

Effects of forest fire on soil nutrients in Turkish pine (*Pinus brutia*, Ten) Ecosystems

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Abstract: Fire is a long-standing and poorly understood component of the Mediterranean forestlands in Turkey. Fire can alter plant composition, destroy biomass, alter soil physical and chemical properties and reduce soil nutrient pools. However, fire can also promote productivity of certain ecosystems by mineralizing soil nutrients and promoting fast growing nitrogen fixing plant species. Fire effects on soils and ecosystems in Turkey and Mediterranean regions are not well understood. This study, uses a retrospective space-for-time substitution to study soil macro-nutrient changes on sites which were burned at different times during the last 8 years. The study sites are in the Fethiye Forest Management Directorate in the western Mediterranean Sea region of Turkey. Our samples show 40% less Soil C, and cation exchange capacity (CEC) at 0-20 cm soil depth two weeks after the fire. Soil C and CEC appear to recover to pre-fire level in one year. Concentrations of Mg were significantly lower on new-burn sites, but returned to pre-fire levels in one year. Total soil N concentrations one and two years after fire were 90% higher than other sites, and total P was 9 times higher on new-burn site than averages from other sites. Some implications of these results for forest managers are discussed.

Key words: Fire, Soil nutrients, Turkish pine

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Introduction

Fire is one of the oldest and most widely used tools used by humans to change forests globally and in the Mediterranean. Between 1937 and 2004, 1.5 million ha of forestlands were burned in Turkey alone. Some sources suggest that 13 % or more of these fires were deliberate (Anonymous, 2006). Apart from the long history of human-set fires in the regions forestland, vegetation on the Mediterranean coast is fire prone and, as a result, foresters in Turkey tend to view fire as a threat to forests rather than a component of disturbance prone ecosystems. Currently no data are available to quantify the effects of fire on forest ecosystem biomass and nutrient pools following fire, and as a result, the range of fire effects (positive or negative) on forests cannot be accurately described or compared among fires or forest types.

Fire is a critically important disturbance agent in the Mediterranean forestlands in Turkey. Fire can change plant composition, destroy biomass and organic matter altering soil chemical and physical properties and increasing susceptibility to erosion (DeBano *et al.*, 1998). Fires may also play a significant role in regulating ecosystem productivity and diversity by promoting mineralization of nutrients stored in organic matter, and allowing the invasion of rapid growing early successional species (Busse *et al.*, 1996; DeBano *et al.*, 1998; Boerner *et al.*, 2009).

Since the effects of fire are controlled by too many factors specific to individual fires (e.g., frequency of fires with similar severity), soils (texture, antecedent moisture and local distribution of nutrient pools) and forest types (species composition, age, stand structure, etc.), it is not appropriate to assert *a priori* whether

the overall effects of fire are beneficial or harmful to any given forest ecosystem. The role of fires in this region is important and poorly understood, therefore, the objective of this study was to investigate changes in some of the soil chemical properties including, macronutrient concentrations, pH and CEC following wildfires using existing field conditions and conventional soil analytical tools. Results from this study would provide insight into potential fire effects on nutrient pools and also give some direction for badly needed future research.

Materials and Methods

The study sites were located in the Fethiye Forest Management Directorate in the western Mediterranean Sea region of Turkey (N 36° 35' 13"-36° 43'-52" and E 29° 09' 40"-29° 13' 52"). In this study, soil macro-nutrient changes were investigated on sites which were burned with wildfires at different times over the last 8 years. Sites 1-5 were burned as follows: 1-two weeks before sampling (new-burn), 2-one-year-old burn (burned 2003), 3- two-year-old burn (burned 2002), 4 - eight year old burn (1996), and 5-unburned control sites adjacent to the burned sites (forest with no evidence of a recent burn).

Mediterranean climate is characterized by hot dry summers and cool moist winters and supports evergreen sclerophyllous vegetation which is adapted to drought and low soil nutrients (Whittaker, 1977). The mean annual temperature is 17 °C with 800 mm of annual precipitation. The soils type is classified as karstic, terra rossa (Atalay, 1989). Soils generally range in depth to bedrock from 20-30 cm on hillslopes to >1 m on colluvial accumulations and ridges. *Pinus brutia* Ten, a relatively drought tolerant species, is



the dominant tree on the sites up to 1000 m elevation. The understory layer contains fire adapted secondary successional maquis formations (Kaya and Raynal, 2001).

Wildfires in this area typically consume the forest floor, removing understory and weedy plants. Total forest floor organic matter (OM) on the unburned control sites was estimated at 27000 kg ha⁻¹.

In the summer of 2004, two sets of 100 cm³ intact soil core samples were taken from 0-10 and 10-20 cm depths at five randomly chosen locations on each site. One set of soil samples was dried at 105°C in the lab for 24 hr to determine soil moisture content and calculate bulk density. The other sample set was air-dried and the 2 mm < size fraction was prepared for chemical analysis. Total soil C was analyzed using a dry combustion method in a LECO CNS 2000 Carbon Analyzer (Nelson and Sommers, 1996). Total soil N was analyzed after samples were digested using the micro-Kjeldahl method (Kjeltec Auto 1030 Model) (Bremner, 1996). Total soil P and total S were determined using a Spectronic Colorimeter, after digesting samples in nitric and perchloric acid, respectively (Kuo, 1996; Tabatabai, 1996). Exchangeable cations (K, Ca and Mg) were extracted with ammonium acetate (Suarez, 1996). Calcium and Mg were determined using a Perkin-Elmer 3110 atomic absorption spectrometer (AAS). Potassium was determined using a Jenway Flame Photometer. Cation exchange capacity (CEC) was determined from NH₄OAc extraction (Sumner and Miller, 1996). Soil pH was measured from air-dried samples placed in deionized H₂O using a pH meter (Thomas, 1996).

Table - 1: Mean values and SE* of soil pH, bulk density and cation exchange capacity (CEC) in Turkish pine forests burned at different times

Treatment methods	pH*	Bulk density (g cm ⁻³)	CEC (Cmol _c kg ⁻¹ soil)
Unburned-forest	7.1 ± 0.3 ^a	1.04 ± 0.07 ^a	26 ± 0.4 ^a
New-burn	7.3 ± 1.3 ^a	0.94 ± 0.07 ^a	16 ± 1.3 ^b
One-year burn	6.8 ± 0.7 ^a	1.16 ± 0.09 ^a	28 ± 1.2 ^a
Two-year burn	7.2 ± 0.02 ^a	1.00 ± 0.03 ^a	27 ± 0.4 ^a
Eight-year burn	6.7 ± 0.04 ^a	0.99 ± 0.04 ^a	25 ± 0.4 ^a

* Within a column, means with a common lowercase letter are not significantly different at p < 0.05

Table - 2: Mean values and SE* of soil macronutrient concentrations in Turkish pine forests burned at different times

Treatment methods	Total				Exchangeable		
	C (%)*	N (%)	P (mg kg ⁻¹)	S (mg kg ⁻¹)	Ca (mg kg ⁻¹)	K (mg kg ⁻¹)	Mg (mg kg ⁻¹)
Unburned-forest	2.8 ± 0.08 ^a	0.16 ± 0.01 ^b	27 ± 4.8 ^b	415 ± 107 ^a	4040 ± 543 ^a	250 ± 55 ^a	664 ± 47 ^a
New-burn	1.7 ± 0.1 ^b	0.15 ± 0.01 ^b	246 ± 16 ^a	417 ± 65 ^a	3558 ± 18 ^a	331 ± 12 ^a	358 ± 53 ^b
One-year burn	3 ± 0.09 ^a	0.24 ± 0.006 ^a	35 ± 3.6 ^b	263 ± 22 ^a	3594 ± 109 ^a	334 ± 3 ^a	718 ± 84 ^a
Two-year burn	3 ± 0.01 ^a	0.29 ± 0.009 ^a	34 ± 4 ^b	226 ± 3 ^a	4611 ± 615 ^a	339 ± 90 ^a	594 ± 168 ^{ba}
Eight-year burn	2.9 ± 0.03 ^a	0.11 ± 0.03 ^b	14 ± 1.7 ^b	216 ± 15 ^a	4079 ± 80 ^a	149 ± 4.7 ^a	729 ± 84 ^a

C = Carbon, N = Nitrogen, P = Phosphorus, S = Sulphur, Ca = Calcium, K = Potassium, Mg = Magnesium, * = Within a column, means with a common lowercase letter are not significantly different at p < 0.05

After conducting a one-way ANOVA, Scheffe's mean separation test was performed to differentiate the means of variables for each location. SAS was used for all statistical analyses (SAS Institute, Inc., 1996). Results were considered significant at p < 0.01.

Results and Discussion

Soil pH and bulk density were similar across the sites at 0-20 cm soil depth (Table 1). However significant differences in soil CEC were found among the sites (p < 0.0001). Although soil CEC was down 40% immediately after fire on one year and older burn sites it was similar to pre-fire levels (Table 1).

Our results suggest that there were differences (p < 0.0001) among sites in 0-20 cm soil C, N, P and Mg concentrations. Two weeks after fire, soil C concentrations were 40% lower than other sites, and soil total N concentrations one and two years after fire were 90% higher than the other sites. New-burn site samples had almost 9 times more total P than the average P concentrations of samples from the other sites. Mg concentrations were significantly reduced after fire but, it returned to the pre-fire conditions in the following years (Table 2).

Soil CEC values of samples collected two weeks after fire were 40% less than samples from unburned sites. However, in samples collected one year following fire CEC had returned to pre-fire levels. Soil OM plays a significant role in CEC (Wild, 1988; Tiessen *et al.*, 1994). In this study, results suggest an average loss of 27000 kg ha⁻¹ of forest floor OM; these losses presumably account for the reduction in CEC.

Organic matter is an important source of most available nutrients. Organic matter also provides chemically active cation exchange sites that retain soluble cations including NH₄⁺, K, Ca, and Mg (Waring and Running, 1998). Fire causes rapid loss of OM which can occur at temperatures below 100°C, between 250 and 400°C phenolic (OH) and carboxyl (COOH) groups are lost (DeBano *et al.*, 1998). It is not known whether any erosion caused nutrient losses after the fires and before sampling. However, little or no evidence of surface erosion was noted during fieldwork. Two weeks after fire, soil C and Mg concentrations were reduced by 40 and 47% compared to the unburned sites, but returned to pre-fire levels in samples collected one year after burning.

Nitrogen loss via volatilization occurs at temperatures < 50°C (DeBano *et al.*, 1998). However, ammonium can be formed during decomposition of secondary amide and amino acids. DeBano *et al.* (1998) report that large amounts of ammonium can be found in the ash and underlying soil after low severity fires. Thus, soil total N concentrations one and two years after fire were almost 90% more than the other sites in the current study. These results are consistent with lower severity fire and suggest massive mineralization of site stored N. These findings suggest vulnerability of these mineralized pools to erosion or solution export during heavy rains following fires (Boerner *et al.*, 2009).

Pre-fire P is contained in organic matter or inorganic minerals. Organic P is slowly mineralized during decomposition of organic matter. Relatively large amounts of highly available P can be found in the ash and on the soil surface immediately after some fires (DeBano *et al.*, 1998). In the new-burn sites, there was almost 9 times more total P than the average P concentrations of the other sites. Available P can be immobilized in alkaline soils by forming insoluble apatite-like precipitates if enough Ca ions are present (Dumontet *et al.*, 1996). Regional soils tend to be calcareous, suggesting that P availability may be limited even when high concentrations are present in the soil.

Even though fire can cause losses of nutrients to the atmosphere via volatilization, fly-ash and leaching through the soil, concentrations of K, P and divalent cations in ash usually increase due to releases caused by burning, decreased uptake by plants and increased microbial mineralization due to increased soil moisture (Dumontet *et al.*, 1996; Korb *et al.*, 2004).

Precipitation which does not cause runoff and erosion can dissolve the ash on the soil surface and carry the chemical elements down into the profile soil, where the ions are susceptible to losses by leaching past the root zone. Erosion losses (either in solution or in suspension in runoff) vary with distribution of ash, slope, infiltration capacity of the soil after the fire, and the amount and duration of rainfall after fire. Losses to ground water are greatest for K followed by NH_4^+ , Mg and Ca. Importance of leaching depends on the amount of leaching, the proportion of leached ions held by the soil strata, and the distribution of roots or fungal mycelia capable of taking up soluble ions. Nutrient losses by leaching and erosion decrease with time as the vegetation becomes reestablished and total runoff and erosion potential caused by fires is diminished.

From the above it may be concluded that OM losses during fire may have the largest effect, resulting in the on result site's nutrient depletion in these infertile forestlands. Even though, fire result in losses of nutrients to the atmosphere *via* volatilizations, fly-ash and leaching through the soil, concentration of N and P in soil increases. These changes may have species specific benefits for some plants by increasing the short-term availability of nutrients for plant growth. Turkish foresters are reluctant to use fire in forestlands,

however, in some cases prescribed fires with lower severity and higher frequency may act as a mineralizing agent increasing the short-term availability of nutrients in regeneration sites.

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