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Seasonal variation of microbial activity in soil and forest floor under three different fir plantations

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Abstract

Microbial activity is one of the important processes for biochemical cycles in soil and forest floor of ecosystems. Because, some of the carbon dioxide and nutrients needed by plants are released during the microbial activity. In this study, the relationships between environmental factors (moisture, temperature, pH, electric conductivity, C, N, Na, Ca, Mg, K, P) and seasonal variations of microbial respiration, microbial biomass-C and metabolic quotient (qCO2) in the forest floor and soil (0-5cm) under three adjacent fir plantation plots (Abies nordmanniana ssp. bornmuelleriana Mattf. (Ab), Abies cilicica Carr. (Ac) and Abies nordmanniana ssp. nordmanniana Mattf (An)) are investigated in Atatürk Arboretum, located in Istanbul-Turkey. A bimonthly sampling (from May-2012 to March-2013) was carried out by collecting 54 samples for each soil and forest floor samples within each species. According to the results, soil microbial respiration (SMR) has a significantly lower value in A_b plot. Although SMR and soil microbial biomass-C (SMBC) were correlated with moisture and temperature in A_n plot, they were correlated with nutrients in the other plots. In general, an increase in soil respiration rates was observed in autumn and early spring. Forest floor microbial respiration (FFMR), microbial biomass-C (FFMBC) and metabolic quotent (qCO_2) did not differ among the plots. The measured FFMR, FFMBC and qCO_2 parameters were lower in autumn than spring. Forest floor microbial parameters were thought to be drived by the variation of nutrients quantities. As a result, the microbial processes in both soil and forest floor were changed with the effect of different factors, although there was no clear difference among the plots.

Keywords: Microbial respiration, Microbial biomass-C, qCO_2, Abies

Introduction

Microorganism activities are one of the most important ecosystem components evaluated as an indicator of soil quality protection and sustainability (Kara and Bolat, 2008; Bolat *et al.*, 2015; Oyedele *et al.*, 2015). Microbial biomass and microbial respiration are considered as an index to evaluate soil microbial activity and health (Schoenholtz *et al.*, 2000; Mariani *et al.*, 2006).

Soil microbial biomass plays an essential role in soil fertility and nutrient retention in terrestrial ecosystems (Allen and Schlesinger, 2004) and serves as a resource of nutrients available for plant development. For instance, soil microbial biomass variations reflect immobilization levels–mineralization of nutrients (carbon and nitrogen) (Yang *et al.*, 2010). Similarly, Oktay and Tecimen (2016) indicated that nitrogen mineralization in summer was close to zero and this fact could happen due to microbial immobilization. Microbial biomass is a viable component of soil organic matter, accounting for 1-5% of the total organic matter content (Jiang *et al.*, 2009) and faster response to alterations in soil than soil organic matter (SOM) (Brookes *et al.*, 2008; Araujo *et al.*, 2010; Haripal and

Sahoo, 2014). The chemical and physical properties of the soil can both directly and indirectly affect the distribution and structure of the decomposer community. Many studies have investigated the relationships among microbial community structure, activity and environmental factors such as moisture, temperature, pH, nitrogen, carbon and nutrients (Na, Ca, P, Mg, S, etc.) (Diaz-Ravina *et al.*, 1993; Priess and Fölster, 2001; Nsabimana *et al.*, 2004; Pietri and Brookes, 2008; Pei *et al.*, 2016; Soong *et al.*, 2018; Wang *et al.*, 2018). However, the precise and detailed mechanism of how the microbial community structure or activities respond to changes in environmental parameters is still uncertain (Singh, 2018).

Vegetation can directly influence the microbial activity and microbial biomass through the impact on microclimate and the amount and quality of the forest floor. Relatedly, Prescott and Grayston (2013) stated that vegetation characteristics affect the microbial activity and microbial community structure.

Due to the release of carbon dioxide and nutrients during the process (Glassman *et al.*, 2018), litter decomposition is an important process for the nutrient cycle in soils of forest ecosystems. Litter decomposition rate is affected by abiotic (litter chemistry, nutrient presence, etc.) and biotic (soil microorganisms, fauna, etc.) factors (Wang *et al.*, 2018). For example, low nutrient concentration in the forest floor can reduce microbial respiration and biomass (Priess and Fölster, 2001). In addition, Prescott and Grayston (2013) emphasized that examining the relationships between cations in the forest floor and the microbial community can be instructive in understanding the mechanisms underlying different nutrient cycles and microbial community structures under different tree species.

The Abies family (Pinaceae) is represented by two species and six subspecies in Turkey (Çakır, 2018). *Abies nordmanniana* ssp. *bornmuelleriana* Mattf., *Abies nordmanniana* ssp *nordmanniana* Mattf. and *Abies cilicica* Carr. are the most common abies species in Turkey. These species constitute to 670390 ha of entire forest area in Turkey (OGM, 2013) and are found in different regions such as Marmara, Mediterranean and Black Sea. In the sense of this study, it is crucial to state that these tree species were planted in Atatürk Arboretum in 1960. It is determined that the stands have the same site characteristics such as soil type, climate etc. (Çakır, 2018).

The aim of the study is to investigate the seasonal changes of microbial parameters (microbial respiration and microbial biomass carbon) in forest floor and soil under three fir species in the same site and their relationship with various environmental factors (moisture, temperature, pH, electric conductivity, C, N, Na, Ca, Mg, K, P).

Material and Methods

Research Area

The study area, Atatürk Arboretum, is located in Belgrad Forest in Istanbul, Turkey (41°09′48″–41°10′55″ N and 28°57′27″–28°59′2 7″ E, 140 m asl.). According to the long-term data from the Bahçeköy Meteorology Station, the average annual temperature and precipitation is 13.0 °C and 1121 mm, respectively. Belgrad Forest has a maritime climate with moderate water deficiency in summers. The soil in the research area is Luvisol (WRB) and soil texture is loamy. The vegetative period lasts for 7.5 months (230 days) on average (Çakır, 2018).

Field data

Sampling was carried out in three adjacent fir plantation plots (*Abies nordmanniana* ssp. *bornmuelleriana* Mattf., *Abies cilicica* Carr. and *Abies nordmanniana* ssp *nordmanniana* Mattf).

Sampling was performed at the central 40 × 40 m plot within each plot to minimize the negative edge effects. The sample plots had homogeneity of abiotic environmental conditions (the aspect, slope, elevation and soil type). Sampling was carried out by collecting both 54 samples in soil and forest floor within each species (3 species × 3 cores × 6 dates = 54 cores) on each sampling date (a bimonthly from May-2012 to March-2013). Soil samples were taken from the upper 5 cm of soil layer with steel soil cores with a 100 cm^3 volume. The forest floor organic matter was collected from 0.25 m^2 area. Three replicated samples (soil and forest floor) were taken systematically and composited on each plot.

Chemical Measurements

Soil samples were oven-dried at 105 ˚C and entire roots and materials larger than 2 mm were removed by use of 2 mm sieve. Soil acidity (pH) and electrical conductivity (EC) were measured from 1:2.5 and 1:5 ratios of soil to deionized water soil slurry, respectively. Exchangeable cations (K, Ca, Mg, Na) in 10 g soil samples were extracted with ammonium acetate solution (1 N, pH = 7). Exchangeable P in 2 g samples were extracted with sodium bicarbonate solution (0.5 M, pH = 8.5). The concentrations of the individual cations were determined by ICP/OES (Perkin Elmer Optima DV7000) (Akburak *et al.*, 2018).

The dry mass of forest floor samples was determined at 65 °C for 48 h. Samples were digested with concentrated HNO_3 (% 65) and H_2O_2 (% 37) in a microwave oven (Berghoff Speedwave). The total concentration of elements (P, K, Ca, Mg, Na) were measured by ICP/OES (Perkin Elmer Optima DV7000). The carbon (C) and nitrogen (N) contents of soil and forest floor were determined with dry combustion method, using a LECO Truspec CN-2000 analyzer (Çakır and Akburak, 2017).

Microbial parameters measurement

To measure microbial respiration (MR), soil samples (20 g oven-dry soil equivalent) and forest floor samples (5 g oven-dry mass equivalent) were incubated for 7 days at 25 °C in 500 ml vessels and 10 ml of sodium hydroxide (1 M) was placed in the media to absorb the respired CO_2-C. The released CO_2–C was determined by adding $BaCl_2$ and later titrating with 1 M hydrochloric acid in the end of every 7 days (Alef and Nannipieri, 1995). Microbial biomass-C (MBC) was determined by the substrate-induced respiration (SIR) method. SIR was acquired by adding 60 mg glucose to soil samples (20 g oven-dry soil equivalent) . The released CO_2 was trapped in 0.05 M sodium hydroxide for 4-h incubation at 25 °C and measured by titration (Alef and Nannipieri, 1995). The metabolic quotient, qCO_2, was calculated by dividing microbial respiration with microbial biomass carbon (qCO_2 = MR / MBC) (Anderson and Domsch, 1986).

Statistical analysis

All data were tested for normal distribution using the Kolmogorov-Smirnov test. The data that did not accord with normal distribution were transformed with Box-Cox transformation. The significance of differences among tree species was tested by one-way analysis of variance (ANOVA) followed by Duncan test ($p < 0.05$). In addition, correlations between microbial parameters and environmental variables were determined using the simple Pearson correlation coefficient. The statistical analyzes were performed in SPSS 21.0 package program.

Results

Soil

Soil N, Mg and K ratio were significantly lower in A_b plot compared to other fir plots. However, P was significantly higher in A_b plot. Soil C and C/N ratios in A_c plot were significantly higher ($p < 0.05$) than the other two plots. Soil pH was significantly higher ($p < 0.05$) in A_n plot.

The respiration rate ranged from 0.18 - 1.04 µg CO_2-C g^- h^- in the A_b, 0.36 - 0.72 µg CO_2-C g^- h^- in A_c plot, and 0.47 - 1.01 µg CO_2-C g^- h^- in A_n plot (Figure 1). SMR in the A_n plot was significantly and 1.46 times higher in the A_b plot, 1.33 times higher in the A_c plot ($p < 0.05$). Although SMBC and $SqCO_2$ were at the lowest level in the A_b plot, there were not statistical differences among the plots (Table 1).

Table 1: Chemical, physical and microbial properties of soil in the study plot

	A. bornmuelleriana	***A. cilicica***	***A. nordmanniana***
	Mean ± Std.Er.	**Mean ± Std. Er**	**Mean ± Std. Er**
SMR (µg CO_2-C g^- h^-)	0.49 ± 0.07 a	0.54 ± 0.04 b	0.72 ± 0.06 b
SMBC (mg C g^- h^-)	0.27 ± 0.03 a	0.32 ± 0.04 a	0.31 ± 0.03 a
$SqCO_2$ (µg CO_2-C mg C h^-)	1.84 ± 0.22 a	1.95 ± 0.24 a	2.40 ± 0.22 a
SN* (%)	0.17 ± 0.01 b	0.19 ± 0.01 a	0.18 ± 0.01 ab
SC* (%)	5.28 ± 0.55 b	6.91 ± 0.44 a	4.65 ± 0.38 b
SCN	29.57 ± 1.55 b	35.37 ± 1.15 a	25.33 ± 1.31 c
SM* (%)	28.75 ± 2.81 a	34.96 ± 3.07 a	31.59 ± 3.10 a
ST* (^{0}C)	16.08 ± 1.24 a	16.69 ± 1.29 a	16.02 ± 1.26 a
pH*	5.15 ± 0.08 a	5.08 ± 0.08 a	5.58 ± 0.03 b
EC* (µS cm^-)	178.73 ± 19.58 a	185.52 ± 13.90 a	198.41 ± 11.58 a
Ca (mg kg^-)	1177.21 ± 66.45 a	1337.27 ± 52.83 a	1357.92 ± 70.06 a
Na (mg kg^-)	17.40 ± 1.50 a	24.41 ± 2.10 b	15.36 ± 1.40 a
K (mg kg^-)	88.93 ± 7.90 b	124.63 ± 9.24 a	111.47 ± 8.16 a
Mg (mg kg^-)	118.95 ± 7.52 b	237.32 ± 30.07 a	198.13 ± 22.61 a
P (mg kg^-)	47.62 ± 5.49 a	42.16 ± 3.10 a	31.43 ± 1.601 b

SMR : Soil microbial respiration, SMBC: Soil microbial biomass-Carbon, $SqCO_2$: Soil metabolic quotient, SN: Soil nitrogen, SC: Soil carbon, SCN: Carbon/nitrogen, SM: Soil moisture, ST: Soil temperature, pH: Soil acidity, EC: Soil electric conductivity, Ca: Calcium, Na: Sodium, K: Potassium, Mg: Magnesium, P: Phosphorous.
Means with different letters in the same line are different ($P < 0.05$).
"*" From Çakır (2018)

While SMR showed temporarily a parallel change among plots, an increase were observed for the respiration rates in autumn and early spring in all plots (Figure 1a). SMBC temporarily decreased from spring to autumn and reached the highest level in March in all plots (Figure 1b). $SqCO_2$ showed a parallel change among all plots and reached its highest level in September (Figure 1c). Additionally, a high level of change for both SMR and $SqCO_2$ was observed in A_n plots (Figure 1a, c).

A positive relationship was found between SMR and SMBC, SqCO2, N, P, EC, SM (soil moisture) in the A_b plots, with $SqCO_2$ ST (soil temperature) in the A_n plots. Whereas, there was only a significant positive relationship with Na and K in the A_c plots ($p < 0.05$). Additionally, a negative relationship was determined with SM in the A_n plot and with SCN in the A_c plot (Table 2).

In terms of SMBC, there was a positive relationship with EC and P in A_b plots, while the only significant one was between with K in A_c plots and with SM in A_n plots. However, while there was no negative relationship in A_b plots, SMBC showed negative relation with $SqCO_2$ and C in A_c plot and with SqCO2, SM, EC and Ca in A_n plot (Table 2).

In terms of SqCO2, while there was no significant relationship in Ac plot, linear correlations were determined with N and SM (Ab plots) and ST and EC (An plot). In addition, An plot had a negative relationship with SqCO2 and SM (Table 2).

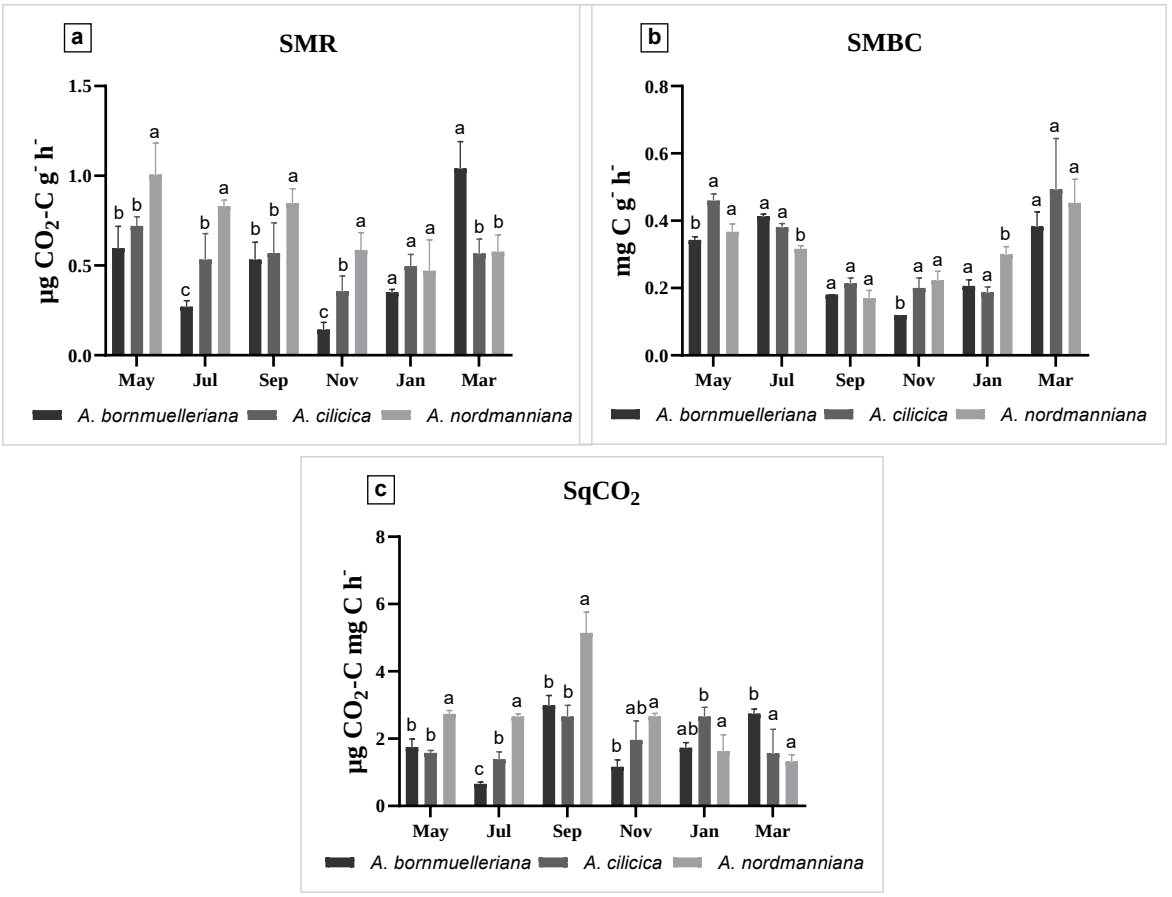

Figure 1: Seasonal variations of soil microbial parameter. (a: SMR; Soil microbial respiration, b: SMBC; Soil Microbial Biomass-C, c: qCO2; metabolic quotient).

Forest floor

In terms of FFMR, FFMBC, and $FFqCO_2$, no significant differences were encountered among the plots. The mass of the forest floor (FF) in A_n was significantly higher than the A_b and A_c ($p < 0.05$) although in A_n, the FFC was significantly lower than the other plots (Table 3). K concentrations in A_b plot were significantly different from A_c and A_n plots.

FFMR in all plots showed a decline in the autumn period (Figure 2a). FFMBC temporarily decreased from spring to autumn (Figure 2b). In addition, $FFqCO_2$ showed a parallel change among all plots, reaching its highest level in November (Figure 2c).

According to relationships between the variables, the amount of FFMR in the A_b plot showed a linear correlation with FFMBC, $FFqCO_2$ and Ca, and a negative correlation with Na. While there was a positive relationship with FFMBC and FM, a negative correlation was observed with N, C, P in the An plot. While it showed a positive relationship with FFMBC, FFM and a negative correlation with N, C, P in the A_n plot was observed. In the A_c plot, FFMR had a positive correlation with FFMBC and FFqCO2, and a negative relationship with P (Table 4).

In terms of FFMBC, there was no linear correlations in the A_b and A_c plots, while there was a linear correlation with K in the A_n. However, there were negative correlations with Na in A_b plot, with P in A_c plot and with $FFqCO_2$, Ca in A_n plots (Table 4).

In respect of $FFqCO_2$, there was a positive correlation with Ca and a negative correlation with K in the A_b plot. While it showed a negative correlation with FFN and Mg in the A_c plot and CN, C and K in the A_n plot. Also, there was a linear correlation between $FFqCO_2$ and FF in the A_n plot (Table 4).

Table 2: Pearson correlation coefficients among the soil variables in the study

A. bornmuelleriana	**SMR**	**SMBC**	**SqCO2**	**SN**	**SC**	**SCN**	**SM**	**ST**	**pH**	**EC**	**Ca**	**Na**	**K**	**Mg**
SMBC	***0.48***													
SqCO2	***0.73***	-0.22												
SN	***0.59***	0.29	***0.48***											
SC	0.40	0.21	0.33	***0.87***										
SCN	0.24	0.15	0.17	***0.68***	***0.94***									
SM	***0.56***	-0.14	***0.67***	0.30	0.31	0.23								
ST	-0.21	0.31	-0.39	0.04	0.03	0.08	***-0.72***							
pH	-0.06	-0.13	0.05	-0.11	-0.08	-0.02	0.12	-0.18						
EC	***0.49***	***0.47***	0.24	***0.68***	***0.71***	***0.67***	0.17	0.16	0.28					
Ca	-0.12	0.07	-0.15	0.15	***0.45***	***0.62***	-0.04	0.20	0.07	***0.47***				
Na	0.24	0.44	-0.02	***0.50***	***0.48***	0.42	-0.10	0.43	-0.08	***0.72***	***0.44***			
K	0.36	0.30	0.21	***0.70***	***0.51***	0.35	-0.03	0.12	-0.06	***0.63***	0.19	***0.74***		
Mg	0.18	0.27	0.07	***0.47***	***0.57***	***0.63***	-0.14	0.33	0.01	***0.72***	***0.79***	***0.65***	***0.60***	
P	***0.58***	***0.49***	0.24	***0.63***	***0.67***	***0.61***	0.40	-0.07	-0.33	***0.52***	0.29	0.42	0.30	0.36
A. cilicica	**SMR**	**SMBC**	**SqCO2**	**SN**	**SC**	**SCN**	**SM**	**ST**	**pH**	**EC**	**Ca**	**Na**	**K**	**Mg**
SMBC	0.39													
SqCO2	0.22	***-0.81***												
SN	-0.15	-0.37	0.33											
SC	-0.34	-0.42	0.25	***0.93***										
SCN	***-0.46***	-0.40	0.14	***0.77***	***0.95***									
SM	0.03	-0.11	0.14	-0.42	***-0.46***	***-0.46***								
ST	0.21	0.29	-0.19	0.16	0.11	0.07	***-0.82***							
pH	0.12	0.40	-0.32	0.34	0.26	0.18	0.03	0.04						
EC	-0.22	-0.29	0.19	***0.72***	***0.65***	***0.51***	-0.30	0.16	0.31					
Ca	-0.18	-0.15	0.08	0.27	0.30	0.30	-0.03	-0.10	0.10	0.21				
Na	***0.47***	0.26	0.01	0.25	0.16	0.12	***-0.46***	***0.49***	-0.01	0.15	-0.05			
K	***0.53***	***0.44***	-0.11	0.24	0.06	-0.04	-0.19	0.26	0.35	-0.05	-0.27	***0.67***		
Mg	0.32	0.12	0.07	0.40	0.37	0.34	-0.29	0.15	0.23	-0.03	-0.06	***0.68***	***0.76***	
P	-0.15	-0.16	0.11	0.40	0.31	0.20	-0.16	-0.03	-0.06	0.39	***0.53***	-0.01	-0.13	-0.20
A. nordmanniana	**SMR**	**SMBC**	**SqCO2**	**SN**	**SC**	**SCN**	**SM**	**ST**	**pH**	**EC**	**Ca**	**Na**	**K**	**Mg**
SMBC	-0.01													
SqCO2	***0.64***	***-0.76***												
SN	0.16	0.02	0.08											
SC	0.22	-0.32	0.34	***0.66***										
SCN	0.22	-0.38	0.38	0.40	***0.94***									
SM	***-0.50***	***0.44***	***-0.65***	0.00	-0.38	***-0.50***								
ST	***0.72***	-0.29	***0.69***	0.03	0.36	***0.45***	***-0.90***							
pH	-0.13	0.11	-0.20	0.07	0.15	0.14	0.23	-0.21						
EC	0.04	***-0.60***	***0.44***	0.14	0.35	0.32	-0.26	0.24	***0.44***					
Ca	-0.27	***-0.57***	0.22	-0.02	0.36	***0.44***	-0.15	0.04	0.08	***0.51***				
Na	0.24	-0.10	0.21	0.14	0.34	0.33	-0.07	0.24	***0.48***	***0.59***	0.23			
K	0.27	-0.30	0.37	0.26	***0.47***	0.41	-0.24	0.40	0.40	***0.73***	0.26	***0.73***		
Mg	0.25	-0.36	0.39	***0.52***	***0.65***	***0.53***	-0.09	0.25	***0.44***	***0.63***	0.40	***0.62***	***0.81***	
P	0.42	0.20	0.13	0.23	0.38	0.38	-0.08	0.23	0.02	-0.06	-0.24	0.22	0.17	0.10

SMR : Soil microbial respiration, SMBC: Soil microbial biomass-Carbon, $SqCO_2$: Soil metabolic quotient, SN: Soil nitrogen, SC: Soil carbon, SCN: Carbon/nitrogen, SM: Soil moisture, ST: Soil temperature, pH: Soil acidity, EC: Soil electric conductivity, Ca: Calcium, Na: Sodium, K: Potassium, Mg: Magnesium, P: Phosphorous. Significant differences ($P \leq 0.05$) are marked with bold and italic

Table 3: Chemical, physical and microbial properties of the forest floor in the study plot

	A. bornmuelleriana	***A. cilicica***	***A. nordmanniana***
	Mean ± Std. Er	**Mean ± Std. Er**	**Mean ± Std. Er**
FFMR (µg CO_2-C g^{-} h^{-})	4.18 ± 0.64 a	4.26 ± 0.62 a	4.70 ± 0.66 a
FFMBC (mg C g^{-} h^{-})	2.40 ± 0.28 a	1.96 ± 0.24 a	2.37 ± 0.31 a
FFqCO_2 (µg CO_2-C mg C h^{-})	1.99 ± 0.36 a	2.22 ± 0.27 a	2.39 ± 0.36 a
FFN* (%)	1.58 ± 0.02 a	1.19 ± 0.03 a	1.39 ± 0.03 a
FFC* (%)	42.96 ± 0.46 a	41.92 ± 0.88 a	37.09 ± 1.19 b
FFCN*	27.32 ± 0.43 ab	28.26 ± 0.83 a	26.45 ± 0.82 b
FF* (g m^{-2})	1027.02 ± 49.97 a	1005.04 ± 67.28 a	1452.86 ± 84.61 b
FFM (%)	44.93 ± 2.12 a	41.27 ± 2.98 a	46.97 ± 2.04 a
Ca (mg kg^{-})	14326.67 ± 369.46 a	14650.83 ± 567.98 a	14272.50 ± 498.38 a
Na (mg kg^{-})	54.08 ± 5.26 a	68.23 ± 8.30 a	52.57 ± 4.46 a
K (mg kg^{-})	922.75 ± 42.78 a	1081.77 ± 34.37 b	1072.517 ± 50.21 b
Mg (mg kg^{-})	1193.82 ± 46.69 a	1291.25 ± 30.11 a	1339.583 ± 42.89 a
P (mg kg^{-})	475.67 ± 8.08 a	462.04 ± 12.92 a	479.192 ± 9.46 a

FFMR : Forest floor microbial respiration, FFMBC: Forest floor microbial biomass-Carbon, FFqCO_2: Forest floor metabolic quotient, FFN: Forest floor nitrogen, FFC: Forest floor carbon, FFCN: Forest floor Carbon/nitrogen, FF: Forest floor amount, FFM: Forest floor moisture, Ca: Calcium, Na: Sodium, K: Potassium, Mg: Magnesium, P: Phosphorous. Means with different letters in the same line are different (P < 0.05).
"*" from Çakır (2018)

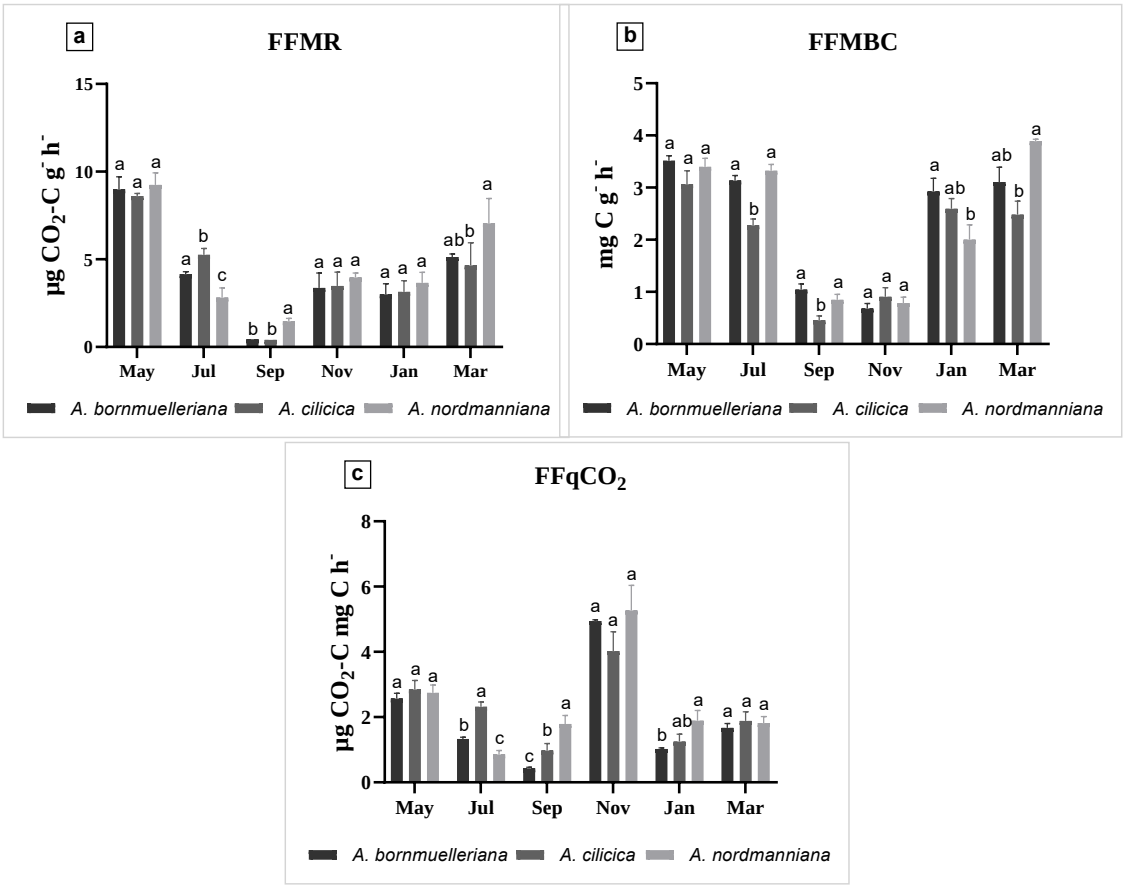

Figure 2: Seasonal variations of forest floor microbial parameters. (a: FFMR, Forest floor microbial respiration, b: FFMBC: Forest Floor Microbial Biomass-C, c: FFqCO2: Forest Floor metabolic quotient)

Table 4: Pearson correlation coefficients among the forest floor variables in the study

A. bornmuelleriana	**FFMR**	**FFMBC**	**FFqCO2**	**FFN**	**FFC**	**FFCN**	**FF**	**FFM**	**Ca**	**Na**	**K**	**Mg**
FFMBC	***0.72***											
FFqCO2	***0.63***	-0.02										
FFN	0.17	0.01	0.16									
FFC	0.11	0.14	0.06	0.32								
FFCN	-0.09	0.09	-0.12	***-0.75***	0.38							
FF	0.24	-0.08	0.26	0.34	0.03	-0.34						
FFM	0.23	0.39	-0.13	-0.14	-0.42	-0.15	0.04					
Ca	***0.50***	0.19	***0.48***	-0.19	0.06	0.22	0.22	-0.25				
Na	***-0.69***	***-0.63***	-0.30	-0.21	-0.16	0.11	-0.25	-0.15	-0.08			
K	-0.29	0.37	***-0.72***	-0.10	-0.05	0.07	-0.36	0.35	***-0.52***	0.11		
Mg	0.04	0.15	-0.18	0.31	-0.28	***-0.49***	0.11	0.32	-0.22	0.02	***0.49***	
P	0.38	0.15	0.19	-0.21	-0.05	0.20	0.07	-0.17	***0.63***	0.14	-0.35	-0.03
A. cilicica	**FFMR**	**FFMBC**	**FFqCO2**	**FFN**	**FFC**	**FFCN**	**FF**	**FFM**	**Ca**	**Na**	**K**	**Mg**
FFMBC	***0.76***											
FFqCO2	***0.46***	-0.08										
FFN	-0.23	0.09	***-0.45***									
FFC	0.07	0.04	-0.22	-0.18								
FFCN	0.15	-0.02	0.06	***-0.71***	***0.82***							
FF	-0.23	-0.31	0.29	0.04	***-0.72***	***-0.57***						
FFM	0.06	0.27	-0.14	***0.50***	-0.39	***-0.56***	0.25					
Ca	0.07	-0.06	-0.20	0.26	0.30	0.05	-0.12	-0.01				
Na	-0.20	-0.09	-0.37	0.28	0.19	-0.03	0.06	-0.02	***0.75***			
K	-0.19	-0.19	-0.37	0.05	0.25	0.16	-0.10	-0.21	***0.71***	***0.87***		
Mg	-0.22	0.07	***-0.46***	***0.66***	-0.03	-0.36	-0.26	0.34	0.13	0.09	-0.03	
P	***-0.50***	***-0.50***	-0.38	***0.48***	0.09	-0.19	-0.10	-0.03	***0.70***	***0.54***	***0.55***	***0.48***
A. nordmanniana	**FFMR**	**FFMBC**	**FFqCO2**	**FFN**	**FFC**	**FFCN**	**FF**	**FFM**	**Ca**	**Na**	**K**	**Mg**
FFMBC	***0.62***											
FFqCO2	0.36	***-0.50***										
FFN	***-0.47***	-0.27	-0.24									
FFC	***-0.50***	0.06	***-0.60***	***0.45***								
FFCN	-0.26	0.26	***-0.53***	-0.14	***0.81***							
FF	0.24	-0.25	***0.59***	***-0.57***	***-0.61***	-0.37						
FFM	***0.46***	0.11	0.35	-0.27	***-0.43***	-0.24	0.02					
Ca	-0.36	***-0.48***	0.26	0.00	0.18	0.25	0.29	-0.18				
Na	0.02	-0.15	0.15	0.23	0.12	-0.03	-0.18	***0.52***	0.02			
K	0.11	***0.43***	***-0.46***	0.14	-0.02	-0.17	-0.27	-0.31	***-0.81***	-0.41		
Mg	0.39	0.21	0.19	***-0.52***	-0.41	-0.17	0.27	-0.18	-0.42	***-0.53***	***0.43***	
P	***-0.56***	-0.26	-0.27	0.39	***0.47***	0.28	-0.04	***-0.59***	***0.66***	-0.07	-0.22	***-0.57***

FFMR : Forest floor microbial respiration, FFMBC: Forest floor microbial biomass-Carbon, $FFqCO_2$: Forest floor metabolic quotient, FFN: Forest floor nitrogen, FFC: Forest floor carbon, FFCN: Forest floor Carbon/nitrogen, FF: Forest floor amount, FFM: Forest floor moisture, Fe: Iron, Ca: Calcium, Na: Sodium, K: Potassium, Zn: Zinc, Cu: copper, Mg: Magnesium, Mn: Manganese, P: Phosphorous. Significant differences ($P \leq 0.05$) are marked with bold and italic

Discussion

Soil

Soil basal respiration provides an estimate of microbial activity (Bolat *et al.*, 2015). The SMR rate obtained in the study sites ranged from 0.18 to 1.04 µg CO_2-C g^{-} h^{-}. These results are similar to those obtained with other studies (Hofman *et al.*, 2004; Bolat, 2014; Bolat *et al.*, 2015). SMR in A_b plot was significantly lower than other species. This may be due to the low amount of N, SM and SMBC in this plot compared to other fir species in the study site. Previous studies indicated that change of microbial respiration have relation with factors such as mineralized N, moisture and MBC (Priess and Fölster, 2001; Nsabimana *et al.*, 2004).

Generally, a temporary increase in respiration rates was observed in fall and spring across all plots. As it was pointed out in Bolat *et al.* (2015), this increase might be a consequence of a promoting microbial

activity which was triggered by higher soil temperature and moisture in these seasons. In addition, there were significant differences among the related species in July and November. Baldrian (2017) pointed out that seasonal variation is the most important driving force of microbial change with the soil temperature. When the interactions between SMR and variables are examined, it was seen that ST has a strong effect on SMR in the A_n plot, while the presence of nutrients (N, Na, K and P) in the A_b and A_c plots were effective on SMR. As the results demonstrated in many studies, the microbial respiration is related to available nutrients (Cheng *et al.*, 2013; Li *et al.*, 2015; Spohn, 2015; Wang *et al.*, 2018) and microbial biomass (Mariani *et al.*, 2006; Bolat *et al.*, 2015; Qu *et al.*, 2018). Likewise, Spohn (2015) found that respiration have linear correlation with soil temperature. Wang *et al.* (2003) suggested that soil respiration under favorable temperature and moisture conditions was principally determined by substrate supply rather than by the pool size of MBC. As a result, it can be stated that different environmental factors have different effects on microbial process among plots.

The mean SMBC values were not showed significant differences among the plots. This may be due to the fact that soil properties (such as ST, SM and pH) that affect SMBC do not differ between the plots. However, in terms of seasonal variations, SMBC decreased from spring to autumn and reached its highest level in all plots in March. Similar to the results of this study, Qu *et al.* (2018) stated that MBC was showed an increase early in the growing season (May) and then gradually decrease (July). This seasonal change may have two possible causes. The first one is the seasonal change in soil moisture and temperature. Second, the reduction in soil microbial biomass may be the result of mineralization of nutrients as stated by Jia *et al.* (2005). Soil microbial biomass is strongly affected by multiple factors such as local abiotic conditions and plant traits (Pei *et al.*, 2016). Considering the relationship between SMBC and environmental variables, there is a positive relationship with EC and P in the A_b plot, while there is a positive relationship only with K in the A_c plot, with SM and a negative relationship with EC and Ca in the A_n plot. Previous studies showed that the microbial biomass is strongly dependent on soil properties such as exchangeable Ca, and pH (Wolters and Joergensen, 1991; Agnelli *et al.*, 2001). While the relationships between MBC and C, N were determined in the studies (Park *et al.*, 2002; Mariani *et al.*, 2006; Pei *et al.*, 2016), no significant relationships were detected in presented study. Similar to current study results,Tan *et al.* (2008), Pei *et al.* (2016), Docherty *et al.* (2015) and Cheng *et al.* (2013) stated that moisture and nutrients have significant relationships with SMBC. The results showed that although SMBC under different tree species did not differ, soil microbial biomass are drived by different factors.

The qCO_2 is a measure that varies according to the state of the microbial biomass, the availability of nutrients, and various abiotic factors (Wardle and Ghani, 1995; Gonçalves *et al.*, 2009). qCO_2 showed a parallel change between plots and reached its highest level in September. This situation can be explained as in this period, with moisture and temperature changes (low moisture and high temperature) as it was stated by Yuan and Yue (2012). In addition, $SqCO_2$ has generally changed at high levels in A_n plot. Increase of qCO_2 was interpreted as a microbial response to adverse environmental stresses that was observed when the soil conditions were unfavorable (Wardle and Ghani, 1995). $SqCO_2$ had a positive relationship with N and SM in the A_b plots, had a negative relationship with SMBC in the A_c plot and had a positive relationship with ST and EC, and had a negative relationship with SM in the A_n plot. These results show that moisture is the limiting factor in A_n plot and microbial biomass plays a role as the limiting factor in A_c plots.

Forest floor

In this study, FFMR ranged from 0.41 to 9.24 µg CO_2-C g^{-} h^{-}. These values are lower than the values found for fir forests by Bolat *et al.* (2015). Although the a mean FFMR values did not differ significantly among the species, forest floor properties (FFC, FFCN, FF and K) differed among plots. FFMR in all

plots was observed as it decreased in the autumn period and an increase afterwards. This can be explained by the change in the amounts of FMBC. In relation to this, when the relationships among the variables were evaluated, it showed a linear correlation between FFMR and FFMBC in all plots. In addition, FFMR had a positive correlation with Ca in the A_b plot, a positive relationship with FM and a negative relationship with N, C and P in the A_n plot. Also, it has shown the only negative relationship with P in the A_c plot. Wardle (1992) stated that microbial activity may also be limited by the availability of N or P. Contrary to the presented study results, Allen and Schlesinger (2004) found a linear correlation between FFMR and C, N, P. As a result, nutrient status may also affect the activity of the microflora.

Microbial biomass mediates the conversion of biogenic nutrients between inorganic and organic components (Wu *et al.*, 2000). FFMR values were similar and there was no difference between the plots in terms of average FFMBC amounts. It had decreased from spring to autumn in terms of the temporal change. This variation can be caused by changes in temperature and humidity. Similar to the study results, Butenschoen *et al.* (2011) found that the litter microbial biomass decreases with increasing temperature. In addition, it is possible to say that the mobilization and immobilization status of nutrients can be temporally effective. As a matter of fact, when the relationships between FFMBC and variables are evaluated, there was no positive relationship in the A_b and A_c plot while there was a positive relationship with K in the A_n plot. On the contrary, the results showed a negative relationship with Na in A_b plot, with P in A_c plot and with Ca in A_n plot. This observation shows that different nutrients may have a limiting effect on a variation of forest floor microbial biomass among the plots.

The mean values of $FFqCO_2$ were not showed a significant difference among the plots like the other microbial parameters and it reached the highest level in November. This can be explained by the mobilization process of nutrients. Because the $FFqCO_2$ showed a negative relationship with K in the A_b plot, with P in the A_c plot, and with Ca in the A_n plot. This result supports the view that the limiting factors mentioned above were caused by different nutrients.

Conclusion

In the presented study, SMBC, $SqCO_2$ values did not show a significant difference among the three different fir species, and SMR has the lowest value in *Abies nordmanniana* ssp. *bornmuelleriana* Mattf. plot. While SMR and SMBC were associated with moisture and temperature conditions in the *Abies nordmanniana* ssp *nordmanniana* Mattf plot, they had interactions with nutrients (N, Na, K and P) in other plots. Microbial parameters in forest floor did not differ between plots. Temporarily, a decrease in microbial parameters have been detected from spring to autumn in plots. Forest floor microbial parameters prominently changed under the influence of nutrients (Ca, N, C, P and K). As a result, in this short-term study, although there was no clear difference between the plots, the microbial processes in both soil and forest floor changed with the effect of different factors. These results will contribute to understanding the relationships between microbial processes and biochemical cycles in plantations. In future studies, considering the long-term measurements of these interrelations, including microbial community structure and enzyme activities, will also provide a clearer evaluation opportunity in plantations constituted different species.

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