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Soil Respiration in Young and Old Oriental Spruce Stands and in Adjacent Grasslands in Artvin, Turkey

Aydın TÜFEKÇİOĞLU*, Mehmet KÜÇÜK
Department of Forestry, Kafkas University, 08000, Artvin - TURKEY

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Abstract: Soil respiration is a good indicator of soil quality. In this study, the influence of species type and sampling time on soil respiration in young and old oriental spruce (*Picea orientalis* (L.) Link.) stands without understory and with a *Rhododendron ponticum* L. understory and in adjacent grasslands were investigated in Genya Mountain, Artvin, Turkey. Soil respiration was measured approximately monthly from May to October using the soda-lime technique. Mean daily soil respiration across all sites ranged from 0.26 to 2.66 g C m^{-2} d^{-1}. There were significant differences between grasslands and old forest sites, but no significant differences between young forest sites and grasslands. Seasonal changes in soil respiration were strongly related to temperature changes. Over all sites, soil temperature and soil moisture together accounted for 75% of the seasonal variability in soil respiration. Mean soil respiration rates correlated strongly with fine root (<2 mm) biomass ($R = 0.91$, $P < 0.001$), surface (0-15 cm) soil sand content ($R = 0.71$, $P < 0.05$), surface soil silt content ($R = -0.69$, $P < 0.05$), and subsurface (15-35 cm) soil pH ($R = 0.60$, $P < 0.05$). Overall, grasslands had significantly higher soil respiration rates than did adjacent old forests, indicating greater biological activity within the grasslands.

Key Words: soil biological activity, oriental spruce, grasslands, C cycle

Türkiye-Artvin Yöresindeki Genç ve Yaşlı Ladin Meşçerelerinde ve Bitişiğindeki Çayırlıklarda Toprak Solunumu

Özet: Toprak solunumu toprak kalitesinin önemli göstergelerinden bir tanesidir. Bu çalışmada, Artvin-Genya Dağı mevkisindeki genç ve yaşlı doğu ladini (ormangülü diri örtüsü olan ve olmayan) ormanlarında ve bitişiğindeki çayırlıklarda, bitki türü ve örnekleme zamanının toprak solunumu üzerindeki etkileri belirlenmeye çalışılmıştır. Toprak solunumu Mayıs ayından Ekim ayına kadar soda-kireç yöntemi yardımıyla belirlenmiştir. Ortalama toprak solunumu 0,26-2,66 gr C m^{-2} $gün^{-1}$ olarak değişmiştir. Yaşlı ladin ormanı ile çayırlık arasındaki toprak solunumu farkı istatistiki olarak anlamlı iken, genç doğu ladini ormanı ile çayırlık arasında istatistiki anlamda önemli fark bulunamamıştır. Toprak solunumundaki mevsimsel değişimler toprak sıcaklığındaki mevsimsel değişimlere paralel olarak gerçekleşmiştir. Toprak sıcaklığı ve toprak nemi, toprak solunumundaki varyasyonun %75'ini açıklamaktadır. Ortalama toprak solunumu; ince kök kütlesi ile (<2 mm) ($R = 0.91$, $P < 0.001$), üst toprağın (0-15 cm) kum oranı ile ($R = 0.71$, $P < 0.05$), üst toprağın toz oranı ile ($R = -0.69$, $P < 0.05$), ve yüzeyaltı toprağın (15-35 cm) pH'sı ile ($R = 0.60$, $P < 0.05$) anlamlı olarak değişmektedir. Sonuç olarak, çayırlık alanlar, yaşlı orman alanlarına kıyasla daha fazla toprak solunumuna sahiptirler, bu da çayırlık alanlarda daha yüksek bir biyolojik aktivitenin olduğunu göstermektedir.

Anahtar Sözcükler: toprak biyolojik aktivitesi, doğu ladini, çayırlık, karbon döngüsü

Introduction

Soil respiration is the release of CO_2 from soils to the atmosphere and it is an important process in the carbon cycle in forest and grassland ecosystems. Soils are major global sources and sinks of CO_2 and therefore play an important role in regulating atmospheric concentrations of CO_2. Almost 10% of the atmosphere's CO_2 passes through soils each year. This is more than 10 times the CO_2 released from fossil fuel combustion (Raich and Schlesinger, 1992).

Soil respiration is a sensitive indicator of several essential ecosystem processes, including metabolic activity in soil, persistence and decomposition of plant residue in soil, and conversion of soil organic carbon to atmospheric

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* Correspondence to: atufekci27@yahoo.com

CO_2 (Rochette et al., 1997). In addition, Parkin et al. (1996) stated that soil respiration is a good indicator of soil quality.

Soil moisture and soil temperature are 2 significant determinants of soil respiration (Singh and Gupta, 1977; Raich and Tüfekçioğlu, 2000). Rochette et al. (1997) observed that soil respiration in moist soil was 2 to 3 times greater than that in drier soils. Most researchers also reported an increase in soil respiration with increasing soil temperature (for example, Kowalenko et al., 1978).

Soil respiration varies with vegetation type (Raich and Tüfekçioğlu, 2000). However, analyzing published soil respiration data Raich and Tüfekçioğlu (2000) found no predictable significant ($P<0.05$) differences in soil respiration between cropped and vegetation-free soils, between grassland and cropped soils or between forested and cropped soils. They did, however, find higher rates of soil respiration in grasslands than in forests, and in grasslands and forests than in adjacent croplands.

Estimates of soil respiration have been made in a variety of ecosystems and have been summarized in reviews by Schlesinger (1977), Singh and Gupta (1977), Raich and Schlesinger (1992) and Raich and Tüfekçioğlu (2000). Despite this considerable body of information on soil respiration in different parts of the world, there have been no soil respiration studies on the forest and grassland ecosystems of Turkey.

The objectives of this study were to compare rates of soil respiration among young oriental spruce stands (SSYs), old oriental spruce stands with no understory (SSOs), old oriental spruce stands with a *Rhododendron ponticum* L. understory (SSRs) and in adjacent grasslands, and to identify the underlying environmental variables most likely causing differences in soil respiration among sites, and among seasons within sites. We hypothesized that grasslands have higher rates of soil biological activity, and therefore higher rates of soil respiration than do adjacent spruce stands.

Materials and Methods

The study site is located at Genya Mountain in Artvin, Turkey. The site with a northern aspect and gentle slope (10-20%), ranges in elevation from 1490 m to 1510 m. Soil at the site is a podsolic well-drained sandy-loam. Soil respiration levels were measured in SSYs, in SSOs, in SSRs and in adjacent grasslands. Young stands were around 15 years old and were established after clearcutting by planting and natural regeneration. Old stands were around 90 years old with normal canopy cover. Plot sizes were 20 x 20 m. Dominant grass species in the grassland sites were smooth brome (*Bromus inermis* Leysser.), *Agrostis tenuis* L., timothy (*Phleum pratense* L.), Kentucky bluegrass (*Poa pratensis* L.) and *Festuca* spp. Grassland sites were under heavy grazing until last year when grazing was stopped.

Soil samples were taken randomly from 0-15 cm and 15-35 cm soil depths by digging a soil pit in each plot in October. Soil samples were air-dried, ground and passed through a 2 mm mesh-sized sieve. Organic matter contents of the soils were determined according to the wet digestion method described by Kalra and Maynard (1991)(modified Walkley-Black method). Soil texture was determined by Bouyoucos` Hydrometer Method described by Gülçur (1974). Soil pH was determined by a combination glass-electrode in H_2O (soil-solution ratio 1: 2.5) (Kalra and Maynard, 1991).

The biomass of fine (0-2 mm) roots was assessed by collecting six 35-cm deep, 6.4-cm diameter cores per plot in October (Harris et al., 1977; Tüfekçioğlu et al., 1999; Tüfekçioğlu et al., 2003). Roots were separated from the soil by soaking in water and then gently washing them over a series of sieves with mesh sizes of 2.0 and 0.5 mm. Roots were sorted into diameter classes of 0-2 mm (fine root), 2-5 mm (small root) and 5-10 mm (coarse root) root classes. The roots from each size category were oven-dried at 65 °C for 24 h and then weighed.

Soil respiration rates were measured approximately monthly in 3 randomly selected locations in each of the 3 plots per site from May 2003 to October 2003 using the soda-lime method (Edwards, 1982; Raich et al., 1990). The soda-lime method may underestimate actual soil respiration rates at high flux rates (Ewel et al., 1987; Haynes and Gower, 1995). However, the method does distinguish between higher and lower flux rates and, therefore, it is an appropriate method for comparing sites.

Buckets 20 cm tall and 27.5 cm in diameter were used as measurement chambers. One day prior to measurements, plastic rings with the same diameter were placed over the soil and carefully pushed about 1 cm into the soil. All live plants inside the plastic rings were cut to prevent aboveground plant respiration. Carbon dioxide was absorbed with 60 g of soda-lime contained in 7.8 cm diameter by 5.1 cm tall cylindrical tins. In the field, the plastic rings were removed, measurement chambers were placed over the tins of soda-lime, and the chambers were held tightly against the soil with rocks. After 24 h the tins were removed, and the contents oven dried at 105 °C for 24 h and then weighed. Blanks were used to account for carbon dioxide absorption during handling and drying (Raich et al., 1990). Soda-lime weight gain was multiplied by 1.69 to account for water loss (Grogan, 1998). Soil temperature was measured at a 5 cm soil depth adjacent to each chamber in the morning. Diurnal variations in soil temperature were expected to be smaller at these sites because of shading of sunlight by the plant canopy. Gravimetric soil moisture was determined by taking soil samples at 0-5 cm depth and drying them at 105 °C for 24 h on the day that the soda-lime tins were removed from the plots.

Statistical comparisons were made using SPSS. We used ANOVA to compare soil respiration rates, soil temperatures, and soil moisture contents among sites. Paired comparisons among sites and sampling dates were determined using the Least Significant Difference test at $\alpha = 0.05$. Step-wise multiple regression analysis was performed to evaluate the importance of soil temperature and soil moisture on seasonal soil respiration rates. The possible effects of soil properties and fine root biomass on soil respiration rates were evaluated with correlation analysis.

Results and Discussion

Mean daily soil respiration ranged from 0.26 to 2.66 g C m^{-2} d^{-1} among all sites (Figure 1a). These values are within the ranges reported by Kucera and Kirkham (1971), Coleman (1973), Singh and Gupta (1977), Jurik et al. (1991), Lessard et al. (1994), Hudgens and Yavitt (1997) and Tüfekçioğlu et al. (2001). The highest rates were observed in mid-August, when soil temperatures were high, while the lowest rates were observed in May, when soil temperatures were minimal (Figure 1b). Soil respiration increased from spring to summer and decreased from summer to fall, as is typical in temperate latitudes (for example, Kowalenko et al., 1978; Hudgens and Yavitt, 1997). Our results indicated that temperature was limiting during the fall and spring and that moisture was limiting during the summer and fall. Kowalenko et al. (1978) reported that temperature was limiting during the winter and spring and that moisture was limiting during the summer and fall on soil respiration in field soils in Canada.

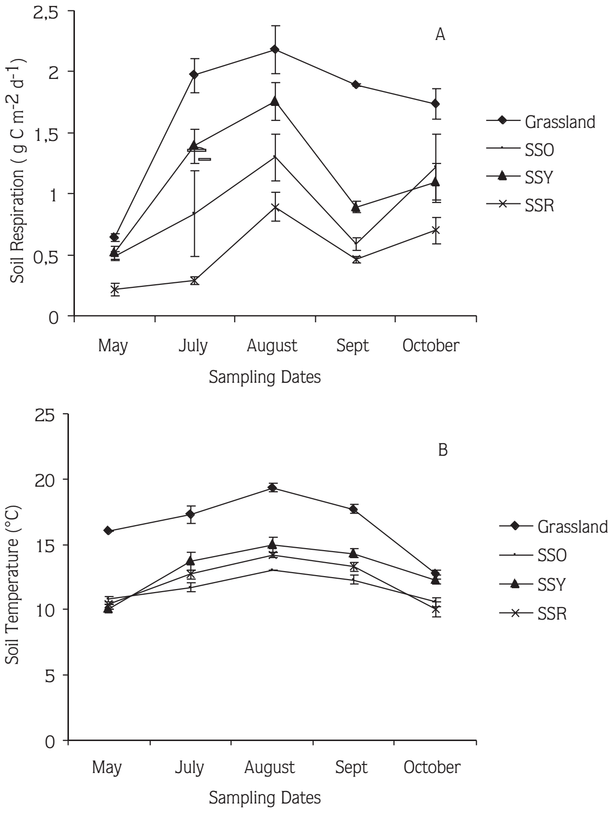

Figure 1. Mean monthly (± 1 SE) soil respiration rates (A) and soil temperature (B) in young (SSY) and old oriental spruce stands with understory (SSR) and without understory (SSO) and in adjacent grasslands.

Soil respiration varied significantly among the sites (P < 0.01). Soil respiration was significantly lower in old spruce stands (SSOs and SSRs) than in grassland sites (Table 1). Similar results were reported by Raich and Tüfekçioğlu (2000). They reported that grasslands had ~20% higher soil respiration rates than did comparable forest stands. Higher soil respiration rates in grassland sites were probably due to higher soil temperatures and fine root biomass values in these sites. Soil temperature and fine root biomass are significant determinants of soil respiration in temperate latitudes (Kelting et al., 1998; Tüfekçioğlu et al., 2001).

Table 1. Mean values of soil respiration, soil temperature, soil moisture, soil organic matter, soil sand, clay and silt content, pH and root biomass in the 4 sites investigated in this study (n = 3 plots per site). Root data refer to the surface 35 cm of soil. Standard errors are in parentheses.

Vegetation types		Grassland	Old spruce stand with no understory	Young spruce stand	Old spruce stand with understory
Mean soil respiration (g C m^{-2} d^{-1})		1.68 (0.27)	0.89 (0.16)	1.13 (0.21)	0.59 (0.13)
Mean soil temperature (ºC)		16.6 (1.1)	11.7 (0.4)	13.1 (0.9)	12.5 (0.9)
Mean soil moisture (%)		35.3 (3.9)	31.4 (2.5)	35.1 (3.7)	27.1 (2.3)
Mean soil organic matter (%)	0-15 cm	5.58 (0.36)	7.57 (0.96)	6.54 (0.58)	6.11 (0.95)
	15-35 cm	2.90 (0.33)	4.43 (0.59)	3.39 (0.41)	3.69 (0.18)
Mean sand content (%)	0-15 cm	66.4 (2.6)	57.5 (4.3)	58.2 (3.9)	5.23 (4.5)
	15-35 cm	44.9 (7.6)	53.2 (2.2)	56.2 (3.0)	51.59 (6.6)
Mean clay content (%)	0-15 cm	16.8 (2.6)	25.5 (3.5)	24.0 (2.4)	23.2 (2.6)
	15-35 cm	30.7 (3.9)	2.7.0 (1.1)	28.4 (3.6)	27.6 (3.3)
Mean silt content (%)	0-15 cm	16.9 (1.4)	17.1 (1.3)	17.8 (1.8)	24.5 (1.9)
	15-35 cm	24.4 (3.9)	19.8 (1.3)	15.6 (1.2)	20.8 (3.8)
Mean soil pH	0-15 cm	5.33 (0.10)	5.29 (0.28)	5.41 (0.19)	4.98 (0.26)
	15-35 cm	5.57 (0.06)	5.32 (0.25)	5.17 (0.09)	4.83 (0.26)
Mean fine root biomass (<2 mm) (g m^{-2})		785 (24)	498 (19)	564 (25)	404 (21)

There were significant differences in soil respiration among sampling dates, but with different temporal patterns for forest and grassland vegetation types. Soil respiration increased from May to August in all sites and decreased from August to October in grasslands while decreasing from August to September, and increasing from September to October in the other sites. These differences in temporal patterns of soil respiration were probably driven by moisture and temperature differences among sites. There was no change in soil moisture from August to September in grassland sites, but in the same period soil moisture content decreased by an average of 26.3% in the other sites. Transpiration from the aboveground tissues and interception of rain by the forest canopy might account for these soil moisture differences among sites. The temperature decrease from August to October in forest sites was more gradual compared to grassland sites.

Soil temperature varied significantly among the sites and sampling dates ($P < 0.01$) (Figure 1b). Soil temperatures in the grassland sites were significantly different from those in the other sites ($P < 0.05$) (Table 1). There were no other significant temperature differences among sites. Averaged over all sites, soil temperatures were significantly higher in July than in October.

Soil moisture content differed significantly between sampling dates. Overall soil moisture contents were significantly higher in October than in May, July and September ($P < 0.05$) (Figure 2). Mean soil moisture contents (average of 5 sampling dates) were 35.3%, 31.4%, 35.1% and 27.1 in grasslands, in SSO, SSY and

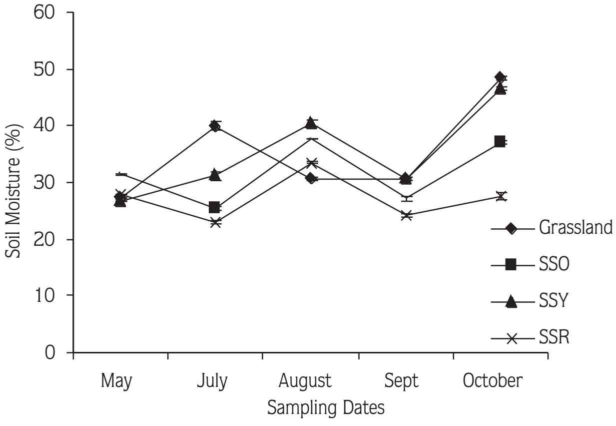

Figure 2. Mean monthly (± 1 SE) soil moisture contents (0-5 cm depth) in young (SSY) and old oriental spruce stands with understory (SSR) and without understory (SSO) and in adjacent grasslands.

SSR sites, respectively (Table 1). Higher soil moisture contents in July, September and October in grassland sites compared to SSO and SSR sites were probably the result of higher canopy interception in the forest stands than in grasslands. Çepel (1971) reported that interception ranged from 17 to 31% for forest stands and from 6 to 17% for grasslands in Turkey.

Within sites, seasonal changes in soil respiration were correlated most highly with soil temperature. When all sites were considered together, mean daily soil respiration varied with soil temperature and moisture ($r^2 = 0.75$, $P < 0.001$):

$$SR = 0.14\ T + 0.0429\ M - 2.194$$

where SR is the soil respiration rate (g C m^{-2} d^{-1}), T is morning surface-soil (0-5 cm depth) temperature (ºC) and M is surface-soil (0-5 cm depth) gravimetric moisture content (% H_2O). All 3 parameters were significant ($P < 0.01$). According to stepwise regression results, 46% and 29% of variation in soil respiration can be explained by soil temperature and soil moisture, respectively. This indicated that soil temperature was the most important determinant of soil respiration in these high elevation sites.

Among sites, mean annual soil respiration rate correlated positively with fine root biomass, surface soil (0-15 cm) sand content, mean soil temperature, mean soil moisture and subsurface soil (15-35 cm) pH, and correlated negatively with surface soil silt content ($P < 0.05$) (Table 2). Soil temperature and soil sand content were positively correlated, suggesting that high soil temperatures were associated with sandy soils (Kantarcı, 2000).

Soil respiration had the highest correlation with mean fine root biomass ($r = 0.91$). Respiration by roots and their associated microbial components represents a significant part of soil respiration in most ecosystems (Bowden et al., 1993; Kelting et al., 1998). While live roots directly contribute to soil respiration, dead roots and root exudates provide carbon as an energy source and nutrients for microbial biomass. Grayston et al. (1996) reported that root exudates stimulate microbial growth and activity because they are readily assimilated, and they may act as primers for the degradation of existing soil organic matter.

In a native prairie, belowground litter contributed 20-25%, root respiration contributed 25-30%, and decay of organic matter contributed 30-35% of the total soil respiration (Buyanovsky et al., 1987). Root respiration accounted for 33-50% of total soil respiration in broad-leaved forests, 17-40% in grasslands, and 12-38% in crop fields in temperate regions (Raich and Tüfekçioğlu, 2000).

Conclusions

In this study, grasslands had higher rates of soil respiration than did adjacent old forest sites. These higher rates of soil respiration are evidence of the high rates of biological activity and C cycling through the soil. Our results suggest that old forests might be better than grasslands in terms of carbon accumulation into the soil and forest floor in these high elevation sites.

Table 2. Pearson correlation coefficients among measured variables in the study area (n = 12). Soil properties belong to the surface 0-15 cm. Asterisks refer to the level of significance; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$

Variables	FRB	T	M	pH	Sand (%)	Clay (%)	Silt (%)	SOC
SR[1]	0.91***	0.83***	0.65*	0.28	0.71*	-0.50	-0.68*	-0.33
FRB[2]	1.0	0.87***	0.75**	0.28	0.65*	-0.53	-0.54	-0.23
T[3]		1.0	0.43	0.17	0.62*	-0.69*	-0.25	-0.47
M[3]			1.0	0.24	0.33	-0.06	-0.54*	0.07
pH				1.0	0.61*	-0.51	-0.49	0.25
SOC[1]					-0.28	0.41	0.01	1.0

[1] SR: soil respiration (g C m^{-2} d^{-1}); SOC: Mean soil organic matter content (%).

[2] FRB: fine root biomass (kg ha^{-1}),

[3] M: Mean soil moisture (%), T: Mean soil temperature (C); (0-5 cm depth)

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