitation until 1970s. After Horton's work, the first conceptual model, which described interception as an evaporative loss, was developed by Rutter et al. (1971) (Muzylo et al. 2009). In Turkey, the first measurements in this subject started after the first half of the twentieth century (Balcı 1958; Çepel 1965) and continued with the works of Özyuvacı (1976), Özhan (1982), and Zengin (1997). In a global perspective, various studies related to throughfall, stemflow, and interception have been conducted on many different tree and plant species (Xiao et al. 1998; Marin et al. 2000; Xiao et al. 2000a, b; Huber and Iroume 2001; Xiao and McPherson 2002; Levia and Frost 2003; Mases 2004; Kang et al. 2005; Holwerda et al. 2006; Zhang et al. 2006; Gerrits et al. 2007; Ahmadi et al. 2009; Asadian and Weiler 2009; Prada et al. 2009; Siles et al. 2010;

Özhan et al. 2011, Tsiko et al. 2011; Basea et al. 2012; Saito et al. 2013; Yurtseven et al. 2013; Yurtseven and Zengin 2013; Livesley et al. 2014; Liua et al. 2015; Sun et al. 2015). Consequently, interception studies are very important for identifying water-cycle elements related to various types of stands and evaluating the water budget in our country, where significant variations in the forest ecosystems and climate are observed.

This study, which investigates the effects of coniferous stands on the distribution of precipitation, is important in terms of not only contributing to the literature but also being a subheading for future studies on local afforestation and improvement of water quality. In this study, the amounts of interception, stemflow, throughfall, and precipitation reaching the soil are examined in pure black pine, pure Scots pine, and mixed black pine–Scots pine stands, which are coniferous forest types in the Daday region, and the differences according to tree species are presented.

This study is also important because it is the first study on the process of determining and monitoring the hydrological properties of forest areas designated by the Forest Stewardship Council (FSC) in Kastamonu. The Forest Stewardship Council (FSC) is an independent, not-for-profit, nongovernmental organization established to support environmentally appropriate, socially beneficial, and economically viable management of the world's forests. The FSC vision is that the world's forests meet the social, ecological, and economic rights and needs of the present generation without compromising those of future generations (FSC 2017). The first certification work was carried out in Bolu Forest Regional Directorate in 2010 and FSC (Forest Stewardship Council) forest management certificate was obtained (Turkoglu and Tolunay 2014). In Turkey, about 10% of forests are certified (Şen and Genç 2017; Sen and Genc 2018). Kastamonu Forest Regional Directorate has spearheaded the certification process due to the effective and important position in the forestry in Turkey.

Study area

The study area is the Bezirgan Basin (Fig. 1) in the Daday District of the Kastamonu Province, Western Black Sea region, Turkey. The Daday district has a surface area of 997 km^2 and elevation of 800 m. It is surrounded by Ballıdağ in the north and the Sarıçam Mountains in the south (İşler 2010; Kuzka 2013). The Daday stream and the Koldan creek pass through the study area. The Yumurtacı, Taşçılar, and Bezirgan dams are also located in the district and are used for irrigation purposes (Gül 2013).

The Daday–Devrekani massif comprises a progressively deformed continental crust and ophiolitic slices and a Cretaceous flysch that simultaneously collapsed along the continental slope. The uppermost tectonic slice comprises Paleozoic sediments and Early-Jurassic granites intersecting the Paleozoic as well as carbonate-flysch sediments, which were deposited between Late Liassic-Lutetian, post-tectonically covering them (Anonymous 2010). In general, it has chestnut- and red-chestnut-colored soils at mid-depth (90–50 cm) with a slope of 12–30% and a moderate water erosion risk (Anonymous 1993). The Daday district comprises 63,867.8 ha of forested area (URL-1), and the main tree species are black pine, beech, fir, Scots pine, and oak (Anonymous 2010). The annual precipitation in the study area exceeds 1000 mm, and the average annual temperature is 9.8 °C (Table 2). The climate type of the area, which was determined according to the water balance obtained using the Thornthwaite method, is C1 B′1 d b′3 [semi humid-semi arid, medium temperature (mesothermal), little or no excess water, near oceanic climate].

Materials and method

Materials

The research materials comprised original data obtained from the test fields established in the pure black pine, Scots pine, and mixed black pine–Scots pine stands in the Bezirgan Basin of the Daday District and statistical data obtained from various institutions. The data in this study were obtained via field measurements and computer-based calculations. These measurements were conducted after each rainfall event between 2012 and 2014.

Method

To compare the different types of stands in terms of disposition of precipitation and the components constituting this disposition (throughfall, stemflow, interception), all factors (closure, elevation, slope, exposure, and geological structure) except the stand

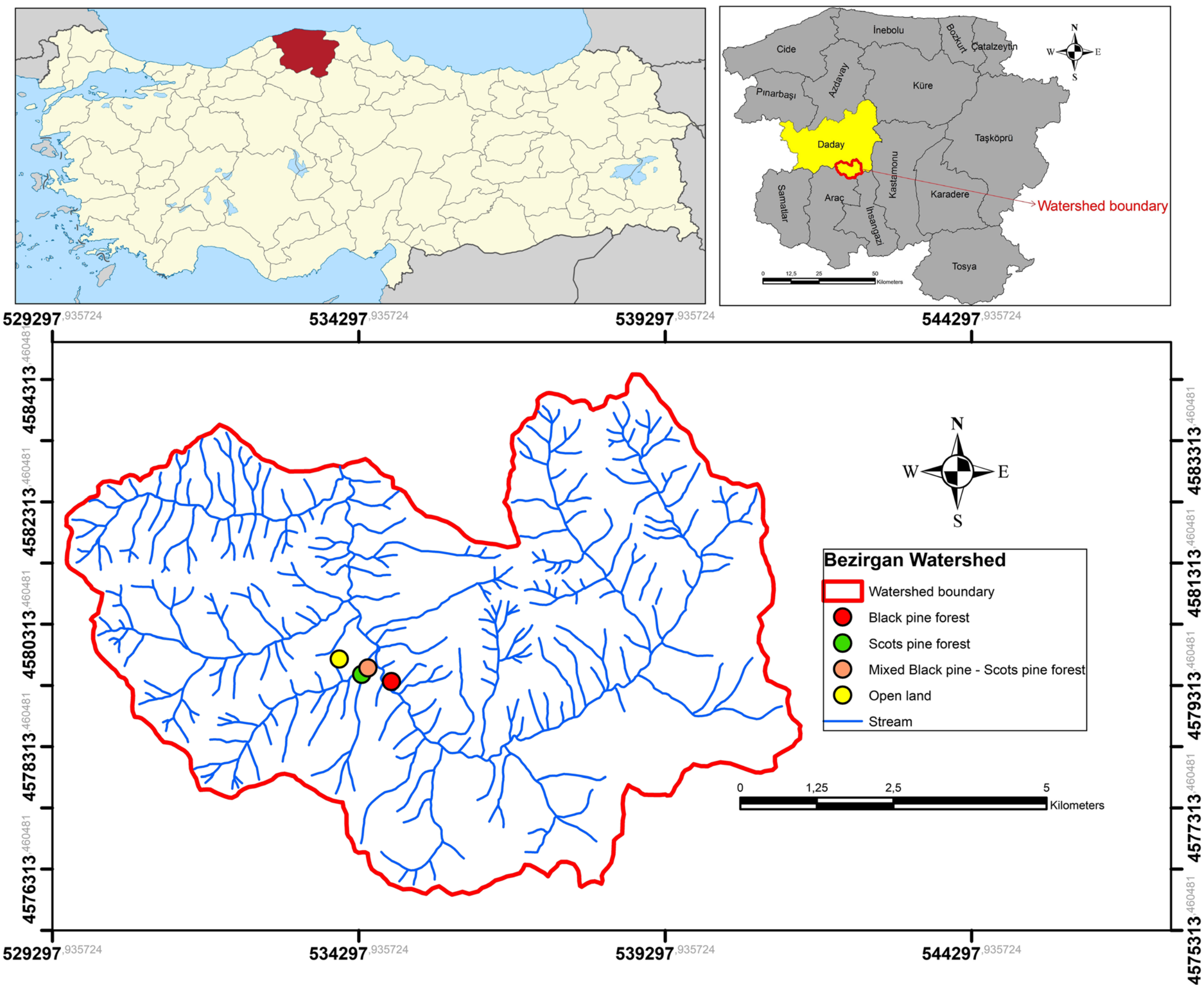

Fig. 1 Location of the study area

types in forest ecosystems were maintained as constant (Zengin 1997). Therefore, similar fields in terms of slope, exposure, location, elevation, and bedrock characteristics were selected as sample plots. In addition, areas close to each other were chosen to ensure meteorological homogeneity between the sample plots. This aspect is especially important to ensure that studied stands are exposed to the same amount of rainfall and sunlight (Özhan 1982). A total of four sample plots with a size of 400 m^2 (20 m × 20 m) were selected for each stand (Özyuvacı 1976; Özhan 1982; Pehl and Ray 1983; Zengin 1997), including three test fields and one control parcel in the open field. The enclosure, elevation, slope, exposure, stand type, and geological structure characteristics of each test site are presented in Table 1.

Similar with the previous studies, standard precipitation gauges were used to determine the amounts of throughfall and precipitation falling into open areas (Özyuvacı 1976; Hewlet 1982; Zengin 1997). The measurements of throughfall were designed to represent the entire area by setting up a total of five standard precipitation gauges in randomly selected points at four corners and at the center of the test fields with a size of 20 m × 20 m in the determined stands (Özhan et al. 2011).

To determine the amount of stemflow, the trees on which the measurement tools installed were selected to represent every diameter level and measurements were then performed (Çepel 1965; Özhan 1982; Zengin 1997). There are five stemflow tools that were installed in each sample plots. Trees with a diameter of 48-44-34-

Table 1 General characteristics of the test fields

Test field	Closure (%)	Elevation (m)	Slope class	Exposure	Stand type	Geological structure
Black pine	71–100	1097	Steep	Sunny	Black pine	Marble
Scots pine	71–100	1054	Steep	Sunny	Scots pine	Marble
Mixed stand	71–100	1042	Very steep	Sunny	Black pine Scots pine	Marble

30-20 cm were selected on the black pine stand, 48-42-38-32-28 cm were selected on the Scots pine stand, and 58-42-38-32-30 cm were selected on the mixed stand. Large diameter and thick-walled plastic hose were used for measuring the stemflow. The hose was longitudinally divided into two parts, and it is wrapped around the tree in a spiral shape. Thus, an inclined water collection and drainage channel was provided.

The total amount of precipitation reaching the soil was calculated as the sum of the stemflow and throughfall amounts.

The interception value was calculated according to Eqs. 1 and 2 (Özhan 1982; Zengin 1997).

$$\text{Interception (mm)} = \text{Precipitation (mm)} - \text{Precipitation reaching the forest floor (mm)} \quad (1)$$

$$\text{Interception (\%)} = \frac{\text{Interception (mm)}}{\text{Precipitation (mm)}} \quad (2)$$

To determine whether there was any difference in the analyzed variables between different stand groups, statistical tests were conducted. The Kruskal–Wallis test was conducted for comparing the mixed groups because the homogeneous conditions necessary for one-way ANOVA were not satisfied ($n < 30$). This test is preferred to measure whether there is a significant difference between two distributions by comparing the measurements of two or more groups with respect to one dependent variable (Büyüköztürk 2010). The Kruskal–Wallis test results obtained for the two groups were similar to the Mann–Whitney test results. Therefore, when there was a significant difference between the groups as a result of comparing the distributions of three or more groups, the Mann–Whitney test was used per two groups to determine the source of the difference. The Mann–Whitney test is the nonparametric counterpart of the *t* test. For this test, the data must be collected randomly. It was accepted that there was a statistically significant difference between groups when the *p* value obtained from the Mann–Whitney test method was less than 0.05. For data analysis, Bonferroni correction was performed, particularly because the error margin increases if the number of samples is less than 30. The Bonferroni correction is determined by the significance level/number of groups formula (Vialatte and Cichocki 2008). In this study, the significance level (p) was determined by the Bonferroni correction as $0.05/3 = 0.0167$ when the number of groups was 3 and as $0.05/4 = 0.0125$ when the number of groups was 4. All statistical analyses were conducted with SPSS 11.0 software.

Results and discussion

The measurement results of throughfall, stemflow, and interception constituting precipitation disposition are presented in Table 2. According to the measurement results, the total precipitation amount in the basin for 2 years (2012–2014) was measured as 1083 mm; 57.5% of the precipitation fell in winter and 42.6% in summer.

The values in the table show that the average amount of throughfall that reached the soil surface, including that passing through the spaces in the forest canopy and

Table 2 Throughfall, stemflow, precipitation reaching the soil, and interception values

		Black pine	Scots pine	Mixed stand
Annual precipitation	(mm)	1083,24	1083,24	1083,24
Throughfall	(mm)	755,62	800,47	840,67
	(%)	69,756	73,896	77,607
Stemflow	(mm)	27,85	63,62	33,69
	(%)	2571	5873	3110
Precipitation reaching the soil	(mm)	783,470	864,090	874,360
	(%)	72,327	79,769	80,717
Interception	(mm)	299,770	219,150	208,880
	(%)	27,673	20,231	19,283

dripping from the leaves, branches, shoots, and stems, as a percentage of precipitation in the open area was 69.8% in black pine, 73.9% in Scots pine, and 77.7% in the mixed black pine–Scots pine stands (Fig. 2). Because branches of pine stands make a wider angle with the tree trunk, they allow more precipitation to reach the soil (Zengin 1997). A significant difference was found between the values in terms of the precipitation measurement points and precipitation values measured in the open area ($p < 0.05$). The Mann–Whitney U test and Bonferroni correction were applied, and the significance level for all groups was accepted as 0.0125 ($p < 0.0125$) (Table 3). A significant difference was found between the black pine, Scots pine, and mixed stand open fields in terms of throughfall values. According to previous studies, throughfall values in black pine were found to be 68% (Özhan 1982), 65% (Çepel 1983), and 60.1% (Rich 1997), and those in Beech were found to be 55–76% (Yeşilkaya 1979), 76% (Aussenac 1968), 70–80% (Nihlgard 1969), 82–87% (Leonard 1961), and 67.1% (Çepel 1967). These values are consistent with the results of this study.

The amount of stemflow, which is measured as the percentage of precipitation falling into an open field, was 2.6% in black pine, 5.9% in Scots pine, and 3.1% in the mixed black pine–Scots pine stands (Table 2). The difference in stemflow values was due to external morphological features (Özhan 1982) such as the types of trees constituting the stands, branching state and structure of the bark, and the number of stems that transport the retained water to the soil surface (Balcı and Özyuvacı 1988). In the Scots pine stand, the angle of the branches with the trunk was narrower compared to the other coniferous species, making it easier to transmit the precipitation retained on the forest canopy to the trunk and preventing it from reaching the soil by dripping. Conversely, in black pine, the branches make a wider angle with the trunk, thus reducing the transmission of rainfall retained on the canopy to the trunk. The thicker branches and bark of black pine and deeper cracks in the bark reduce stemflow (Çepel 1965; Özhan 1982). Statistical evaluation of the measurement results shows that there was no significant difference between the stemflows of the groups according to the Bonferroni correction ($p > 0.0167$) (Table 3). Examination of previous studies shows that the stemflow values obtained from black pine were 0–8, 3.7, and 5.0% (Çepel 1965) and the stemflow values obtained from other pine species were 0.9 (Zengin 1997), 4.0 (Çepel and Eruz 1969), 4.2–3.8, and 4.0% (Çepel 1971).

The average values of precipitation amount reaching the soil, which is equal to the sum of throughfall and stemflow values, were determined as 72.7% in black pine, 79.8% in Scots pine, and 80.7% in the mixed black pine–Scots pine stands (Table 2). When similar studies conducted on this subject were examined, it was found that the precipitation amount reaching the soil was 76.3–70.6% in black pine, 90.0–85.8% (Çepel 1965) and 82.6% (Çepel and Eruz 1969) in Beech, 90.8–84.1% (Çepel 1965) and 80.0% (Çepel and Eruz 1969) in Oak, 68.9% (Çepel and Eruz 1969) in pine species, 77.57% in the mixed coppice stand, 60.99% in the black pine

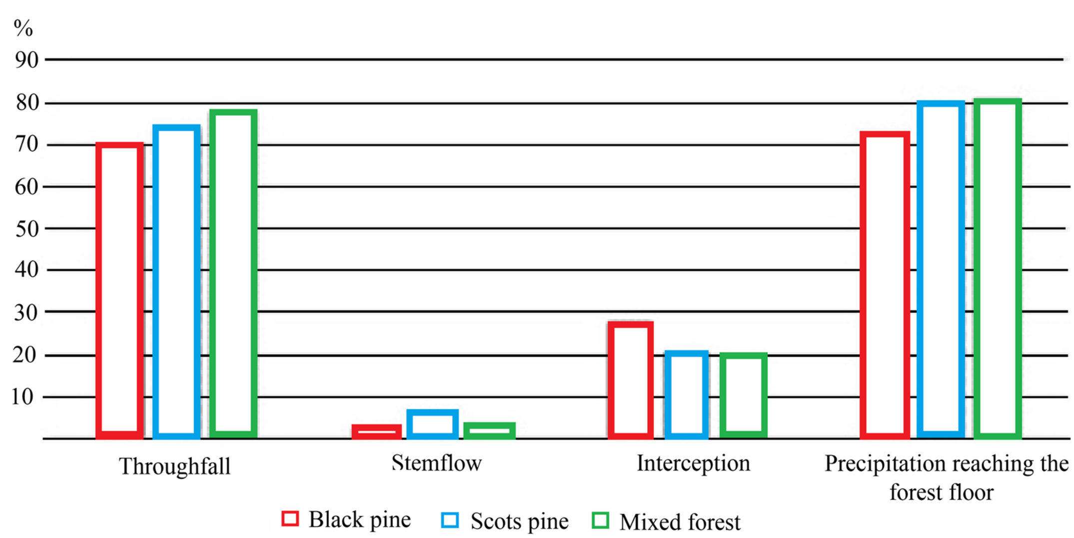

Fig. 2 The amounts of throughfall, stemflow, interception, and precipitation reaching the forest floor in different types of tree species (%)

Table 3 Statistical analysis of precipitation values in different types of tree species in the Bezirgan Basin

	Kruskal–Wallis test results				Mann–Whitney *U* test results	
	Group	*n*	*X* (average)	*P* (significance level)		*P* (significance level)
Precipitation	Black pine	18	41.98	0.001	Black pine–Scots pine	0.610[ns]
	Scots pine	18	44.47		Black pine-Mixed	0.210[ns]
	Mixed	18	46.70		Black pine-Open area	0.001[*]
	Open area	18	60.18		Scots pine-Mixed	0.570[ns]
					Scots pine-Open area	0.002[*]
					Mixed-Open area	0.010[*]
Stemflow	Black pine	18	1.55	0.027	Black pine–Scots pine	0.021[ns]
	Scots pine	18	3.53		Black pine-Mixed	0.223[ns]
	Mixed	18	1.87		Scots pine-Mixed	0.040[ns]
Precipitation reaching the forest floor	Black pine	18	43.53	0.013	Black pine–Scots pine	0.164[ns]
	Scots pine	18	48.00		Black pine-Mixed	0.242[ns]
	Mixed	18	48.57		Black pine-Open area	0.003[*]
	Open area	18	60.18		Scots pine-Mixed	0.924[ns]
					Scots pine-Open area	0.025[ns]
					Mixed-Open area	0.043[ns]
Interception	Black pine	18	16.65	0.179[ns1]		
	Scots pine	18	12.18			
	Mixed	18	11.61			

ns $p > 0.0125$, no significant difference; *ns1* $p > 0.05$, no significant difference

*$p < 0.0125$, significant difference

stand, 74.29% in the Maritime Pine stand, and 71.95% (Zengin 1997) in the Radiata Pine stand. These results were similar to the values obtained in the present study.

The Bonferroni correction was applied among the groups and the significance level was accepted as 0.0125 for all groups. It was determined that there was a significant difference between the amount of precipitation reaching the soil measured in the Karaçam stand and that measured in the open area ($p < 0.0125$) (Table 3).

The interception value measured in three different tree species in the Bezirgan Basin, as percentage of precipitation falling into the open field, was 27.2% in black pine, 20.2% in Scots pine, and 19.3% in the mixed black pine–Scots pine stand (Table 2). As a result of statistical analysis of the interception values obtained from the measurements, there was no significant difference between the groups ($p > 0.05$) (Table 3).

When we examined the interception values obtained from the studies on different tree species, the results of this study were observed to be similar [26% (Çepel 1965), 31.1% (Çepel 1971), and 28.3% (Özhan 1982) in black pine; 18.3% (Crockford and Richardson 1990) in Scots pine; 8–30% (Yeşilkaya 1979), 15% (Aussenac and Boulangeat 1980), 17.4% (Çepel and Eruz 1969), and 22% (Balazs 1983), 31.1% in (Özhan 1982) Beech; 14.1% (Riedl and Zachar 1984), 20.7% (Tang 1993), and 31.1% (Çepel and Eruz 1969) in all other pine species].

Conclusion

When the results of data for 2 years obtained from the test areas in the Bezirgan Basin were analyzed, it was determined that 72.30% of the precipitation in the test area in the black pine stand reached the soil and 27.70% was interception; 79.81% of the precipitation in the Scots pine stand reached the soil and 20.19% was interception; and 80.77% of the precipitation in the mixed black pine–Scots pine stand reached the soil and 19.23% was evaporated by interception and not involved in the water budget of the basin.

Knowing when and for how long the interception will prevent water from reaching the soil in the dam basins contributes to the knowledge of when and to what degree the stands and tree species constituting these stands will affect the water production of the dams. To increase the amount of water produced in a basin, plant species that consume water and prevent water from reaching the soil through transpiration and interception and thus prevent water from joining the water budget of the basin should not be preferred. Therefore, in the basins where forest areas with hydrological function are present, leafy species that have less water loss and contribute more to the water budget of the basin should be preferred instead of coniferous species based on their characteristics such as the root structure of the tree, plant leaf surfaces, and water requirement. In forests where water yield has primary importance, it may be preferable to reduce the density of the stand both to increase water yield and to prevent the formation of raw humus.

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