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Soil respiration in apple orchards, poplar plantations and adjacent grasslands in Artvin, Turkey

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Abstract: *In this study, influence of land-use type on soil respiration was investigated in poplar plantation, apple orchard (apple trees with understory grasses) and adjacent grassland sites in Seyitler Area, Artvin, Turkey. Soil respiration was measured approximately monthly in three sampling plots in each land use type from January 2005 to November 2005 using the soda-lime technique. Mean daily soil respiration ranged from 0.63-3.59 g C m^{-2} d^{-1}. Mean soil respiration in apple orchard, poplar plantation and grassland sites were 1.98, 1.45 and 1.12 g C m^{-2} d^{-1}, respectively. Mean soil respiration was significantly greater in apple orchard than in poplar plantations and grasslands. Seasonal changes in soil respiration were related to soil moisture and temperature changes. Mean soil respiration rate correlated strongly with subsurface soil (15-35cm) pH (R = -0,73; p<0.05), sand content (R= 0.96, p<0.001), soil silt content (R= -0.75; p<0.05), soil clay content (R= -0,83; p<0.001) and organic matter content (R= 0,88; p<0.001). No significant correlations were observed between soil respiration and surface (0-15 cm) soil properties and root biomass. Overall, our results indicate that apple orchards with understory grasses have higher soil biological activity compared to poplar and grassland sites.*

Key words: *Soil biological activity, Apple orchard, Grasslands, Carbon cycle, Artvin*
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Introduction

Increasing atmospheric CO_2 concentrations and global climate change have created a strong need for data and information on the global carbon cycle in terrestrial ecosystems. One of the main pathway of fluxes in the global carbon cycle is soil respiration. Soil respiration is the release of CO_2 from soil to the atmosphere. Soils release 75-80 Pg of CO_2-C to the atmosphere annually by soil respiration (Raich and Potter, 1995). Almost 10% of the atmosphere's CO_2 passes through soils each year. This is more than 11 times the current rate of CO_2 released from fossil fuel combustion (Raich *et al.*, 2002).

There are two main sources of respiration in soils: root respiration and soil microbial respiration (Hanson *et al.*, 2000; Kulkarni *et al.*, 2007). Kucera and Kirkham (1971) reported 40% of total soil flux was due to root respiration, Dugas *et al.* (1999) estimated that 90%, Norman *et al.* (1992) estimated 15-70% and Hanson *et al.* (1993) estimated 50%.

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 CO_2 (Rochette *et al.*, 1992; Tufekcioglu *et al.*, 2001). In addition, Parkin *et al.* (1996) stated that soil respiration is a good indicator of soil quality. Soil respiration has strongly influenced by soil moisture and soil temperature (Singh and Gupta, 1977; Raich and Potter, 1995; Raich and Tufekcioglu, 2000; Kowalenko *et al.*, 1978). Rochette *et al.* (1992) observed that soil respiration in moist soil was 2 to 3 times greater than that in drier soils. Soil respiration varies with vegetation type, management practices, environmental conditions and land use type (Raich and Tufekcioglu, 2000; Frank *et al.*, 2006). However, analyzing published soil respiration data, Raich and Tufekcioglu (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.

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 Tufekcioglu (2000). Despite the considerable body of information on soil respiration in different parts of the world, there have been couple of soil respiration studies done in forest and adjacent grassland ecosystems in Turkey (Tufekcioglu and Kucuk, 2004; Tufekcioglu *et al.*, 2006a,b).

The objectives of this study were to compare rates of soil respiration among grasslands, apple orchards with understory grasses and poplar stands and to identify the underlying environmental variables most likely causing differences in soil respiration among sites, and among seasons within sites.

Materials and Methods

The study site is located at Seyitler area in Artvin, Turkey. The site with an eastern aspect and gentle slope (5-10%) has an elevation of 530 m from sea level. Mean annual temperature,

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precipitation and relative humidity of the site are 12°C, 700 mm and 62%, respectively. Soils at the sites are somewhat poorly drained, loamy-clay mollisols. Soil respiration levels were measured in adjacent grasslands, apple orchards and poplar stands (*Populus euroamericana*). Poplar stands and apple orchards were around 20 years old and were established by planting. 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. Similar grass species were also found as understory in apple orchards. Grasses in grassland and apple orchard sites were cut annually for forage production. Plot sizes were 20 x 20 m.

Soil respiration rates were measured approximately monthly in 3 randomly selected locations in each of the 3 plots per site from January to November using the soda-lime method in 1995 (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 hr the tins were removed, and the contents oven dried at 105°C for 24 hr 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. Gravimetric soil moisture was determined by taking soil samples at 0-5 cm depth and drying them at 105°C for 24 hr on the day that the soda-lime tins were removed from the plots.

Soil samples were taken randomly from 0-15 and 15-35 cm soil depths by digging a soil pit in each plot. 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). Soil texture was determined by Bouyoucos Hydrometer Method described by Gulcur (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 (Harris *et al.*, 1977; Tufekcioglu *et al.*, 1999; Tufekcioglu *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 hr and then weighed.

Statistical comparisons were made using SPSS. ANOVA was used 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.

Results and Discussion

Mean daily soil respiration ranged from 0.63 to 3.59 g C m^{-2} d^{-1} among all sites (Fig. 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), Raich and Tufekcioglu (2000), Tufekcioglu *et al.* (2001), Tufekcioglu and Kucuk (2004), Tufekcioglu *et al.* (2006a).

Soil respiration differed significantly with sampling time ($p<0.01$). The highest rates were observed in spring and fall when the soil moisture was relatively high. The lowest rates were observed during summer when the soil moisture was relatively low, and during winter when the soil temperature was relatively low (Fig. 1B and 2). This pattern corresponded well with the annual patterns of temperature and moisture under Mediterranean climate: high temperature associated with low moisture in summer and low temperature associated with high moisture in winter; both were significant determinants of soil respiration in temperate latitudes (Raich and Tufekcioglu, 2000; Tufekcioglu *et al.*, 2001). When one of these two factors is too limiting, it becomes the control factor and the other factor has little effect on the rate of soil respiration. Similar pattern observed by Qi and Xu (2001) in a coniferous forest in the Sierra Nevada Mountains, USA. Holt *et al.* (1990) and Rey *et al.* (2002) also found lower soil respiration rates in summer due to drought. Similarly, 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.

Soil respiration varied significantly among sites ($p<0.01$). Soil respiration was significantly higher in apple orchard than in grassland and poplar plantation sites (Table 1). In a review article, Raich and Tufekcioglu (2000) 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 fine root biomass and higher soil temperature values in spring and fall. Both soil temperature and fine root biomass are

Table - 1: Mean soil respiration, soil temperature, soil moisture, soil organic mater, soil sand, clay and silt content, pH and root biomass in the three sites investigated in this study (n=3 plots per site). Root data refer to the surface 35 cm of soil. Values in parenthesis refer to maximum and minimum

		Vegetation type		
Parameters	**Depth (cm)**	**Poplar plantation**	**Apple orchard (Grass + Apple trees)**	**Grassland**
Mean soil respiration (g C $m^{-2} d^{-1}$)		1.12 (0.63-2.80)	1.98 (0.71-3.59)	1.45 (0.73-2.38)
Mean soil moisture (%)		59.60 (28.5-95.2)	45.73 (14.1-99.2)	54.78 (19.3-96.7)
Mean soil temperature (°C)		13.41 (7.3-19.0)	15.83 (8.2-23.0)	16.84 (7.7-23.2)
Mean soil organic matter (%)	0-15	3.87 (3.75-4.11)	3.73 (3.32-3.99)	3.02 (3.14-3.38)
	15-35	2.24 (1.87-2.42)	3.14 (3.10-3.18)	2.12 (2.05-2.17)
Mean sand content (%)	0-15	42.5 (38.6-49.2)	46.6 (42.2-52.2)	42.0 (36.3-50.4)
	15-35	30.9 (27.1-33.4)	45.9 (44.0-47.6)	36.4 (35.2-38.1)
Mean clay content (%)	0-15	41.0 (33.3-45.5)	35.5 (31.1-40.7)	44.4 (42.7-45.7)
	15-35	50.7 (50.8-54.6)	40.7 (38.2-42.5)	43.0 (40.2-44.3)
Mean silt content (%)	0-15	16.5 (14.9-17.4)	17.9 (15.5-21.6)	13.6 (6.9-18.8)
	15-35	18.4 (18.3-20.8)	13.4 (12.3-14.1)	20.7 (18.7-22.5)
Mean soil pH	0-15	7.4 (7.2-7.6)	7.4 (7.3-7.4)	7.5 (7.3-7.6)
	15-35	7.7 (7.6-7.8)	7.6 (7.5-7.7)	7.7 (7.4-7.9)
Mean fine root biomass (<2 mm) (g m^{-2})		444 (396-478)	504 (423-627)	447 (397-498)

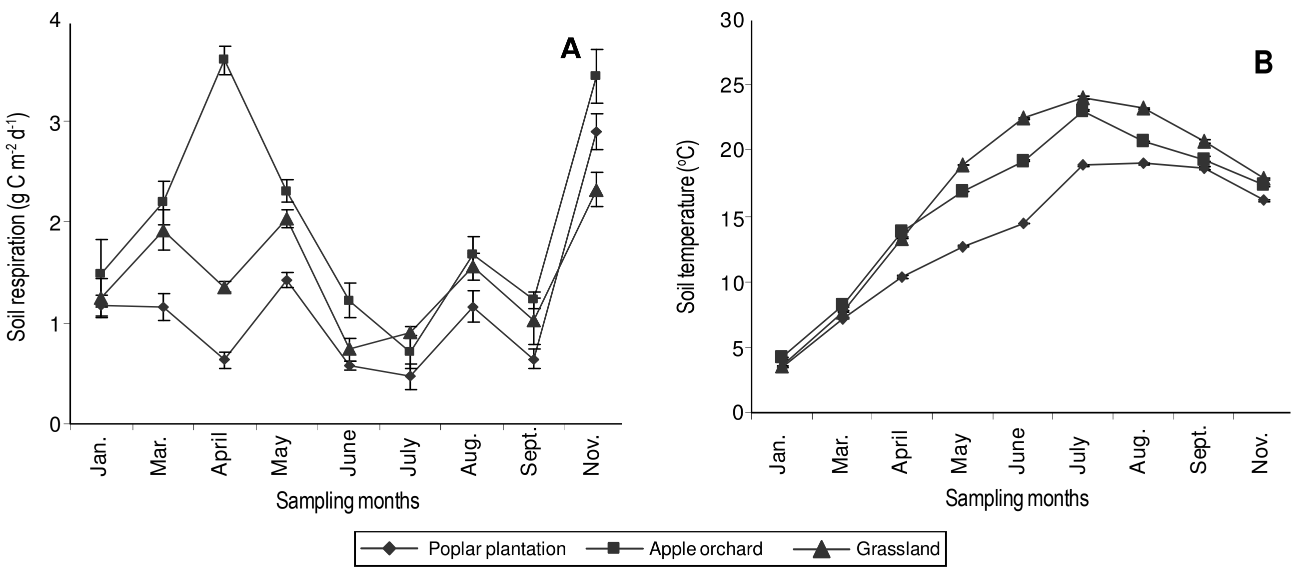

Fig. 1: Mean monthly (± 1 SE) soil respiration rates (A) and soil temperature (B) in apple orchard, grassland and poplar plantation sites

significant determinants of soil respiration in temperate latitudes (Kelting *et al.*, 1998; Raich and Tufekcioglu, 2000; Tufekcioglu *et al.*, 2001; Tufekcioglu and Kucuk, 2004). Hanson *et al.* (2000) stated that root/rhizosphere respiration can account for as little as 10 percent to greater than 90 percent of total in situ soil respiration depending on vegetation type and season of the year.

Soil temperature varied significantly among sites and sampling dates ($p<0.01$) (Fig. 1). Mean soil temperatures were 17.3, 18.5 and 14.7 in apple orchard, grassland and poplar sites, respectively. Soil temperatures in the apple orchard and grassland sites were significantly higher than in the poplar sites ($p<0.05$) (Table 1). There was no significant temperature difference between

Table - 2: Pearson correlation coefficients among measured variables in the study area (n=9). Soil properties; pH, organic matter, sand, silt and clay contents, belong to surface 15-35 cm depth. Asterisks refer the level of significance; *, p<0.05; **, p<0.01; ***, p<0.001

Variables	M	T	pH	SOC	FRB	Sand (%)	Clay (%)	Silt (%)
SR	-0.97***	0.56	-0.73*	0.87*	0.56	0,96***	-0.83***	-0.75*
M	1.0	-0.55	0.26	-0.88**	-0.59*	-0.98***	0.86**	0.75*
T		1.0	-0.01	0.24	0.19	0.60	-0.87*	-0.05
pH			1.0	-0.95**	-0.60	-0.77*	0.45	0.94**
SOC				1.0	0.62	0.91**	-0.66*	-0.91**
FRB					1.0	0.58	-0.45	-0.53

SR: Soil respiration (g C m^{-2} d^{-1}); SOC: Mean soil organic matter content (%), M: Mean soil moisture (%), T: Mean soil temperature (°C), FRB: Fine root biomass (Kg ha^{-1})

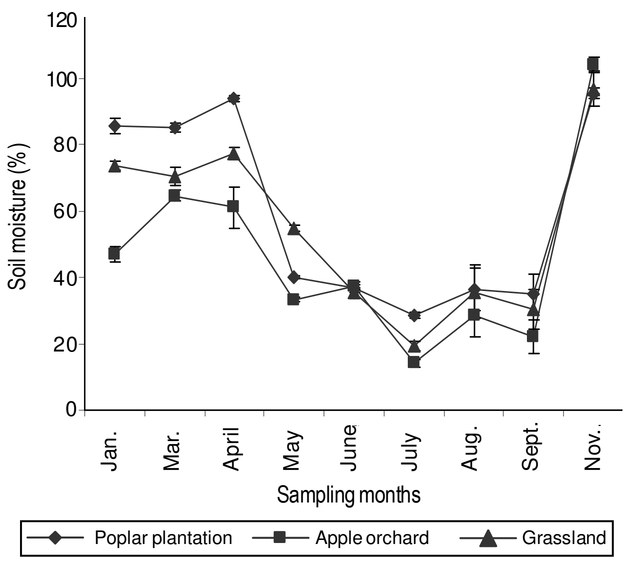

Fig. 2: Mean monthly (± SE) soil moisture contents (0-5 cm depth) in apple orchard, grassland and poplar plantation sites

grassland and apple orchard sites. Soil temperatures were significantly different among all sampling dates.

Soil moisture content differed significantly between sampling dates. Overall soil moisture contents were significantly higher in October than in the rest of the sampling dates (p<0.05) (Fig. 1). Mean soil moisture contents (average of eight sampling dates) were 47.7, 52.5 and 53.5% in apple orchard, grassland and poplar sites, respectively (Table 1). Poplar sites had significantly higher soil moisture content than apple orchard had. There were no significant soil moisture differences between poplar and grassland sites and between apple orchard and grassland sites. Higher soil moisture contents in grassland and poplar sites than in apple orchard was probably the result of higher clay contents in these sites.

Within sites, seasonal changes in soil respiration were correlated most highly with soil moisture. When all sites were considered together, mean daily soil respiration varied with soil temperature and moisture (r^2 = 0.15, p<0.05):

$$SR = 0.015M + 0.025\,T + 0.306$$

where SR is the soil respiration rate (g C m^{-2} d^{-1}), T is morning surface-soil (0-5 cm depth) temperature (°C) and M is surface-soil (0-5 cm depth) gravimetric moisture content (% H_2O). All three parameters were significant (p<0.01). According to stepwise regression results, 13 and 2% of variation in soil respiration can be explained by soil moisture and soil temperature, respectively. When we did the same analysis with summer values, we got an R^2 of 0.39 and stepwise regression analysis revealed no significant temperature effect, indicating very strong soil moisture control on summer soil respiration. Using only late fall, winter and spring values we got an R^2 of 0.19 and stepwise regression analysis revealed no significant soil moisture effect indicating significant soil temperature effect on soil respiration in this period.

Among sites, mean annual soil respiration rate correlated positively with subsurface soil (15-35 cm) sand and organic matter content and correlated negatively with mean soil moisture, subsurface soil (15-35 cm) pH, clay and silt contents (p<0.05) (Table 2). Soil respiration and soil sand content were positively correlated, suggesting that high soil temperatures were associated with sandy soils (Kantarci, 2000). Negative correlations with soil moisture, clay and silt contents indicate poor soil aeration due to high clay contents in soil.

For summary comparisons, annual soil respiration rates were estimated by calculating the average soil respiration rate per month over the duration of the study and assuming October, December and February respiration equaled the averages of the months before and after them. Annual soil respiration totaled 452 g C m^{-2} for poplar plantation, 732 g C m^{-2} for apple orchard and 546 g C m^{-2} for grassland sites. Annual carbon release values found in this study (452-732 g C m^{-2} y^{-1}) are within the ranges reported by others. Our poplar plantation values were lower than those found in poplar plantations in Iowa, USA (1140 g C m^{-2}) (Tufekcioglu *et al.*, 2001) and in Florida (845 g C m^{-2}) (Lee and Jose, 2003). Our grassland values were lower than those found in riparian grasslands in Iowa (1185 g C m^{-2}) (Tufekcioglu *et al.*, 2001) and close to those observed in tallgrass prairie by Risser *et al.* (1981) (660 g C m^{-2} y^{-1}), and Buyanovsky *et al.* (1987) (490 g C m^{-2} y^{-1}), who also used static, closed chamber techniques.

Rates in prairie ecosystems measured with dynamic IRGA-based systems include 450 g C m^{-2} y^{-1} in Missouri (Kucera and Kirkham, 1971), 720 g C m^{-2} y^{-1} in Wisconsin (Wagai *et al.*, 1998), and 1100-2100 g C m^{-2} y^{-1} in Kansas (Bremer *et al.*, 1998; Knapp *et al.*, 1998).

In this study, apple orchards had higher rates of soil respiration than did adjacent poplar plantations and grasslands. These higher rates of soil respiration are evidence of the high rates of biological activity and C cycling through the soil in apple orchards compared to poplar and grassland sites. Seasonal changes in soil respiration were significantly correlated with the soil temperature and moisture. Our results indicated that temperature was limiting during the winter and spring (cold and moist) and moisture was limiting during the summer as was typical under Mediterranean climate.

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