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Soil respiration and root biomass responses to burning in calabrian pine (*Pinus brutia*) stands in Edirne, Turkey

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Abstract: *In this study, soil properties and root biomass responses to prescribed fire were investigated in 25-30 year-old calabrian pine (Pinus brutia Ten.) stands in Edirne, Turkey. The stands were established by planting and were subjected to prescribed burning in July, 2005. Soil respiration rates were determined every two months using the soda-lime method over a two-year period. Fine (≥2 mm diameter) and small root (>2-5 mm diameter) biomass were sampled approximately bimonthly using the sequential coring method. Soil respiration rates in burned sites were significantly higher than in control sites during the summer season but there was no significant difference in the other seasons. Soil respiration rates were correlated significantly with soil moisture and soil temperature. Fine and small root biomass were significantly lower in burned sites than in control sites. Mean fine root biomass values were 3204 kg ha^{-1} for burned and 3772 kg ha^{-1} for control sites. Annual soil CO_2 releases totaled 515 g C m^{-2} for burned and 418 g C m^{-2} for control sites. Our results indicate that, depending on site conditions, fire could be used successfully as a tool in the management of calabrian pine stands in the study area.*

Key words: *Calabrian pine, Forest fire, Root biomass, Soil respiration, Soil properties*
PDF of full length paper is available online
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Introduction

Forest fires are one of the most important problems of the Ministry of Environment and Forestry in Turkey. According to a report published by the same ministry, about 74493 fire cases have been reported from 1937 to 2003 and 1 556 150 ha forest areas have been lost to fire during the same period (Anonymous, 2003). Further global temperature rises have increased the frequency and intensity of forest fires (Neary *et al*., 1999).

Fire causes significant changes in forest ecosystems. It is not only burns the aboveground biomass, but also influences belowground biomass dynamics and soil properties. Fire not only helps increase the decomposition of organic matters but also causes the plant nutrients bound to vegetation and organic dead material to get into soil and inflicts changes on the biological, physical and chemical properties of soil (Debano, 1998; Certini, 2005). Process of burning acts as a rapid mineralizing agent that releases nutrients instantaneously as contrasted to natural decomposition processes, which may require years or more (Debano, 1998).

Fire effects on forest soils and fertility have been studied intensively in the different parts of the world, but there hasn't been much work done in Turkey (Altun *et al*., 2004; Neyisci, 1989). Similarly, there are no studies done on how fire influence root biomass dynamics in forest ecosystems in Turkey. However, both soil respiration and root dynamics are important components of nutrient cycles in forest stands. 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.*, 1997). In addition, Parkin *et al.* (1996) stated that soil respiration is a good indicator of soil quality. Soil respiration also plays an important role in carbon (C) cycling in forest ecosystems, comprising approximately 49-55% of gross primary production (Raich and Tufekcioglu, 2000).

The objectives of this study were to compare soil respiration and root biomass in burned and unburned stands (controls) of calabrian pine (*Pinus brutia* Ten.) and identify the underlying environmental variables most likely causing differences in the measured variables.

Materials and Methods

The study site is located at Kesan Forest District in Edirne, Turkey. Elevation of the site is 100 m and mean slope is 10%. Mean annual rainfall is 570 mm and mean annual temperature is 14.3°C. Soil type is brown forest soil. The study area has a Mediterranean type climate with mild winters and hot-dry summers (Anonymous, 2000).

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The study was done in four young (25-30 years old) calabrian pine stands established by planting. The stands were burned in August, 2005. Root sampling was done in burned and adjacent control areas (one randomly established plots per stand) from September 2005 to May 2007 using the sequential coring method (Harris *et al*., 1977 and Tufekcioglu *et al*., 1999, 2003). The biomass of fine (≤ 2 mm diameter) and small (>2-5 mm diameter) roots were assessed by collecting six 35-cm deep, 6.4-cm diameter cores per plot at each sampling date. A total of 48 root samples were collected from the study area at each sampling date. 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 ≤2 mm (fine root) and >2-5 mm (small root). The roots from each size category were oven-dried at 65°C for 24 hr and weighed.

Soil respiration rates were measured approximately at two to three months interval at three randomly selected locations in each of the three plots per sites from September 2005 to May 2007 using the soda-lime method (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 (Tufekcioglu *et al.*, 2001).

Buckets of 20 cm tall and 27.5 cm in diameter were used as measurement chambers(three buckets per plots). 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, oven dried at 105°C for 24 hr, and 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 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.

Statistical comparisons were made using SPSS program. 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 with the Least Significant Difference test at α=0.05. The possible effects of soil properties and fine root biomass on soil respiration rates were evaluated with a correlation analysis.

Results and Discussion

Mean daily soil respiration ranged from 0.41 to 3.09 g C m^{-2} d^{-1} among all sites (Fig. 1). Mean daily soil respiration values measured in this study are within the ranges reported by Jurik *et al.* (1991), Lessard *et al.* (1994), Hudgens and Yavitt (1997), Schuur and Trumbore (2001), Wütrich *et al.* (2002) and Tufekcioglu *et al.* (2001 and 2004). There were significant differences in soil respiration among sampling dates. Soil respiration rates in May and July were significantly different than the other dates except September 2006. Highest rates were observed in May when there was enough soil moisture in soil, while lowest rates were observed in September when soil moisture was minimal. Soil respiration increased from September to December due to soil moisture increase and decreased from spring to fall because of limiting effects of soil moisture and high summer temperatures. Our results indicated that temperature was limiting during the late fall, winter and early spring, and moisture was limiting during the summer and early fall.

Overall, mean soil respiration rates in burned and control sites were 1.48 and 1.19 g C m^2 d^{-1}, respectively. Soil respiration rates were marginally significant between burned and controls sites ($p < 0.1$). However, ANOVA based on summer soil respiration data revealed significant difference between burned and control sites ($p < 0.05$). Our finding of higher soil respiration rates in burned sites were in consistent with those reported by Knapp *et al.* (1998), Schuur and Trumbore (2001), Tufekcioglu *et al.* (2001), Wütrich *et al.* (2002) and Xu and Wan (2008). The reasons behind these higher rates could be: the increase in the amount of dead roots, the decrease in the activity of live roots due to fire-killing of aboveground parts, the increase in decomposition rate of dead roots, the increased input of some nutrients into soil by ash and relatively higher soil temperatures in burned sites (Fig. 2A).

An increase in dead fine root biomass after fire was reported by Jose *et al.* (1982), Moya and Castro (1992) and Tufekcioglu *et al.* (1999). Dead roots provide carbon as an energy source and

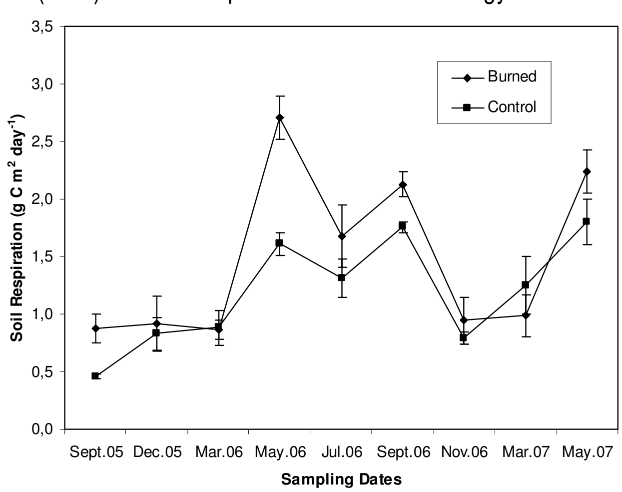

Fig. 1: Soil respiration in burned and control sites (bars indicate standard errors)

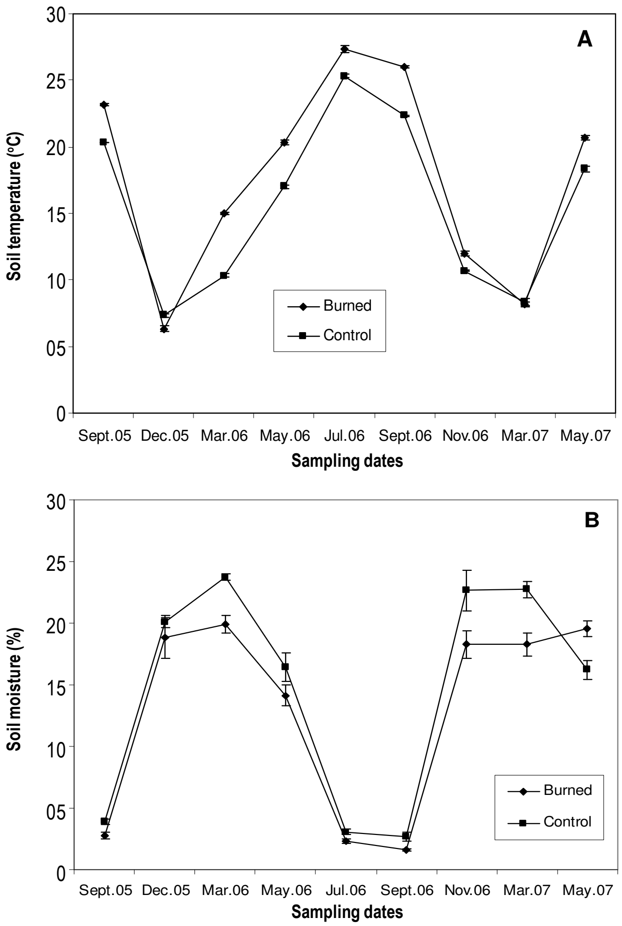

Fig. 2: Soil temperature (A) and soil moisture (B) in burned and control sites (bars indicate standard errors)

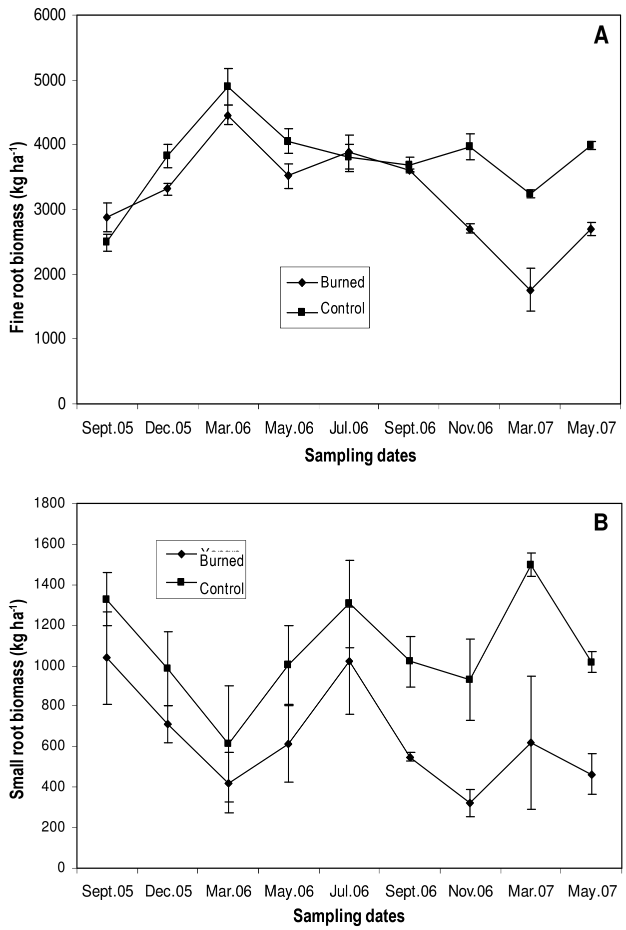

Fig. 3: Fine (A) and small (B) root biomass in burned and control sites (bars indicate standard errors)

nutrients for microbial biomass (Tufekcioglu *et al.*, 2001). Also volatilization of terpenoids and an increase in net N mineralization via removal of a portion of the forest floor could be the other reasons contributing higher rates of soil respiration in burned sites (DeLuca and Zouhar, 2000). Wardle *et al.* (1997) observed that microbial biomass levels were generally lower on fire-excluded islands in northern Sweden compared to islands exposed to more frequent fire intervals. In this study, soil phenolic concentrations on the fire-excluded islands were found to suppress microbial activity and the decomposition of organic materials.

Soil temperature and soil moisture differed significantly among sampling dates ($p < 0.01$) (Fig. 2A, 2B). Overall, there were no significant soil temperature and soil moisture differences between burned and control sites. However, ANOVA based on soil temperature data from May to September (2006) revealed significant difference between burned and control sites ($p < 0.05$). Mean soil temperatures in burned and control sites were 17.7 and 15.6°C, respectively. Mean soil moisture contents in burned and control sites were 12.9 and 14.6%, respectively.

Soil respiration was positively correlated with soil temperature and soil moisture ($p<0.05$). Both factors are significant determinants of soil respiration in temperate latitudes (Singh and Gupta, 1977; Kowalenko *et al.*, 1978; Davidson *et al.*, 1998; Raich and Tufekcioglu, 2000; Tufekcioglu *et al.*, 2001 and 2004). Kowalenko *et al.* (1978) reported that temperature was limiting during the winter and spring and moisture was limiting during the summer or fall on soil respiration in field soils in Canada.

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 ($r^2 = 0.43$, $p < 0.001$):

$$SR = 0.103\,T + 0.054\,M - 1.152$$

where SR is the soil respiration rate ($g\,C\,m^{-2}\,d^{-1}$), T is soil temperature (°C) and M is soil gravimetric moisture content (% H_2O). All three parameters were significant ($p < 0.01$). According to step-wise regression results, 29 and 14% of variation in soil respiration explained by soil temperature and soil moisture, respectively. Among sites, overall soil respiration rates were marginally correlated with soil temperature ($r = 0.77$, $p < 0.07$) and soil moisture ($r = -0.79$, $p < 0.06$).

Mean fine root biomass values were 3204 kg ha^{-1} for burned and 3772 kg ha^{-1} for control sites (Fig. 3A). Mean small root biomass was 641 kg ha^{-1} in burned sites and 1078 kg ha^{-1} in control sites (Fig. 3B). Fine and small root biomass were significantly lower in burned sites compared to controls ($p < 0.05$). These were probably the result of fire killing of aboveground vegetation in burned sites. Similar results were observed by Dress and Boerner (2001) in an oak-hickory forest in Ohio, USA. They found lower live fine root biomass in burned stands compared to controls. Renkin and Despain (2001) observed lower total root biomass in a burned aspen forest. Snyman (2005) reported decreased root production in a semi-arid South African grassland fallowing fire. Overall, fine and small root biomass differed significantly among sampling dates ($p < 0.02$). “There was no significant correlation between fine root biomass and soil respiration.”

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 January and February respiration equaled the average of the March and December rates. Annual soil respiration totaled 515 g C m^{-2} for burned and 418 g C m^{-2} for control sites. Annual soil CO_2 releases totaled 515 g C m^{-2} for burned and 418 g C m^{-2} for control sites. Annual carbon release values found in this study are within the ranges reported by others for forest and grassland ecosystems. Our values were close to those reported by Hart *et al.* (2005) (476 g C m^{-2} yr^{-1}) for ponderosa pine stands and by Risser *et al.* (1981) (660 g C m^{-2} yr^{-1}), Kucera and Kirkham (1971) (450 g C m^{-2} yr^{-1}) and Buyanovsky *et al.* (1987) (490 g C m^{-2} yr^{-1}) for grasslands.

Higher rates of soil respiration and lower fine root biomass in burned stands suggest that fire has improved soil biological activity in burned stands compared to control stands. Annual soil carbon releases to the atmosphere were accelerated by the fire in these mediterranean sites during the study period. From soil biological point of view, our results indicate that fire could be successfully used in the management of these Calabrian pine stands.

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