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Temporal changes of soil respiration under different tree species

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Abstract Soil respiration rates were measured monthly (from April 2007 to March 2008) under four adjacent coniferous plantation sites [Oriental spruce (*Picea orientalis* L.), Austrian pine (*Pinus nigra* Arnold), Turkish fir (*Abies bornmulleriana* L.), and Scots pine (*Pinus sylvestris* L.)] and adjacent natural Sessile oak forest (*Quercus petraea* L.) in Belgrad Forest—Istanbul/Turkey. Also, soil moisture, soil temperature, and fine root biomass were determined to identify the underlying environmental variables among sites which are most likely causing differences in soil respiration. Mean annual soil moisture was determined to be between 6.3 % and 8.1 %, and mean annual temperature ranged from 13.0°C to 14.2°C under all species. Mean annual fine root biomass changed between 368.09 g/m^2 and 883.71 g/m^2 indicating significant differences among species. Except May 2007, monthly soil respiration rates show significantly difference among species. However, focusing on tree species, differences of mean annual respiration rates did not differ significantly. Mean annual soil respiration ranged from 0.56 to 1.09 gC/m^2/day. The highest rates of soil respiration reached on autumn months and the lowest rates were determined on summer season. Soil temperature, soil moisture, and fine root biomass explain mean annual soil respiration rates at the highest under Austrian pine (R^2=0.562) and the lowest (R^2=0.223) under Turkish fir.

Keywords Common garden experiment · CO_2 flux · Fine root · Soda lime method · Soil moisture · Soil temperature

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Introduction

Soil respiration is a major constituent of global carbon cycling. The flux of carbon from soils toward atmosphere as CO_2 form is estimated to have a magnitude of 68–100 Pg C/year. Soil respiration could significantly aggravate or abate atmospheric increases in CO_2, end up effects on climate change (Tang et al. 2006). Ecologists have measured CO_2 evolution from soils for more than a century. Controlling processes of soil carbon (C) cycling are of particular interest because, on a global basis, soils contain twice as much C as the atmosphere (Coleman et al. 2002).

In recent years, much attention has been paid on soil respiration because it is also recognized as a major soil carbon efflux and one of the key components of the carbon cycle in terrestrial ecosystems. It was reported that 40–90 % of the forest ecosystem respiration could be generated by soil respiration. On a global scale, soil respiration is about 10 times greater than that from fossil fuel combustion and deforestation (Raich et al. 2002), and thus even little fluctuation in soil respiration may greatly affect atmospheric carbon and heat balance (Veenendaal et al. 2004; Kane et al. 2005). Recently, because of its debated role in global warming process, soil respiration has become a main issue in global change ecology (Yi et al. 2007).

There is still limited understanding of the environmental factors controlling temporal and spatial variability of soil respiration despite its global importance, as well as considerable scientific commitments to studies in this field over the past decades (Tang et al. 2006).

Soil respiration mainly refers to the release of CO_2 from soils due to the production of CO_2 by roots and soil organisms whose kind, abundance, and production are directly relevant to land use and management. Furthermore, soil respiration is a complicated ecosystem process connecting with both biotic and abiotic factors (Zheng et al. 2005). Soil temperature and soil moisture are two of the most significant environmental factors directing variations in soil CO_2 efflux (Fang and Moncrieff 2001; Liu et al. 2002; Joffre et al. 2003; Zheng et al. 2005; Tang et al. 2006) .

Soil respiration is varied importantly among major biomes, indicating that the rate of soil respiration is affected by vegetation type. Vegetation may affect soil respiration by affecting soil microclimate and structure, the quantity and the quality of litter fall provided to the soil, and the rate of root respiration. Soil respiration rates can differ in adjacent comparisons of different plant communities. Such results point out that vegetation type is a significant indicator of soil respiration rate, and therefore changes in vegetation have the potential to change the responses of soils to environmental change (Raich and Tufekcioglu 2000).

One of the most significant constituents of the C return in forest ecosystems is CO_2 efflux from the soil surface (Tufekcioglu and Kucuk 2004). Forests are notably significant in the carbon cycle because they contain 80 % of the aboveground and 40 % of the belowground global carbon stocks, respectively. Carbon sequestration in forest ecosystems often results from a small difference between photosynthetic carbon fixation and ecosystem respiration, and soil respiration in temperate forests represents approximately 70 % of total ecosystem respiration (Vincent et al. 2006).

Limited numbers of studies have been conducted so far on the forest ecosystems in Turkey despite considerable information on soil respiration in different parts of the world (Tufekcioglu and Kucuk 2004).

The objectives of this study were to compare rates of soil respiration among four adjacent coniferous plantation sites [Oriental spruce (*Picea orientalis* L.), Austrian pine (*Pinus nigra* Arnold), Turkish fir (*Abies bornmulleriana* L.), and Scots pine (*Pinus sylvestris* L.)] and adjacent primary natural Sessile oak (*Quercus petraea* L.) forest and to identify the environmental factors which mostly cause changes in soil respiration among sites.

Materials and methods

Study site

Belgrad Forest is located in Istanbul province in the Marmara geographical region between 41°09′–41°12′N latitude and 28°54′–29°00′ E longitude in Turkey. According to the (long-term) data given by Bahcekoy Meteorology Station, the nearest meteorology station to the research area, mean annual precipitation is 1,074.4 mm, mean annual temperature is 12.8°C, mean maximum temperature is 17.8°C, and the mean minimum temperature is 9°C. The climate of Istanbul Belgrad Forest is maritime climate with medium water deficit in summers. According to the World Reference Base for Soil Resources (WRB), the soil group in the research area is Luvisol (WRB 2006). Soils are well drained and moderately deep. General texture type of soil in research area is loam. Altitude is 140 m, slope is 10–15 %, and it is in the south aspect.

We sampled four adjacent coniferous plantation areas [Oriental spruce (*Picea orientalis* L.), Austrian pine (*Pinus nigra* Arnold), Turkish fir (*Abies bornmulleriana* L.), and Scots pine (*Pinus sylvestris* L.)] and adjacent primary natural Sessile oak (*Quercus petraea* L.) forest as common garden experiments without replications. Common garden experiments provide an opportunity to minimize such confounding effects as the same tree species are planted in adjacent blocks so that climate, parent material, time, hydrology, and previous land use are almost the same. However, common garden experiments are uncommon (Binkley and Giardina 1998) and often without replication (Vesterdal et al. 2008). The study sites were established in 1950–1955 by introducing coniferous tree species instead of natural Sessile oak forest. The soil was left relatively undisturbed, no weed control treatments, no fertilization applied, and not subject to any silvicultural treatment after plantation establishment. We determined the characteristics including density, mean diameter (dbh), and height of trees on sample plots (Table 1). Mean ages of trees were found as 50 by estimating annual year rings taken from three to five randomized sample trees in each plot. Adjacent plots (40×40 m) were established. Sampling was confined to the central 20×20 m area of each plot within the center to reduce edge effects. All of the plots had high homogeneity of abiotic environmental conditions (aspect, slope, elevation, and soil type).

Soil respiration measurement

Soil respiration was measured with the soda-lime method (Raich 1998). Soil respiration rates at high flux rates may be underestimated by this method. Notwithstanding, this method does discriminate between higher and lower effluence rates and, thus, it provides an opportunity to compare sites (Tufekcioglu and Kucuk 2004). In each site (under each species), five sampling subplots and three sampling occasions under per tree species (a total of 15 for each tree species for each month) were chosen in a stratified random manner. A plastic bucket with the same diameter as that of the chambers was established in 1 cm soil depth 24 h prior to any sampling. All live plant parts inside the plastic bucket were removed to prevent vegetation respiration. CO_2 released from the soil inside plastic bucket was absorbed by 60 g of granular (6–12 mesh) soda lime contained in 5 cm diameter by 5 cm tall jars. Blanks were run to account for CO_2 absorbance by five the soda lime during transportation, handling, and the opening and closing of the jar. Before and after each sampling period, the soda lime was oven-dried to constant weight at 105°C. The mass gain of the soda lime during incubation period was multiplied by 1.69 to correct for water release (Keith and Wong 2006). The same locations were sampled each month. Measurements were taken monthly from April 2007 through March 2008.

Soil temperature at the 0–5 cm depth was measured immediately adjacent to each soil respiration chamber. A cylindrical plug of soil 5 cm deep and 5 cm in diameter was collected and placed in an airtight metal tin. Stones, roots, and litter were removed by hand, and the samples were weighed, oven-dried at 105°C, and reweighed to determine their gravimetric soil moisture content.

The biomass of fine roots was assessed by collecting 20 samples (five sampling subplots and four sampling occasions under per tree species) from 35 cm deep, using (inner diameter 6.4 cm) steel soil cores (Tufekcioglu et al. 2003) per subplot in April 2007, July 2007, October 2007, and January 2008. Roots were distinguished from the soil by softly washing them over a series of sieves with mesh sizes of 2.0 mm and 5.0 mm. Roots were separated diameter classes of <2 mm (fine root), 2–5 mm (small root), and >5 mm (coarse root) The fine roots were oven-dried at 65°C for 24 h and then weighed (Tufekcioglu and Kucuk 2004).

Statistical analysis

Statistical comparisons were made using SPSS11 (SPSS 2003). We used ANOVA to compare soil respiration rates, soil temperatures, and soil moisture contents among sites. Comparisons among species and sampling dates were determined using the Duncan test at 0.05 level. To determine the relationship between soil respiration rates as dependent variable and soil temperature, fine root biomass, and soil moisture as independent variables, multiple linear regression analysis was used to describe a mathematical equation. The possible effects of soil temperature, soil moisture, and fine root biomass on soil respiration rates were evaluated with correlation analysis and Pearson correlation coefficients.

Table 1 Density, mean diameter (dbh), and height of trees on sample plots

Characteristics	Austrian pine	Sessile oak	Turkish fir	Oriental spruce	Scots pine
Tree number (ha^{-1})	1,206	444	1,206	1,541	1,005
Diameter (dbh) (cm)	27.3	26.6	16.8	19.7	27.2
Height (m)	16.7	20.0	17.1	16.4	18.0

Results and discussion

Soil temperature and soil moisture

Monthly soil temperature values show significant difference among species ($p>0.001$). However, mean annual soil temperature did not significantly differ (Table 2). Mean annual temperature changed between 13.0°C and 14.2°C. The highest monthly soil temperature was determined under oak and spruce (24.4°C) on August 2007 and the lowest was under spruce (3.9°C) on January 2008 (Fig. 1).

Mean annual soil moisture was determined to be between 6.3 % and 8.1 % under all species. Mean annual values of soil moisture did not differ significantly among species. Some monthly values such as August, December, January, February, and March also did not show significant differences (Table 2). The highest monthly soil moisture was determined under oak (15.3 %) on February 2008 and the lowest was under Scots pine (2.7 % on July 2007) and also under spruce (2.7 %) on July and September 2007 (Fig. 1).

Soil temperature and soil moisture are two of the most important environmental parameters controlling variations in soil CO_2 efflux. However, the relationships between soil respiration and these two environmental parameters vary in different ecosystems (Tang et al. 2006). Soil moisture was determined as the main effective factor on soil respiration in this study. The highest mean annual soil moisture and soil temperature was determined under natural oak forest. In general, soil respiration within each of the tree species was strongly positively correlated with soil moisture and negatively correlated with soil temperature in the whole sampling period in this study. Many researchers reported similar results; for instance, Epron et al. (2004), Cook and Orchard (2008), Rey et al. (2011), and Yohannes et al. (2011) presented that the soil respiration rate was mostly regulated by soil moisture. Soil respiration is not sensitive to moisture under low temperatures (below 5°C) but more responsive at high temperatures (10 to 20°C). Similarly, soil respiration is not sensitive to temperature under low moisture (below 7.5 % volumetrically) but is more responsive to temperature under high moisture content (10 % to 25 %) (Luo and Zhou 2006). The authors found similar results as we reached in the study which can be interpreted that narrow variation on mean annual soil temperature (mean annual soil temperature in research

Table 2 Mean soil temperature and soil moisture under different tree species

	Species	April	May	June	July	August	September	October	November	December	January	February	March	Annual
Soil moisture (%)	Oak	6.4ab	6.6bc	4.1bc	3.6ab	4.8a	4.0ab	9.5a	10.0a	9.5a	10.9a	15.3a	12.6a	8.1a
	Fir	6.7ab	7.8ab	4.5b	4.0a	4.7a	3.3bc	7.9ab	8.1ab	9.0a	10.5a	10.7a	11.0a	7.3a
	Spruce	4.6c	6.6c	3.2d	2.7bc	3.4a	2.7c	7.8ab	7.8ab	7.9a	9.1a	9.9a	10.2a	6.3a
	Austrian pine	7.4a	8.0a	6.0a	4.2a	5.0a	4.6a	5.6c	6.9b	7.7a	9.9a	9.7a	11.3a	7.1a
	Scots pine	5.1bc	5.1d	3.4cd	2.7bc	3.6a	3.6bc	7.5b	9.9a	7.3a	9.8a	10.8a	9.6a	6.5a
Soil temperature (°C)	Oak	12.9a	16.7a	20.9c	21.2a	24.4a	18.9a	11.8a	9.8a	6.2a	6.0a	11.9a	10.2a	14.2a
	Fir	11.7d	16.4a	21.0c	21.2a	24.3a	19.0a	9.0b	8.5b	5.8b	6.0a	11.8a	10.3a	13.8a
	Spruce	10.7a	14.1b	21.7ab	21.2a	24.4a	17.7c	11.8a	8.0c	5.5b	3.9b	11.1b	8.0b	13.2a
	Austrian pine	12.2b	13.5b	21.3bc	20.2b	24.3a	18.2b	9.0b	7.8c	4.8c	4.0b	11.6a	9.9a	13.1a
	Scots pine	11.7c	16.5a	22.1a	21.2a	21.3 b	18.1b	9.0b	8.0c	4.3d	4.0b	9.3c	9.9a	13.0a

Values within columns followed by the same letter are not statistically different at 0.05 significance level

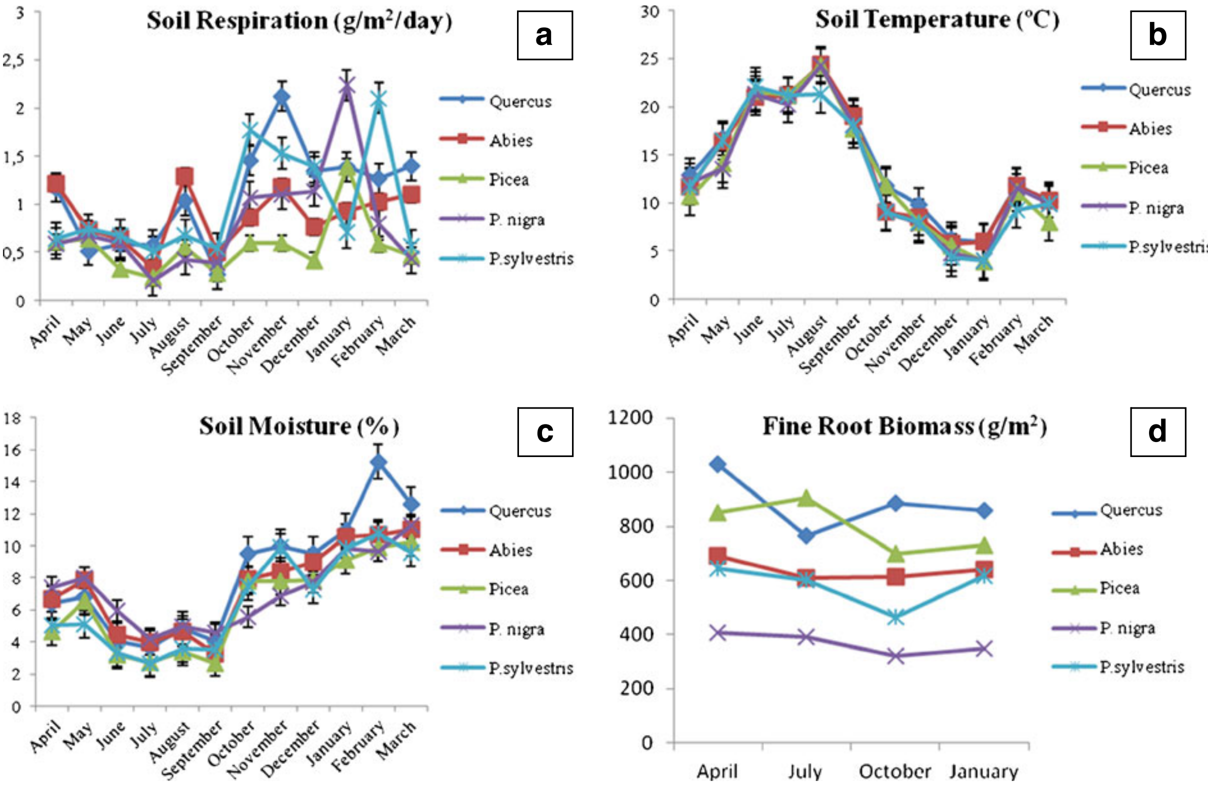

Fig. 1 Seasonal changes of **a** soil respiration (g C/m^2/day), **b** soil temperature (°C), **c** soil moisture (%), and **d** fine root biomass (g/m^2) under different tree species

area changed between 13°C and 14°C) possibly led to the increasing effect of soil moisture on soil respiration. Similarly, Vanhala (2002) reported that soil respiration was mostly regulated by soil moisture and soil pH if soil temperature was constant.

Fine root biomass

Both monthly and mean annual values of fine root biomass differ significantly ($p>0.001$) among species (Table 3). Mean annual fine root biomass ranged from 368.09 g/m^2 to 883.71 g/m^2. The highest monthly fine root biomass was determined under oak (1,027.94 g/m^2) on April 2007 and the lowest was under Austrian pine (323.47 g/m^2) on October 2007 (Fig. 1).

Mean annual fine root biomasses significantly differ among tree species, and the highest fine root biomass was determined under oak. Thus, fine root biomass can be identified as another significant factor with soil moisture to regulate soil respiration in this study. Soil respiration has a positive relation with fine root biomass in all research periods.

In accordance with our results, Adachi et al. (2006) and Yi et al. (2007) reported that soil respiration increased with the amount of the fine roots. Ceccon et al. (2011) also detected a significant linear relationship between fine root density and soil respiration. Tufekcioglu and Kucuk (2004) emphasized that soil respiration had the highest correlation with mean fine root biomass describing possible reasons as respiration by roots and their associated microbial components represent a significant part of soil respiration in most ecosystems while live roots directly contribute to soil respiration; dead roots and root exudates provide carbon as an energy source and nutrients for microbial biomass.

Soil respiration

Except in May, monthly soil respiration rates show significant difference among species ($p>0.001$). However, focusing on tree species, differences on mean annual respiration rates did not differ significantly (Table 3). Mean annual soil respiration ranged from

Table 3 Mean soil respiration and fine root biomass under different tree species

	Species	April	May	June	July	August	September	October	November	December	January	February	March	Annual
Soil respiration (g/m^2/day)	Oak	1.17b	0.51b	0.59a	0.58a	1.04a	0.26b	1.44ab	2.12a	1.34a	1.39b	1.27b	1.40a	1.09a
	Fir	1.21b	0.73a	0.65a	0.38ab	1.29a	0.50a	0.86bc	1.18c	0.77c	0.93c	1.02bc	1.15a	0.88a
	Spruce	0.61a	0.64ab	0.33b	0.23b	0.46b	0.28b	0.59c	0.59d	0.42d	1.39b	0.58d	0.46b	0.56a
	Austrian pine	0.54a	0.65ab	0.60a	0.21b	0.42b	0.39ab	1.08bc	1.10c	1.14b	2.24a	0.79cd	0.44b	0.81a
	Scots pine	0.64a	0.74a	0.68a	0.51a	0.68b	0.54a	1.78a	1.53b	1.38a	0.70c	2.10a	0.57b	0.99a
Fine root biomass (g/m^2)	Oak	1,027.94a			763.24ab			884.55a			859.12a			883.71a
	Fir	689.58bc			609.75b			613.98bc			640.33b			638.41c
	Spruce	850.98ab			905.37a			698.87b			729.70ab			796.23b
	Austrian pine	406.17d			392.95c			323.47d			349.78c			368.09e
	Scots pine	642.94c			603.40b			463.77cd			616.76b			581.72d

Values within columns followed by the same letter are not statistically different at 0.05 significance level

0.56 to 1.09 gC/m^2/day. The highest rates were reached on autumn months and the lowest rates were determined on summer season. The highest soil respiration rates of species was under Austrian pine (2.24 g C/m^2/day) on January 2008; the lowest rate was also determined under Austrian pine (0.21 gC/m^2/day) on July 2007 (Fig. 1).

In general, soil respiration has an increasing rate in autumn. The lower rates of soil respiration were determined in summer (June, July, August, and September) when soil temperature was higher and soil moisture was lower. Soil respiration trend has a similar tendency to soil moisture (Fig. 1).

Soil respiration shows increases on autumn which was mostly depending on soil moisture rise. Contrary to our results, Tufekcioglu et al. (2001) observed that soil respiration increases from winter months to summer months despite decreasing from summer to autumn with the significant relationships between seasonal change of soil respiration and soil temperature. As can be seen similar tendency with the results of this study, Vanhala (2002) reported that soil respiration has a decreasing tendency from spring months to the end of summer period, and then a repeated increase from end of summer. To our knowledge, plant physiological activities are generally maximum on spring and autumn on temperate zone; as a result, soil respiration was stimulated by plant activities on growing season (Raich et al. 2002). Also, soil moisture on growing seasons trigger soil respiration due to increasing microbial activity and physiological root processes. Soil respiration rates reached higher values on autumn months resulting possibly from the autumn period that coincided with rains in research area. Therefore, it is likely that soil respiration was stimulated not only by optimal soil temperature and soil moisture conditions but also by the increase in microbial populations and root activity at these times (Rey et al. 2011). Temporal variations have been described at various time scales, from diurnal to interannual variations. The seasonal variability is mostly explained by soil temperature and soil water content in temperate ecosystems. Litter moisture rain events and soil rewetting after a drought period are among factors that may explain short-term temporal variability of soil respiration. Large spatial variability may be explained by biotic and abiotic factors. Biotic factors involved are root density or biomass quantity and quality of organic matter, microbial biomass, or vegetation characteristics. Soil texture or porosity may also play a role by affecting gas diffusion and biological activity (Vincent et al. 2006). Monthly soil respiration rates significantly differed among tree species despite no significant difference on mean annual soil respiration rates. However, the highest mean annual soil respiration rate was determined under oak, and the descending order of mean annual soil respiration rates of tree species was Sessile oak, Scots pine, Turkish fir, Austrian pine, and Oriental spruce. As mentioned before by many researchers, soil respiration can also change depending on vegetation types because vegetation cover affects soil properties and soil microclimate, amount and characteristics of forest floor, and especially root respiration rate (Raich and Tufekcioglu 2000). Gaertig et al. (2002), in accordance with our results, indicated higher soil respiration rates with more production of fine roots under oak forests in Germany. Similar interpretations can be given as the reason for higher soil respiration under oak than other tree species in this study. Many researchers indicated the differences on respiration rate among different tree species (Li et al. 2004; Brüggemann et al. 2005; Khomik et al. 2006; Yi et al. 2007). In this context, Raich and Tufekcioglu (2000) underlined that substrate quality affected soil respiration rates, but this has not been demonstrated clearly in any study, which can be also inferred that nutrient cycling rate was an inherent property of deciduous and coniferous tree species, with deciduous species having faster nutrient cycling rates.

Relationship of soil respiration with soil moisture, soil temperature, and fine root biomass

Except Austrian pine, soil respiration under other species shows a positive linear correlation with soil moisture. Soil temperature shows a positive linear correlation with soil respiration under Scots pine and fir, and negative linear correlation under other species. Soil respiration had a positively linear correlation with fine root biomass under fir, spruce, and Austrian pine stand and negative linear correlation under oak and Scots pine species as seen on regression equations created by the dependent variable as soil respiration and other independent variables (Table 4).

According to regression results, 0.087–100 % of variation on monthly soil respiration can be explained by soil temperature, soil moisture, and fine root biomass among species (Table 5). Soil temperature, soil moisture, and fine root biomass explain mean annual soil respiration rates at the highest under Austrian pine (R^2=0.562) and the lowest (R^2=0.223) under Turkish fir (Table 5).

Monthly correlation coefficients of soil respiration have generally higher values than mean annual values according to our evaluations on the effects of main effective factors of soil respiration as soil moisture, soil temperature, and fine root biomass. Monthly values of soil temperature, soil moisture, and fine root biomass can explain the soil respiration at higher accuracy compared to mean annual values. In this context, Hanson et al. (2000) gives the rate of fine root respiration to soil respiration between 10 % and 90 %, and Lee et al. (2005) indicated 50 % rate of soil respiration explained by fine roots in temperate deciduous forests; the remaining part can be explained by other effective factors such as pH, microbial respiration, and C/N ratio. Also, Rey et al. (2002) demonstrated that organic matter and dead root decomposition can explain the soil respiration at 55% in coppice oak forest in Italy. In addition, mineralized nitrogen increases microbial respiration by increasing microbial biomass during decomposition of organic matter and forest floor by microorganisms (Luo and Zhou 2006). Gough and Seiler (2004) demonstrated that soil respiration has a linear relationship with mineral soil carbon and root surface area under *Pinus taeda* plantation, and the most effective factor on soil respiration was soil temperature. On the other hand, Tufekcioglu and Kucuk (2004) reported that only one factor as mean fine root biomass had the highest correlation with soil respiration (r=0.91). As given in Wang et al. (2005), the factors for controlling root respiration were very complex. The high variation of the share of root respiration shows that measurement of soil respiration alone is not sufficient to assess the contribution of soil carbon to the atmospheric CO_2. It was reported that soil respiration was controlled by a range of biotic and abiotic factors, such as soil or air temperature, soil water content, litter fall, amounts of litter on soil, nitrogen, carbon, soil microbial biomass, soil pH, aboveground vegetation structure, photosynthetic activity, or plant phenological development (Vincent et al. 2006; Yi et al. 2007). For these reasons, the changes and temporal fluctuations of soil respiration at different rates under different tree species can

Table 4 Descriptive statistics and regression of annual soil respiration under different tree species

Variables	Mean	Standard deviation	R^2	Correlation value (%)
Oak $Y=1.587+0.047x_1-0.039x_2-0.113x_3$				
Respiration	1.093	0.52	0.544	
Moisture	8.12	3.75		0.68
Temperature	14.2	6.07		−0.70
Fine root	883.71	0.29		0.06
Fir $Y=0.177+0.065x_1+0.008x_2+0.056x_3$				
Respiration	0.881	0.30	0.223	
Moisture	7.34	2.75		0.46
Temperature	13.8	6.37		−0.31
Fine root	638.41	0.11		0.08
Spruce $Y=-0.848+0.050x_1-0.027x_2+0.564x_3$				
Respiration	0.556	0.30	0.378	
Moisture	6.33	2.86		0.51
Temperature	13.2	6.71		−0.57
Fine root	726.23	0.29		−0.40
Austrian pine $Y=1.526-0.019x_1-0.069x_2+0.273x_3$				
Respiration	0.806	0.54	0.562	
Moisture	7.12	2.26		0.44
Temperature	13.1	6.61		−0.75
Fine root	368.09	0.12		−0.58
Scots pine $Y=2.734+0.084x_1+0.013x_2-1.329x_3$				
Respiration	0.987	0.56	0.498	
Moisture	6.51	3.18		0.51
Temperature	13.0	6.60		−0.52
Fine root	581.72	0.23		−0.61

x_1 soil moisture, x_2 soil temperature, x_3 fine root biomass

possibly be resulted from a range of biotic and abiotic factors as mentioned above.

Conclusion

In conclusion, the achieved results of the present study can be summarized as follows: Soil moisture can be interpreted as the most limited factor on soil respiration under Belgrad Forest conditions. Soil respiration has a similar temporal tendency with soil moisture. There was no strong correlation between fine root biomass and soil respiration. On the other hand, except spruce, soil respiration under other tree species have similar tendency to temporal changes of fine root biomass. In general, soil respiration rates under each tree species increase on autumn months depending on increases of soil moisture, fine root biomass, and possibly increases in biological activity.

Table 5 Monthly R^2 values of regression analysis on annual soil respiration under different tree species

Species	April	May	June	July	August	September	October	November	December	January	February	March	Mean
Oak	0.735	0.910	0.513	0.964	0.911	0.991	0.888	0.615	0.909	0.997	0.941	0.281	0.544
Fir	0.829	0.987	0.965	0.130	0.855	0.387	1.000	0.087	0.351	0.811	0.998	0.499	0.223
Spruce	0.745	0.997	0.904	0.278	0.666	0.590	0.951	1.000	0.684	0.611	0.183	0.994	0.378
Austrian pine	0.994	0.994	0.845	0.899	0.859	0.990	0.513	0.684	0.209	0.946	0.551	0.972	0.562
Scots pine	0.910	0.967	0.982	0.523	0.845	0.998	0.957	0.669	0.846	0.463	0.936	0.706	0.498

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