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Original Article

Root Biomass and Root Carbon and Nitrogen Stocks of Ash, Alder, and Oak Stands in Karacabey Floodplain Forest

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ABSTRACT

The main aim of this study was to investigate total root biomass and root carbon and nitrogen stocks of ash (*Fraxinus angustifolia* Vahl.), alder (*Alnus glutinosa* L.), and oak (*Quercus cerris*) stands in relation to the well-drained and poorly drained sites in Karacabey floodplain forests. Root samples were taken in autumn (October) using soil cores method and sorted into fine (0–2 mm), medium (2–5 mm), and coarse (5–10 mm) root diameter classes. The results showed that ash and oak stands had higher total root biomass in the poorly drained site (3865 kg ha^{-1} and 1949 kg ha^{-1}, respectively) than in the well-drained site (1569 kg ha^{-1} and 1301 kg ha^{-1}, respectively), whereas alder stands showed the opposite trend with having lower total root biomass in the poorly drained site (1878 kg ha^{-1}) than in the well-drained site (2227 kg ha^{-1}). In general, ash and oak stands had higher root carbon stocks in the poorly drained site than in the well-drained site, whereas alder stands had lower root carbon stocks in the poorly drained site than in the well-drained site. However, for all three tree species root nitrogen stocks were higher in the poorly drained site than in the well-drained site. It is concluded that the differences in stand characteristics, stand ages, tree species, soil properties, and microclimate conditions could be responsible for those variations. Thus, more extensive and detailed root biomass studies are in need to investigate the responses of tree species under different climatic, edaphic, and stand characteristics in flood plain forests of Turkey.

Keywords: Forested floodplain, root carbon and nitrogen stocks, root dynamics, well- and poorly drained sites

Introduction

Increasing the amount of CO_2 in the atmosphere and considering this as one of the most important factors in global climate change (IPCC, 2022) has increased the interest in identifying and understanding ecosystems with high carbon storage capacity (Mukul et al., 2020). Recently, depending on this approach, the carbon storage potential of wetland forest ecosystems (mainly mangroves, riparian, and floodplain forest ecosystems) has emerged as a special study area (Byun et al., 2019; Rieger et al., 2013).

It has been reported in many studies that floodplain forest ecosystems can store more carbon per unit area than many terrestrial forest ecosystems (D'Elia et al., 2017; Duarte et al., 2013). For example, total ecosystem carbon stocks stored in Indo-Pacific mangroves are up to 1023 Mg C ha^{-1} (Donato et al., 2011), which is about three to five times larger than typically found in humid lowland rainforests (Keith et al., 2009). In addition to storing carbon, floodplain forests have also the ability to store other nutrients, such as nitrogen (N) (Shrestha et al., 2012). Most studies in floodplain forest ecosystems have mainly focused on the potential carbon storage components of aboveground (whole trees and forest floor litter) and belowground (soil organic matter) (Cseh et al., 2014; Shupe et al., 2021). However, studies on carbon (C) and nitrogen (N) stocks of belowground root mass of flooded forest ecosystems are quite scarce since these type of studies are considered as time-consuming, labor-intensive, and complex methodology (Adame et al., 2014). On the other hand, many researchers are in agreement that understanding the whole forest ecosystem biomass and C and N stocks will be more successful if the belowground root mass is included in the studies (Wakawa, 2016). Nevertheless, the absence of direct root mass estimation data is frequently observed in biomass studies performed in both terrestrial and forested wetland ecosystems (de Assis et al., 2019).

Field studies in forest ecosystems have shown that site conditions such as microclimate, soil properties, and topography can have significant impacts on root morphology, physiology, and biomass (Kubisch et al., 2015).

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However, it is common to see that an individual floodplain forest can have different soil microsites due to floodwater encroachment and recession all year around (Mikulová et al., 2020). Soil chemistry, bulk density, and drainage characteristics of those soil microsites are often different from each other, which in turn can result in variations in total root biomass, root carbon (RC), and root nitrogen (RN) stocks (Goenster-Jordan et al., 2018; Valtera et al., 2021).

Turkey has also some floodplain forests in several regions, especially in the Marmara and in the Black Sea Regions, but unfortunately, only 11.400-hectare floodplain forests have remained in Turkey, some of which have already been studied in terms of ecology and biology (Ursavaş & Keçeli, 2019). The biomass dynamics of fine roots (FR) and RC and RN concentrations and impacts on soil organic C and N stocks have been studied by a number of researchers using different tree species in terrestrial forests in Turkey (e.g., Akburak et al., 2013; Tufekcioglu et al., 2004). However, there has been no study available in Turkey comparing total root biomass, RC and RN stocks of floodplain forests to other forested wetlands or terrestrial forests. We therefore conducted a field study to (1) estimate and compare TRB, RC, and RN stocks; (2) investigate the effects of well-drained (WD) and poorly drained (PD) site conditions on TRB, RC, and RN stocks; and (3) understand the response of different tree species (ash, alder, and oak) and root diameter classes (fine <2 mm, medium 2–5 mm, and coarse 5–10 mm) under those conditions in Karacabey floodplain forest, northwest of Turkey.

Methods

Study Site

The study was carried out in Karacabey Floodplain Forests, Bursa, Turkey (40°23′38′′– 40°21′43′′ N and 28°23′02′′–28°34′21′′ E) (Figure 1). Most forest stands in Karacabey Floodplain Forests are subjected to long-term waterlogging (PD sites) or complete submersion for 9–10 months every year. However, some forest stands on slightly hilly sites remain under short-term waterlogging (well-drained sites) conditions for only 1–2 months during the winter season every year (Figure 2). This unique floodplain ecosystem is not only dependent on rainfall and air humidity but more on groundwater. Turkish Ministry of Forestry and Water Affairs described the area as "the floodplain is similar to the mangrove forests of tropical regions." The total size of the Karacabey floodplain is approximately 3800 ha. This unique floodplain ecosystem includes a variety of habitats: sand dunes (623 ha), swamp (532 ha), lakes (760 ha), grasslands (390 ha), croplands (545 ha), and floodplain forests (950 ha) (Anonymous, 2019).

The region is characterized by a semi-humid climate. The last 13-year (2007–2020) total annual precipitation and average temperature are 719 mm and 15.5°C, respectively, although the most dominant tree species in the floodplain forests are ash tree (*Fraxinus angustifolia* Vahl.), alder (*Alnus glutinosa* (L.) Gaertn.), and oak species (mostly *Quercus cerris*) (Ursavaş & Keçeli, 2019).

Karacabey plain is in the group of alluvial-filled rift valley caused by tectonic movements. It was formed as a result of the collapses that took place during the quaternary period. There are limeless brown forest soils, alluvial, colluvial, alluvial coastal soils, and rendzina throughout the Kocaçay delta. In the area where the study was carried out, there were alluvial and colluvial soils (Anonymous, 2019).

Root Sampling and Description

Fine roots (0–2 mm), medium roots (MR) (2–5 mm), and coarse roots (CR) (5–10 mm) of ash, alder, and oak stands were collected from the WD and PD sites in autumn (October) 2020.

Total of 12 subplots (3 tree species × 2 sites (WD and PD) × 3 replicate subplots = 12 subplots) with 400-m^2 quadrat were identified in the WD and PD stands. For each tree species, three replicate subplots located approximately 300 m apart were taken in the WD and PD sites. Five mature and taller trees in each subplot were chosen to determine stand age (year), height (m), and diameter breast height (dbh, cm) (Table 1) (Carus, 1998). Tree age was determined by counting each annual growth ring in the trunk of the tree. A Blume-Leiss was used to determine tree heights. A diameter tape was used to measure the dbh. Canopy cover was visually decided in each plot and then this determination was corrected by measurements of stem number and diameter at breast height.

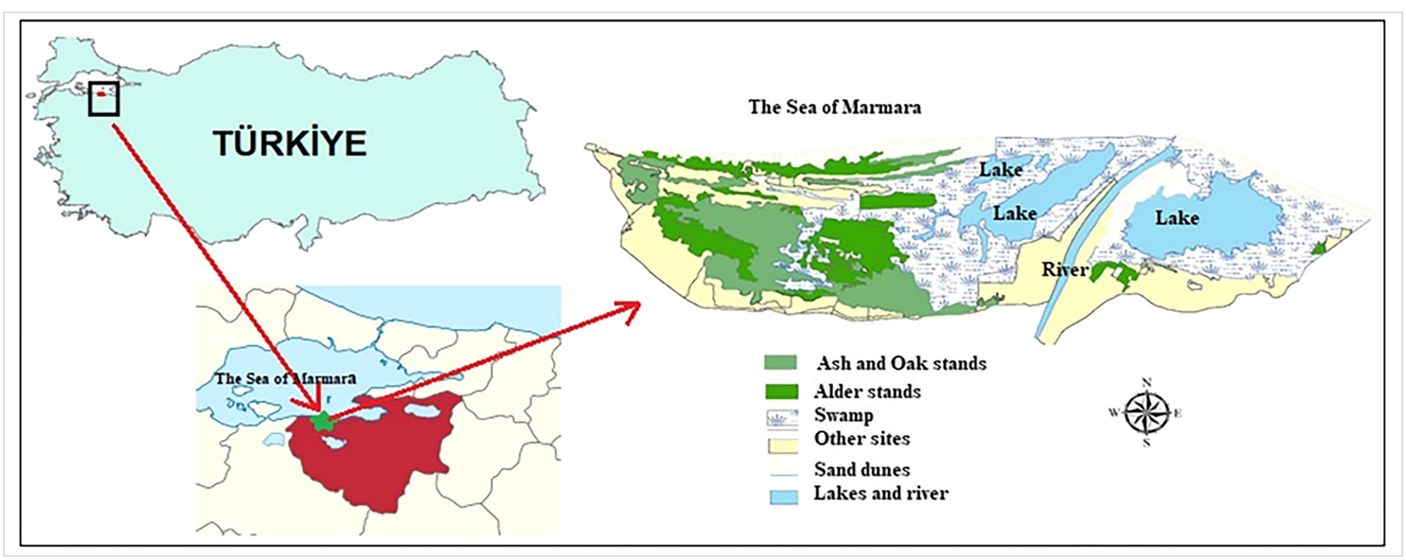

Figure 1.
The Location of Karacabey Floodplain Forests Near the Sea of Marmara.

Figure 2.
Poorly Drained (PD) and Well-Drained (WD) Soil Microsites Can be Seen in Karacabey Floodplain Forests at the Same Time. Top Pictures from Ash Tree Stands with PD (left) and WD (right) sites. Bottom Pictures from Alder Stands with PD (left) and WD (right) Sites.

Five trees were selected in each subplot, and around each tree, at the distance not longer than 1.50 m from tree trunks. Five soil samples with tree roots were collected using a soil core with 6.4 cm diameter and 34 cm height (Tufekcioğlu et al., 2004). Total of 300 soil cores were taken (3 tree species × 2 sites (WD and PD) × 3 replicate plots × 5 sampling trees × 5 soil cores around each tree = 300 soil cores). The soil core samples were placed into bags, brought to the laboratory, and stored in a refrigerator at 4°C prior to the analysis. In the laboratory, the roots were separated from mineral soil using a two-stage washing process. In the first stage, samples were soaked overnight to extract coarse mineral parts, such as stones and unnecessary organic parts (e.g., dead wood, bark, seeds, and seedlings). Roots were picked from the sample by hand or using a pair of tweezers to separate them from the remaining mineral soil. The roots were finally removed and put in a bucket filled with clean water. A second stage was carried out to extract clean roots by gently washing them on a screen.

Three root-diameter classes were distinguished as FR (0–2 mm), medium roots (2–5 mm), and CR (5–10 mm), which are most commonly used in the literature (Finér et al., 2011; Tufekcioğlu et al., 2004). Herbaceous roots (e.g., grasses, weeds, and herbs) were also separated from the tree roots. The herbaceous roots formed masses that were clearly distinguishable from the tree roots. The separated FR, medium roots, and CR were then dried until they reached constant weight. After that, they were weighed to determine the dry biomass. Measurements of root biomass in gram per soil core volume were then scaled to kilogram per hectare.

Soil Sampling and Analyses

Soil samples were also collected from the WD and PD sites in October 2020, when the soil had minimum moisture and the water table was at the lowest depth (150 cm). The soil samples were collected from depths of 0–30 cm. The moist soil field samples were air-dried, crushed, and then hand sieved through a less than 2 mm screen to remove stones,

Table 1.
Mean Stand Characteristics of Ash, Oak, and Alder Trees Collected from the Well-Drained (WD) and the Poorly Drained (PD) Sites

Studied Sites	Tree Species	Age (years)	Tree Height (m)	Diameter Breast Height (cm)
Well-drained	*Fraxinus angustifolia*	70 (62–77)	15.4 (9.1–18.5)	34.7 (31.4–36.2)
	Alnus glutinosa	48 (38–63)	21.8 (18.2–26.1)	35.5 (32.3–38.3)
	Quercus cerris	99 (82–116)	25.7 (19.7–29.2)	40.8 (38.1–46.2)
Poorly drained	*Fraxinus angustifolia*	79 (60–87)	17.0 (10.5–22.5)	37.9 (33.2–40.3)
	Alnus glutinosa	49 (35–64)	24.0 (16.3–26.4)	36.8 (34.6–39.2)
	Quercus cerris	104 (90–117)	28.8 (22.4–32.2)	43.8 (39.4–47.9)

Table 2.
Soil Properties (0–30 cm) of Ash, Oak, and Alder Trees Collected from the Well-Drained (WD) and the Poorly Drained (PD) Sites

Studied Sites	Tree Species	pH	Electrical Conductivity (Ds m^{-1})	Bulk Density (g cm^{-3})	Clay (%)	Silt (%)	Sand (%)	Soil Type
	Fraxinus angustifolia	6.88^{a}	0.78^{c}	1.41^{b}	15^{a}	13^{a}	72^{a}	Loamy sand
Well-drained	*Alnus glutinosa*	6.66^{a}	0.59^{b}	1.35^{a}	17^{a}	12^{a}	71^{a}	Loamy sand
	Quercus cerris	6.56^{a}	0.27^{a}	1.27^{a}	19^{a}	9^{a}	72^{a}	Loamy sand
	Fraxinus angustifolia	6.28^{a}	0.92^{c}	1.30^{b}	26^{a}	10^{a}	64^{a}	Sandy clay loam
Poorly drained	*Alnus glutinosa*	6.16^{a}	0.74^{b}	1.26^{ab}	29^{a}	9^{a}	62^{a}	Sandy clay loam
	Quercus cerris	6.08^{a}	0.36^{a}	1.20^{a}	30^{a}	12^{a}	58^{a}	Sandy clay loam

Note: The same letters are not significantly different among the tree species in well-drained and poorly drained sites.

roots, large organic particles, and macrofauna. After that, they were bulked to give a single representative soil sample for each subplot.

Soil pH was determined by a combination glass electrode in H_2O (soil:solution ratio 1:2.5). Electrical conductivity (EC) was determined in 1:1 soil water extract by using a conductivity meter and expressed as deciSiemens per meter (Kaçar, 2016). Soil organic matter was determined by the modified Walkley-Black method as described by Ramamoorthi and Meena (2018). Soil texture was determined by Bouyoucos' hydrometer method (Kaçar, 2016). Soil bulk density was determined by the undisturbed core sampling method (Kaçar, 2016). Soil bulk density was used to calculate soil organic C and N stocks.

Statistical Analysis

The data were analyzed using one-way and multiple analyses of variance to examine the relationship between tree species and the WD and PD sites. Differences among mean values were analyzed using Turkey's honestly significant difference (HSD) test ($\alpha = .05$) (using MS EXCEL Professional Plus 2021 and SPSS).

Results

Stand and Soil Characteristics

The mean age of ash tree stands was 70-year-old in the WD site and 79-year-old in the PD site. Alder stands were much younger than the ash tree stands, ranging from 48-year-old in the WD site to 49-year-old in the PD site. Oak stands were the oldest with mean age of 99-year-old in the WD site and 104-year-old in the PD site.

Oak stands in both the WD and PD sites had the highest mean tree height (25.7 m and 28.8 m, respectively) and dbh (40.8 cm and 43.8 cm, respectively), while ash tree stands had the lowest tree height (15.4 m and 17.0 m, respectively) and dbh (34.7 cm and 37.9 cm, respectively). Alder stands showed the values between oak and ash tree stands (Table 1). In general, mean age, height, and dbh values of the stands in the WD sites were lower than in the PD site (Table 1), but these differences were not statistically significant between the WD and PD sites.

There were also no significant differences in soil pH and texture among the three tree species in both the WD and PD sites (Table 2). However, EC and bulk density showed a decrease from ash and alder stands to oak stands in both sites. As for the differences in soil properties between the WD and PD sites, soil pH, bulk density, and sand content were found to be higher in the WD sites than in the PD sites for all tree species, whereas EC and clay content were found to be lower in the WD sites than in the PD sites for all tree species (Table 2).

Root Biomass

Biomass values of FR, medium roots, and CR in ash, oak, and alder stands collected from the WD and the PD sites are given in Figure 3.

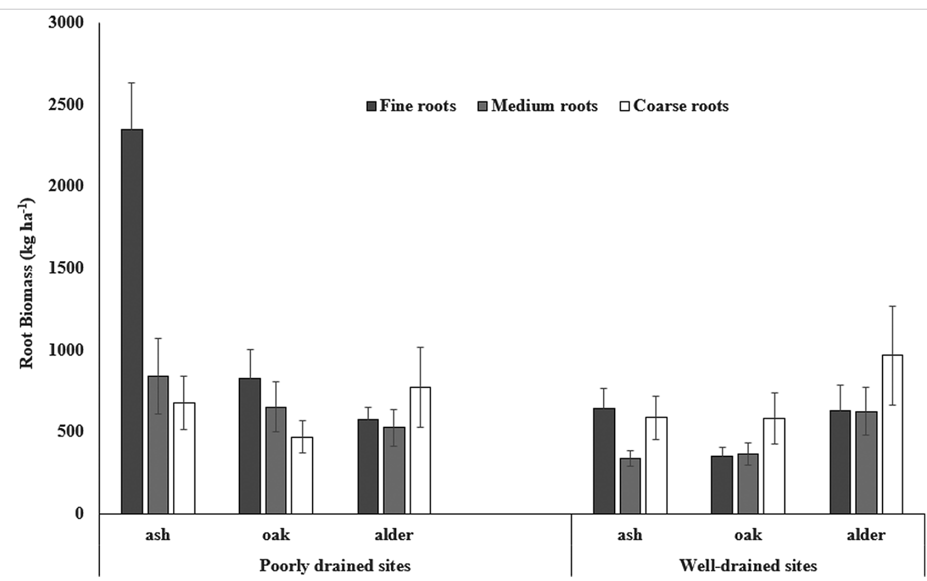

Figure 3.
Fine, Medium, and Coarse Root Biomass of Ash, Oak, and Alder Stands Collected from the Poorly Drained and Well-Drained Sites.

Table 3.
ANOVA of Root Biomass

	Source	SS	*df*	MS	F	Eta squared
Fine root	Tree species (T)	22.178.499	2	11.089.249	36.774***	.637
	Sites (S)	13.026.386	1	13.026.386	43.198***	.507
	T × S	22.965.192	2	11.482.596	38.079***	.645
	Error	12.665.000	42	301.547		
Medium roots	Tree species (T)	507.545	2	253.772	2.111ns	.091
	Sites (S)	204.955	1	204.955	1.705ns	.039
	T × S	1.762.385	2	1762.385	7.331**	.259
	Error	5.048.762	42	120.208		
Coarse roots	Tree species (T)	209.717	2	104.858	0.002ns	.000
	Sites (S)	98.069	1	98.069	2.673ns	.113
	T × S	253.578	2	126.789	3.232*	.133
	Error	1.647.674	42	39.230		
Total root biomass	Tree species (T)	17.292.578	2	17.292.578	14.884***	.262
	Sites (S)	22.361.717	1	11.180.858	9.624***	.314
	T × S	49.634.774	2	24.817.387	21.361***	.504
	Error	48.795.953	42	1.161.808		

Asterisks refers the level of significance: *$p < .05$; **$p < .01$; ***$p < .001$. ns = not significant.

The main effects of the sites (S) and tree species (T) on TRB were all significant ($p < .001$) (Table 3). Site × T interaction was also significant ($p < .001$) for the TRB indicating that the TRB behaved in different ways according to the root diameter class and tree species (Table 3). This was mostly due to the differences in fine root biomass (FRB) which showed significant ($p < .001$) variation among the three tree species and between the WD and the PD sites ($p < .001$) (Table 3).

Total root biomass in the WD site was ranked in the order as alder (2227 kg ha^{-1}) > ash (1569 kg ha^{-1}) > oak (1301 kg ha^{-1}) stands. Compared to the WD site, TRB in alder stands was lower (1878 kg ha^{-1}) in the PD site, whereas it was higher in ash and oak stands (3865 kg ha^{-1} and 1949 kg ha^{-1}, respectively).

In the WD site, FR was mostly responsible for TRB in ash tree stands (41%), followed by CR (37%) and medium root (21%) (Figure 3). In contrast to ash tree stands, the CR was mostly responsible for TRB in alder and oak stands with similar percentage (about 44%), followed by medium root (about 28%) and FR (about 28%).

Compared to the WD site, the contribution of FR to TRB in the PD site was higher in ash tree and oak stands (61% and 42%, respectively), but it was very similar for alder stands (31%) (Figure 3). The contributions of medium root to TRB for ash, oak, and alder stands (22%, 33%, and 28%, respectively) in the PD site were also not varied much compared to the WD site. However, the contribution of CR to TRB in the PD site was lower in ash, oak, and alder stands (18%, 24%, and 41%, respectively) compared to the WD site (Figure 3).

Root Carbon and Nitrogen Concentration

Among the three root diameter classes, in both sites, CR had the highest C concentration, followed by medium root and FR for all tree

Table 4.
Mean Carbon and Nitrogen Concentrations in Three Root Diameter Classes of Ash, Alder, and Oak Tree Species Collected from the Well-Drained (WD) and the Poorly Drained (PD) Sites

		C (%)			N (%)		
Studied Sites	Tree Species	Fine	Medium	Coarse	Fine	Medium	Coarse
	Fraxinus angustifolia	50.4^{bA}	53.1^{bB}	55.9^{bC}	4.13^{bC}	2.72^{bB}	1.56^{bA}
Well-drained	*Alnus glutinosa*	43.2^{aA}	45.3^{a}	50.8^{aC}	5.10^{cC}	3.51^{cB}	2.43^{cA}
	Quercus cerris	51.4^{bA}	53.8^{bB}	56.3^{bC}	3.40^{aB}	1.54^{aA}	1.10^{aA}
	Fraxinus angustifolia	52.7^{bA}	54.6^{bB}	57.0^{bC}	5.96^{bC}	4.72^{bB}	2.63^{aA}
Poorly drained	*Alnus glutinosa*	44.9^{aA}	47.2^{aB}	52.2^{aC}	7.93^{cB}	7.34^{cB}	6.52^{bA}
	Quercus cerris	53.3^{bA}	55.5^{bA}	58.1^{bB}	4.28^{aB}	2.77^{aA}	2.57^{aA}

Note: The similar letters by column are not significantly different among the tree species in well-drained and poorly drained sites. The similar capital letters are not significantly different among the tree root classes.

species (Table 4). Among the three tree species, in the WD site, ash and oak stands showed more or less similar mean C concentration in FR, medium root, and CR (about 51%, 53%, and 56%, respectively), which were higher than that in alder stands (43%, 45%, and 51%, respectively).

Mean C concentrations in FR, medium root, and CR in the PD site were about 1–2% higher than in the WD site for all tree species (Table 4). Similar to the WD site, ash and oak stands also showed similar mean C concentration in FR, medium root, and CR (about 53%, 55%, and 58%, respectively), which were also higher than that in alder stands (about 45%, 47%, and 52%, respectively).

In contrast to mean C concentration, mean N concentration was highest in FR, followed by medium root and CR for all tree species. In the WD site, alder stands had the highest N concentration in FR (5.10%), medium root (3.51%), and CR (2.43%), whereas oak stands had the lowest (3.40%, 1.54%, and 1.10%). Ash tree stands showed N concentrations between alder and oak stands with 4.13% for FR, 2.72% for medium roots, and 1.56% for CR.

In the PD site, the mean N concentration was higher in FR, medium, and CR for all tree species. Similarly, alder stands had the highest N concentration in FR (7.93%), medium root (7.34%), and CR (6.52%), whereas oak stands had the lowest (4.28%, 2.77%, and 2.57%). Ash tree stands showed N concentrations between alder and oak stands with 5.96% for FR, 4.72% for medium roots, and 2.63% for CR.

Root Carbon Stocks

The main effects of the sites (S) and tree species (T) on total RC stocks were all significant ($p < .001$) (Table 5). Site–T interaction was also significant ($p < .001$) for the total RC stocks indicating that the total RC stocks act in different ways according to the root diameter class and tree species (Table 5). As seen for TRB, this was also mostly due to the differences in fine RC stocks which showed significant ($p < .001$) variation among the three tree species and between the WD and the PD sites ($p < .001$) (Table 5).

Total RC stock in the WD site was ranked in the order alder (977 kg C ha^{-1}) > ash (832 kg C ha^{-1}) > oak (650 kg C ha^{-1}) stands. Compared to the WD site, total RC stock in the PD site was higher for ash (2081 kg C ha^{-1}) and oak (1131 kg C ha^{-1}) stands, whereas it was lower for alder stands (911 kg C ha^{-1}) (Figure 4).

In the WD site, CR contribution to total RC stocks was highest for all tree species, ranging from 41% in ash stands and 42% in oak stands to 43% in alder stands (Figure 4). Medium root contribution was similar in oak and alder stands (30% and 29%, respectively), while its contribution was only 22% in ash stands. Fine root contribution was higher than medium root contribution. It was highest in ash tree stands (37%), while it showed a lower but similar contribution (28%) for oak and alder stands.

In the PD site, the contribution of CR, medium root, and FR to total RC stocks did not vary much for alder stands (44%, 27%, and 29%, respectively) compared to the WD site. Medium root contribution was also similar for oak and ash tree stands (32% and 22%) compared to the WD site. However, FR contribution to total RC stocks showed an increase in ash tree (59%) and oak (39%) stands (Figure 4).

Root Nitrogen Stocks

The main effects of the sites (S) and tree species (T) on the total RN stocks were all significant ($p < .001$) (Table 6). Site–T interaction was also significant ($p < .001$) for the total RN stocks indicating that the total RN stocks acted in different ways according to the root diameter class and tree species (Table 6). This was mainly

Table 5.
ANOVA of Root C Stocks

	Source	SS	*df*	MS	F	Eta squared
Fine root	Tree species (T)	5.346.150	2	2.673.075	28.230***	.537
	Sites (S)	4.114.598	1	4.114.598	43.454***	.509
	T × S	6.285.975	2	3.142.987	33.193***	.612
	Error	3.976.939	42	94.689		
Medium roots	Tree species (T)	124.349	2	62.174	2.068ns	.090
	Sites (S)	101.200	1	101.200	3.367ns	.074
	T × S	438.456	2	219.228	7.293**	.258
	Error	1.262.456	42	30.058		
Coarse roots	Tree species (T)	190.460	2	95.230	2.221ns	.096
	Sites (S)	41.579	1	41.579	0.970ns	.023
	T × S	218.033	2	109.016	2.542ns	.108
	Error	1.801.138	42	42.884		
Total root biomass	Tree species (T)	8.556.851	2	4.278.425	12.346***	.370
	Sites (S)	5.004.210	1	5.004.210	14.440***	.256
	T × S	13.041.013	2	6.520.506	18.816***	.473
	Error	14.555.030	42	346.548		

Asterisks refers the level of significance: *$p < .05$; **$p < .01$; ***$p < .001$. ns = not significant.

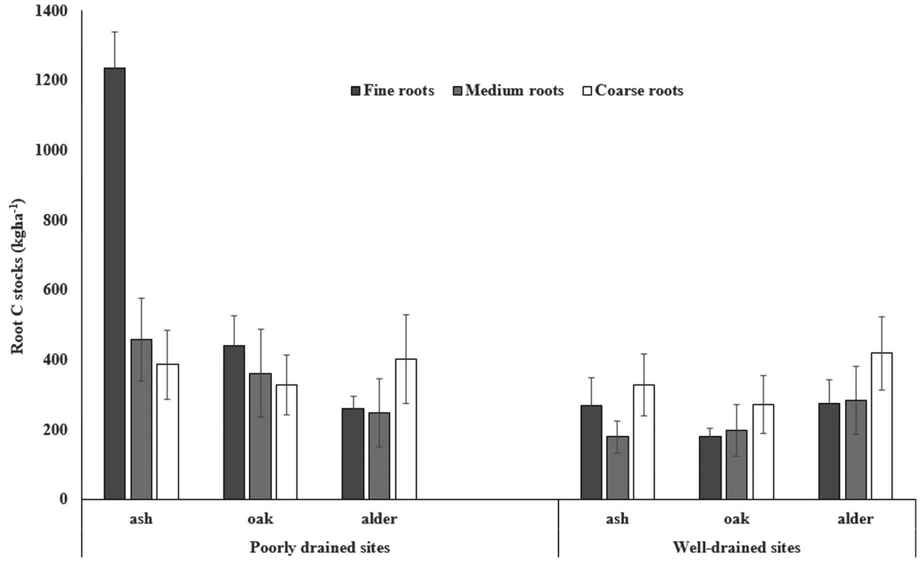

Figure 4.
Fine, Medium, and Coarse Root Carbon Stocks of Ash, Oak, and Alder Stands Collected from the Poorly Drained and Well-Drained Sites.

due to the differences in fine RN stocks, but the differences in medium and coarse RN stocks showed significant ($p < .001$) variation among the three tree species and between the WD and the PD sites ($p < .001$) also accounted for the differences in total RN stocks (Table 6).

Total RN stock in the WD site was ranked in the order alder (71 kg N ha^{-1}) > ash (31 kg C ha^{-1}) > oak (24 kg C ha^{-1}) stands. Compared to the WD site, total RN stock in the PD site was higher for ash (159 kg N ha^{-1}), alder (110 kg N ha^{-1}), and oak (66 kg N ha^{-1}) stands (Figure 5).

Both in the WD and PD sites, FR contributed mostly to total root N stocks, followed by medium roots and CR. However, FR contribution for ash, oak, and alder stands was lower (44%, 50%, and 40%, respectively) in the WD site than in the PD site (74%, 65%, and 50%, respectively) (Figure 5). In the contrary, medium root contribution for ash, oak, and alder stands was higher (37%, 27%, and 39%, respectively) in the WD site than in the PD site (19%, 21%, and 37%, respectively). Similar to the medium root contribution, CR contribution for ash, oak, and alder stands were also higher (19%, 24%, and 21%, respectively) in the WD site than in the PD site (7%, 14%, and 13%, respectively) (Figure 5).

Table 6.
ANOVA of Root N Stocks

	Source	SS	df	MS	F	Eta squared
Fine root	Tree species (T)	67.635	2	33.817	29.688***	0.586
	Sites (S)	60.172	1	60.172	52.824***	0.557
	T × S	80.680	2	40.340	35.414***	0.628
	Error	47.842	42	1.139		
Medium roots	Tree species (T)	4.607	2	2.303	11.937***	0.362
	Sites (S)	3.540	1	3.540	18.342***	0.304
	T × S	1.725	2	8.628	4.471*	0.176
	Error	8.105	42	1.929		
Coarse roots	Tree species (T)	5.180	2	2.590	23.820***	0.531
	Sites (S)	1.359	1	1.359	12.499**	0.229
	T × S	.166	2	.833	0.767ns	0.035
	Error	4.566	42	.108		
Total root biomass	Tree species (T)	74.831	2	37.415	16.954***	0.447
	Sites (S)	79.477	1	79.477	36.014***	0.462
	T × S	69.496	2	34.748	15.746***	0.429
	Error	92.688	42	2.206		

Asterisks refers the level of significance: *$p < .05$; **$p < .01$; ***$p < .001$. ns = not significant

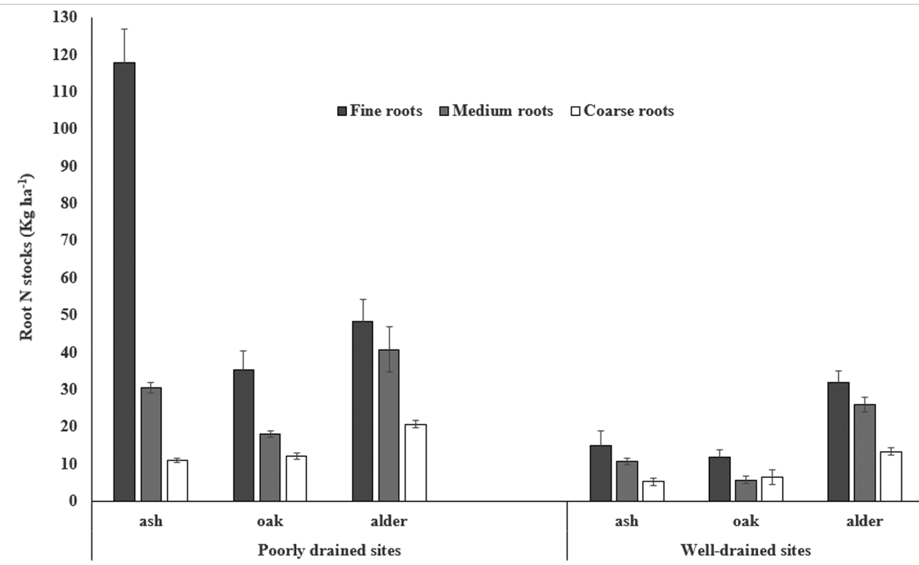

Figure 5.
Fine, Medium, and Coarse Root Nitrogen Stocks of Ash, Oak, and Alder Stands Collected from the Poorly Drained and Well-Drained Sites.

Discussion

This study has shown that the WD and PD conditions on the soil surface significantly vary TRB, RC, and RN stocks of ash, alder, and oak stands in Karacabey floodplain forests. The results of the study are unique and pioneer for Turkey's flooded forests, and to our knowledge, there has been no study carried out previously on this subject in Turkey. The results have indicated that under the PD soil conditions, ash and oak trees behave in a similar way with having higher TRB and thus RC stocks compared to the values in the WD site. In the contrary, alder trees act different way with lower TRB and RC stocks in the PD site than in the WD site. However, as for the RN stocks all three tree species show similar trends with higher RN stock in the PD site than in the WD site. Among the three root diameter classes studied, the differences in the FRB were clearly seen between the WD and PD sites which mostly explained the difference in the TRB and RC and RN stocks between the two sites.

Similar responses of TRB under high water conditions on soil surface have been reported from different forested wetlands (mangrove, riparian, and floodplain forests) using different tree species. For example, it is reported by a number of authors that mangrove forests can allocate more biomass to belowground since tree species in mangrove forests suffer from nutrient limitation, low soil redox conditions, and permanent flooding (Castañeda-Moya et al., 2013; Hongwiset et al., 2021; Yoshikai et al., 2021). The latter, permanent flooding was mostly seen in our study sites, especially after the winter season. Under the PD sites, ash and oak trees had higher TRB, whereas alder trees did not seem to increase TRB or to allocate more biomass belowground. This could be explained as the adaptation ability to the water conditions and root traits of tree species. In literature, it has generally been stated that soil inundation reduces root growth of most woody plants by inhibiting root formation and branching, growth of existing roots and mycorrhizae (Thomas, 2021), and by inducing root decay (Saint-Laurent et al., 2019). But, flood-tolerant angiosperms and gymnosperms can adapt to very wet soils by changing the root trails (Zhang et al., 2021). Among those flood-tolerant species, in general, alder root systems can penetrate deeply into wet and anaerobic soils (Tulik et al., 2020). Oak species can produce cordate root systems, which contain a higher percentage of FR in deeper soil horizons (Ma et al., 2014). However, ash tree shows lower tolerance to wet soils and it is known that ash trees have shallow-rooted to avoid permanently water-saturated soil conditions (Beyer et al., 2013). This may explain why TRB and also FRB of ash trees in our study was highest compared to oak and alder trees, which shared similar site conditions. On the other hand, with the soil core (6.4 cm diameter and 34 cm height) method, we only estimated the root biomass of 0–30 cm soil depth. Thus, the root mass of deeper soil depth should be taken into an account for the future studies in order to better explain those differences in TRB among the tree species and between the different soil microsites in flood plain forests.

In forest ecosystems, FR can decay faster than aboveground tree tissues (e.g., needles/leaves and branches) (Sariyildiz, 2015; Sariyildiz et al., 2005). This makes FR a highly dynamic and significant component of forest C and N and accumulation in the soil. That is why more studies can be found on the FRB from other forest trees both in terrestrial and floodplain forests. Previous studies on tree root biomass showed that carbon concentration in FR varied significantly among different tree species and carbon concentration positively correlated to root diameters (Akburak et al., 2013; Fu et al., 2015). We also found that C concentration increased with increasing root diameter. However, RN concentration decreased with increasing root diameter. Similar findings are also reported in the previous studies which are in agreement that in contrast to RC concentration, root N concentration is negatively correlated with root diameters (Yanai et al., 2017).

The results of TRB and FRB from the current study are comparable with some findings, for example, mean TRB in mangrove forest reported by Cormier et al. (2015) ranged from 4.5 to 26.4 Mg ha^{-1}, by Robertson and Alongi (2016) from 3.3 to 4.4 Mg ha^{-1} and by Adam et al. (2014) from 9.5 to 30.4 Mg ha^{-1}, which were substantially higher than the TRB estimated in our study from both WD and PD sites for alder (from 1.89 to 2.23 Mg ha^{-1}), oak (from 1.30 to 1.95 Mg ha^{-1}) and ash trees (from 1.57 to 3.87 Mg ha^{-1}). Cormier et al. (2015) found that mean FRB (<2 mm) ranged from 1.5 Mg ha^{-1} to 5.7 Mg ha^{-1}, while Adam et al. (2014) reported that FRB (<2 mm) was in the range of 1.7 Mg ha^{-1} to 3.2 Mg ha^{-1}. Mean total FRB in boreal, tropical evergreen, and tropical deciduous forests (6.0 Mg ha^{-1}, 5.7 Mg ha^{-1}, and 5.7 Mg ha^{-1}, respectively) claimed by Jackson et al. (1997) were also higher than our current study (1.49 Mg ha^{-1} for ash, 0.59 Mg ha^{-1} for oak and 0.61 Mg ha^{-1} for alder).

A few studies reported the FRB of oak and even less for alder and ash tree stands. For example, the mean FRB of 20–131-year-old sessile oak stands reported by Leuschner and Hertel (2003) was 3.16 Mg ha^{-1} and varied from 1.63 to 4.15 Mg ha^{-1}. Mean FRB (<2 mm) and medium root biomass (2–5mm) of 67-year-old pedunculate oak was 2.0 Mg ha^{-1} and 1.8 Mg ha^{-1}, respectively (Curiel Yuste et al., 2005). Our data showed much lower FRB (0.826 Mg ha^{-1} in the PD site, and 0.350 Mg ha^{-1} in the WD site) and SRB (0.65 Mg ha^{-1} in the PD site, and 0.37 Mg ha^{-1} in the WD site) for 99-year-old oak (*Q. cerris*) stands. Jagodzinski et al. (2016) showed that the mean FRB of alder (*A. glutinosa*) ranged from 0.71 Mg ha^{-1} (4-year-old stands) to 1.27 Mg ha^{-1} (76-year-old stands). Our data had lower FRB (0.579 Mg ha^{-1} in the PD site, and 0.634 Mg ha^{-1} in the WD site) for 48-year-old alder (*A. glutinosa*) stands. Kubisch et al. (2015) reported for six tree species aged between 90- and 150-year-old including European ash (*F. excelsior* L.) that FRB was 2.70 Mg ha^{-1} for European ash, 3.01 Mg ha^{-1} for European beech, 2.18 Mg ha^{-1} for small-leaved lime, 2.47 Mg ha^{-1} for European hornbeam, 1.94 Mg ha^{-1} for Sycamore maple, and 1.42 Mg ha^{-1} for Norway maple. We found similar results of FRB for 75-year-old ash (*F. angustifolia* Vahl.) stands under the PD site (2.35 Mg ha^{-1}) but lower results (0.644 Mg ha^{-1}) under the WD site. It seems that TRB and RB of different root diameter classes vary according to tree species, age, locations, soil conditions, and type of floodplain forests. On the other hand, most of the methods of determining root biomass in forested wetlands carry uncertainties (Addo-Danso et al., 2016; From et al., 2021). Adame et al. (2017) stated that using small diameter soil cores resulted in estimating a lower amount of root biomass in mangrove forests.

The variation in total root biomass as well as RC and RN concentrations of ash, alder, and oak tree stands between the WD and PD sites resulted in significant variation in the belowground RC and RN stocks between the two sites in floodplain forests. However, RC stocks of TRB for ash, oak, and alder tree stands were lower (1.43, 0.89, and 0.94 Mg ha^{-1}, respectively) than the results reported from other flood plain forests. For example, Giese et al. (2003) showed that carbon pools for only the root components (<5 mm) of four riparian forests in the South Carolina Coastal Plain ranged from 1.85 Mg ha^{-1} to 4.36 Mg ha^{-1}. Rieger et al. (2013) found that only carbon stock of FRB of floodplain forests in the Donau-Auen National Park varied from 2.82 Mg ha^{-1} to 3.97 Mg ha^{-1}. Root N stocks in our study were also lower than the results reported from other flood plain forests. For example, in our study, N stocks of FR for ash, oak, and alder tree stands were 0.066, 0.024, and 0.040 Mg ha^{-1}, respectively. Vieira et al. (2011) reported for Atlantic Forest in Brazil that fine root N biomass varied from 0.07 to 0.21 Mg ha^{-1}, which was higher than the results from our study.

The contrasting responses of TRB and FRB to high water conditions have also been reported in the literature. For example, in contrast to our findings for alder stands, TRB of alder (*A. glutinosa*) was more than two-fold in the rewetted site compared to the drained site (Schwieger et al., 2020). In their study, very FR <1 mm were mostly responsible for the difference, which accounted for 51% of the RB. Schwieger et al. (2020) stated that the lower oxygen concentrations under high soil water conditions might have reduced nodule activity and forced the tree to rely more on nutrient acquisition through roots which thus resulted in higher root biomass in the rewetted sites. The larger TRB under the rewetting site is needed to oxidize the rhizosphere by releasing oxygen from the root tips to facilitate nutrient uptake in anoxic soil conditions. In our study, this could be the case for ash and oak trees but not alder trees which had lower TRB but higher root N stocks under the PD sites compared to the WD site. The different results in our study among tree species could be attributed to site differences in nutrient limitation, soil redox conditions as well as differences in root traits, root decay of tree species, and sediment deposition, which exclusively takes place in floodplain forests and is shown to reduce FR growth (Simone et al., 2011) but our study was not intended to investigate all these mechanisms.

Conclusion and Recommendations

Total root biomass and RC and RN stocks of alder, ash, and oak trees in Karacabey floodplain forests vary significantly between the PD and WD site conditions. However, the magnitude of these variations differs among the three tree species and between the root diameter classes (FR, medium roots, and CR). This study is unique in documenting the first-time results on root biomass and RC and RN from Turkish floodplain forests. Under PD conditions, ash and oak trees give similar trends with increasing total root biomass and RC stocks, especially in FRB, whereas alder trees show opposite trends with lower total root biomass and RC stocks. However, under PD site conditions, all three tree species tend to increase RN stocks compared to the WD site conditions. The results of total root biomass and RC and RN stocks seem to be very low compared to the other floodplain forests. The large difference between root biomass and RC and RN stocks estimated in other floodplain forests and those estimated here may be attributed to abiotic and climatic differences, management, forest structures such as a number of tree stems, or methodological differences in estimating root biomass and C and N stocks. We conclude that the soil core method which is mostly used method for the root biomass studies may underestimate belowground total root biomass and also RC and RN stocks in Karacabey floodplain systems. Thus, other root biomass estimation methods (soil excavation, monolith, etc.) should be tested to get better results in future studies. More extensive studies are also in need to investigate the effects of stand types, stand ages, soil types, and microclimate conditions on total root biomass and also RC and RN stocks in relation to various water conditions.

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