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Effect of fire on soil nutrients and under storey vegetation in Chir pine forest in Garhwal Himalaya, India

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ABSTRACT

The study was carried out in the *Pinus roxburghii* Sargent (Chir pine) forest in the sub-tropical region of Garhwal Himalaya to assess the effect of fire on soil nutrient status at different altitudes (700 m, 800 m and 1000 m), soil depths (0–20 cm, 20–40 cm and 40–60 cm) and on under storey vegetation. The soil nutrients and under storey vegetation were assessed before fire (pre-fire) and after fire (post-fire). The results of the study indicate that fire plays an important role in soil nutrient status and under storey vegetation. The nutrients (soil organic carbon, nitrogen, phosphorus and potassium), decreased in post-fire assessment and with increasing altitudes, and soil depths, compared to pre-fire assessment. The under storey vegetation diminished after fire in all forest sites. The study concludes that in Chir pine forest, fire plays a role in reducing soil nutrients along the altitudinal gradient, soil depths and under storey vegetation. Thus, these nutrients can be saved through some management practices e.g. by early controlled burning and by educating local villagers about the negative impacts of severe wild fires on soil and vegetation.

1. Introduction

In the Himalayan region, forest fire damages flora, fauna, human livelihoods, and the local climate every year. The Chir Pine (*Pinus roxburghii*) forests are more prone to forest fire because they shed their resin containing leaves during summer. The fire cycle in the forests generally repeats every year, and face problems every year. The reasons of forest fire may vary, but ignition is set often intentionally to disrupt forest operations. Literature on forest fires in Indian forests shows that fire plays a vital role in context to damages throughout the country. The available evidence suggests that fires are employed deliberately to maintain grasses for cattle, and also facilitate the collection of fodder and several non-wood forest products.

P. roxburghii is a large evergreen tree with a rounded or umbrella shaped crown and massive branch system [34]. Disturbed sites that create large canopy openings and exposed topsoil are widely reported to promote stands of *P. roxburghii* [28]. The trees are used for construction, firewood, fencing posts, and the forest is often used for livestock grazing and leaf litter collection. Ironically, these are the most favoured species for house construction and other uses because of its straight bole and ease of carving.

Fire as a disturbance agent plays a vital role in *P. roxburghii*, *Picea spinulosa* and *Pinus wallichianna* forests [26]. These forests become extremely vulnerable to fires when they are located on dry sites. Pure stands of *P. wallichianna* and *P. roxburghii* forests are destroyed by fire every year, though the matured stands of later are more resistant to fire than the former. Under fire influence, the chemical structure of soil organic matter (SOM) can be altered through partial combustion and through the production of highly recalcitrant black C [22]. Changes in soil structure can influence decomposability [3] and hydrophobicity [10]. Impact of fire tends to vary according to wind and weather conditions [17]. For all these reasons, there is significant variability in the combustion losses of soil C and nutrients during wildfire and estimates of SOM, C, and nutrient changes associated with fire remain highly uncertain. Fire plays a critical role in soil energy and C balance as it combusts SOM, reducing the depth, and changing the structure of SOM, altering chemical composition, increasing noncombustible elements and nutrient abundance [15], and potentially increasing [29] or decreasing [35] nitrogen (N) availability.

The effect of fire on the nutrients of an ecosystem depends on the type and frequency of fire, the available fuel load, time and season of the burn, vegetation type, topography and post-fire climatic conditions of the site [33]. A fire of mild intensity may stimulate seedling establishment and growth by increasing temperature and nutrient status of soil by removal of litter and vegetation cover [25]. Depending on the type of fire, the availability of nutrients for plant uptake increases, or they can be volatilized and lost from the site. Fire may have different effect on nutrients either causing

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direct loss through the transfer of nutrients to the atmosphere as gases [30], or indirect losses by erosion of ash and soil during storms [21]. The studies on effect of fire on the nutrients status in Himalayan forest are very limited [1,4]. Although the studies on nutrient status along altitudinal gradients and depths and effect of fire on understorey vegetation have so far not been carried out by any worker in *P. roxburghii* forests in Garhwal Himalayas.

The hypothesis for this study was that, (i) does fire influence the soil nutrients at different altitudes and soil depths. (ii) does fire influence the under storey vegetation. Therefore, the present study was carried out in *P. roxburghii* forest to understand the influence of fire on nutrient status (SOC, N, P and K) and under storey vegetation.

2. Materials and methods

2.1. Study area

The study sites was located at 30°13′N78°47′E and 30°13.2′N78°46.8′E on northern aspect near Srinagar Garhwal in Garhwal Himalaya. Three sites of *P. roxburghii* forest were selected along the altitudinal gradient at 700, 800 and 1000 m above sea level. *P. roxburghii* forest is found naturally on a variety of geological formations. In the Himalayan valley, considerable stretches of Chir pine forests are found on quartzite, where the trees attain large dimensions. If quartzite occurs in higher altitudes, *P. roxburghii* may reach a higher limit. It is a hardy species and can grow on poor soil conditions but depth and porosity of the soils have an important effect on its growth. The common understorey species were *Acchmanthan gosspina*, *Rhus parviflora* and *Carrissa spinarum*, etc.

The climate of the region is monsoonic and can be divided into summer, rainy and winter seasons. The temperature ranges from 12.8 °C in December–January to 32 °C in April–June. The mean monthly rainfall in the area ranges between 129 mm (July) and 600 mm (August). The other details of the study area are presented in Table 1. The soils of the area are well drained and acidic in nature. Fire was severe on the site and burned almost all underground vegetation and woody perennial shrubs, while trees were temporary affected by blighting of bark and wilting of leaves and some trees were totally damaged by fire (Plate d). The weather conditions of the sites are slightly hotter (temperature) approximately 25–30 °C (mid April). The air movements are slow but some times it increases the intensity of fire. The sampling period of study was from February 2009 to May 2009, during this period no rainfall was found.

2.2. Data collection and analysis

Soil samples were collected randomly in the month of February–March 2009 for the analysis of pre-fire nutrient status from each altitude at three different depths (0–20, 20–40 and 40–60 cm). A total of 27 samples were collected in pre-fire conditions, and similarly soil sampling was repeated for the post-fire in May–June 2009. The post-fire samples were collected close to the previous sampling area to avoid sampling error at sites. The soil samples were analyzed for soil organic carbon (SOC), nitrogen (N), phosphorus (P), and potassium (K). SOC was estimated according to Walkley and Black method [37]. Nitrogen was estimated by Kjeldahl and phosphorous and potassium as described by Jackson [19].

The phytosociological analysis of under storey vegetation was done especially for shrubs closer to collected soil samples (pre-fire and post-fire) area by laying quadrat (each of 1 m × 1 m size) randomly at each altitude. The vegetation data was quantitatively analyzed for density and frequency [7].

3. Results

3.1. Effect of fire on soil nutrients at different depths

The nutrients of the collected soil samples were analyzed along the altitudinal gradient at different soil depths under pre-fire and post-fire conditions. At 700 m altitude, the percentage of SOC (pre-fire) was 1.02 ± 0.03 (0–20 cm), 0.8 ± 0.08 (20–40 cm) and 0.42 ± 0.03% (40–60 cm) and under post-fire, SOC was 0.96 ± 0.06, 0.78 ± 0.1 and 0.33 ± 0.05% for respective depths. Nitrogen in pre-fire site was 0.051 ± 0.002, 0.04 ± 0.004 and 0.021 ± 0.002%, but in post-fire areas the values of nitrogen reduced as: 0.045 ± 0.007, 0.035 ± 0.007 and 0.018 ± 0.003% in the depths of 0–20, 20–40 and 40–60 cm respectively. The values of phosphorus also decreased from 24.67 ± 2.27 to 21.61 ± 2.09, 22.29 ± 2.27 to 19.54 ± 1.67 and 19.34 ± 2.75 to 17.46 ± 0.41 kg ha^{-1} from pre-fire to post-fire in the depths of 0–20, 20–40 and 40–60 cm respectively. Potassium also followed same decreasing trend from pre-fire to post-fire viz; 146.35 ± 10.10 to 103.6 ± 2.37, 114.61 ± 11.97 to 90.72 ± 1.58 and 88.48 ± 7.35 to 83.44 ± 7.12 kg ha^{-1} respectively. (Table 2).

The pattern was also same at 800 m altitude, where percentage of SOC decreased with increasing depth from 1.07 ± 0.15 (0–20 cm) to 0.28 ± 0.04 (40–60 cm) and declined to 1.0 ± 0.06 to 0.20 ± 0.02% in pre and post-fire respectively. The values of NPK in the upper soil level (0–20 cm) of pre-fire were 0.053 ± 0.013%, 25.94 ± 1.12 kg ha^{-1} and 118.24 ± 47.86 kg ha^{-1} which decreased with increasing depths to 0.014 ± 0.001%, 21.90 ± 2.05 kg ha^{-1} and 89.98 ± 5.05 kg ha^{-1} (at 40–60 cm). Nitrogen and phosphorus values decreased in post-fire at all soil depths, however Potassium increased in post-fire in the upper most soil stratum from 118.24 ± 47.86 to 122.08 ± 12.11 kg ha^{-1} and decreased in the lower depths (Table 2). At 1000 m altitude, the trend was also similar for all the depths. The SOC and NPK decreased with increasing

Table 1
Characteristics of the study site throughout the year.

Parameter	Jan 2009	Feb.	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec 2009
Study period		■	■	■	■	■						
Prefire soil collection		■	■									
Post fire soil collection					■	■						
No rains		■	■	■	■	■						
Low temperature	■	■										
Moderate temperature			■	■								
High temperature					■	■						
Winter season	■	■									■	■
Spring season			■									
Summer season				■	■	■						
Rainy season							■	■				
Fire Season				■	■							
No fire	■	■	■			■	■	■	■	■	■	■

Plate: Show effect of fire on *Pinus roxburghii* forests.

Table 2
Soil nutrient status (±standard deviation) of pre-fire and postfire along altitudinal gradients in pine forest.

Elevation (m asl)	Depth	SOC (%)		Nitrogen (%)		Phosphorus (kg ha^{-1})		Potassium (kg ha^{-1})	
		Pre-fire	Post-fire	Pre-fire	Post-fire	Pre-fire	Post-fire	Pre-fire	Post-fire
700 m	0–20	1.02 ± 0.03	0.96 ± 0.06	0.051 ± 0.002	0.045 ± 0.007	24.67 ± 2.27	21.61 ± 2.09	146.35 ± 10.10	103.6 ± 2.37
	20–40	0.8 ± 0.08	0.78 ± 0.1	0.04 ± 0.004	0.035 ± 0.007	22.29 ± 2.27	19.54 ± 1.67	114.61 ± 11.97	90.72 ± 1.58
	40–60	0.42 ± 0.03	0.33 ± 0.05	0.021 ± 0.002	0.018 ± 0.003	19.34 ± 2.75	17.46 ± 0.41	88.48 ± 7.35	83.44 ± 7.12
800 m	0–20	1.07 ± 0.15	1.0 ± 0.06	0.053 ± 0.013	0.049 ± 0.003	25.94 ± 1.12	23.58 ± 1.23	118.24 ± 47.86	122.08 ± 12.11
	20–40	0.535 ± 0.07	0.66 ± 0.08	0.028 ± 0.003	0.033 ± 0.004	23.58 ± 1.51	21.8 ± 1.46	115.36 ± 1.11	92.96 ± 5.13
	40–60	0.28 ± 0.04	0.20 ± 0.02	0.014 ± 0.001	0.01 ± 0.001	21.90 ± 2.05	20.13 ± 2.07	89.98 ± 5.05	70.19 ± 2.32
1000 m	0–20	1.125 ± 0.05	1.02 ± 0.02	0.056 ± 0.004	0.051 ± 0.001	26.25 ± 1.09	25.45 ± 0.29	114.96 ± 79.63	120.58 ± 1.29
	20–40	0.505 ± 0.12	0.63 ± 0.25	0.025 ± 0.005	0.031 ± 0.012	24.47 ± 1.04	24.07 ± 0.17	113.49 ± 1.72	64.86 ± 46.93
	40–60	0.256 ± 0.14	0.15 ± 0.008	0.013 ± 0.005	0.007 ± 0.0005	21.80 ± 0.76	21.8 ± 0.45	86.99 ± 9.39	72.11 ± 6.16

depths, and it was also reduced in post-fire in all the depths, except for potassium at top layer (0–20 cm) which increased from 114.96 ± 79.63 to 120.58 ± 1.29 kg ha^{-1} (Table 2).

3.2. Effect of fire on soil nutrients at different altitudes

The soil organic carbon decreased with increasing altitude from 0.75 ± 0.05 (700 m asl) to 0.62 ± 0.10% (1000 m asl) in pre-fire and 0.69 ± 0.32 to 0.60 ± 0.43% in post-fire conditions for respective altitudes (Fig. 1a). Nitrogen decreased in post-fire and also decreased with increasing altitude (Fig. 1). Phosphorus values were lower in post-fire sites as the values increased with increasing altitudes. The values for phosphorus ranged between 22.10 (700 m) to 24.18 kg ha^{-1} (1000 m) for pre-fire and 19.53 (700 m) to 23.77 kg ha^{-1} (1000 m) for post-fire soils (Fig. 1b). Potassium decreased in post-fire compared to pre-fire. The values of potassium were 105.15 (1000 m) to 116.48 kg ha^{-1} (700 m) for pre-fire and 85.85 (1000 m) to 95.07 kg ha^{-1} (800 m) for post-fire respectively.

3.3. Effect of fire on under storey vegetation

The effect of fire on under storey vegetation was also assessed and the dominant shrub species at different altitudes are shown in Table 3. The density of under storey species greatly decreased after fire (Plates c and d), and the number of species declined very much immediately after fire (Table 3). Among the species *Rhus parviflora* was the most resistant to fires as this species was severely damaged by fire but survived.

4. Discussions

Fire as a disturbing agent plays a vital role in many coniferous forests, and particularly *P. roxburghii*, *P. spinulosa* and

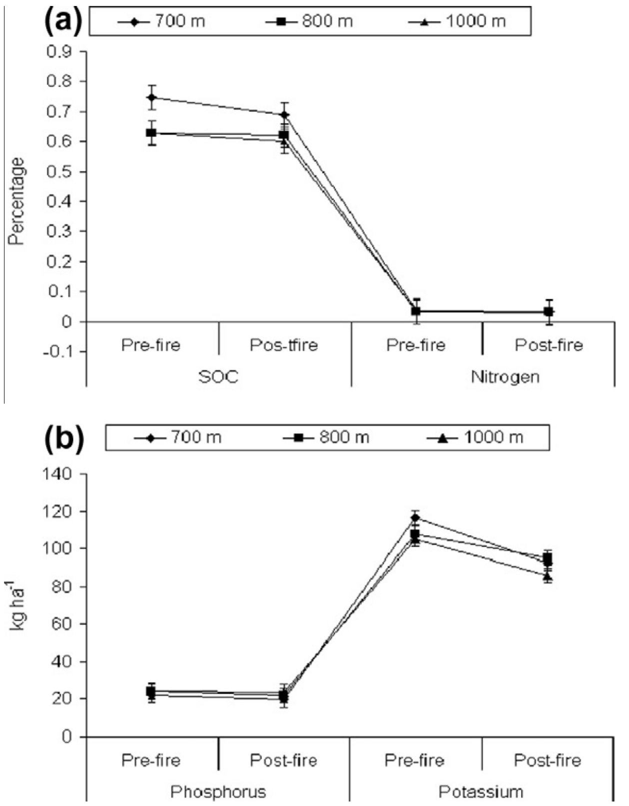

Fig. 1. (a and b) Show the soil nutrient status (pre-fire and post-fire) along altitudinal gradients in pine forest.

P. wallichianna are no exception [26]. These forests are extremely vulnerable to fires when they are located on dry sites. Dense, wilting grass cover; especially, in March and April provide highly inflammable litter on the forest floor (Plate a). Pure stands of *P. roxburghii* (Plate a) forest are destroyed by severe fires every year (Plates e and f).

The SOC in both pre-fire and post-fire conditions decreased with increasing soil depth. It is clear that fire played important role in reducing SOC. Nitrogen also followed a similar trend. Phosphorus also decreased with depth, but potassium comparatively increased in post-fire areas.

The study shows that nutrient levels declined with altitudes and soil depth in *P. roxburghii* forests, and that nutrient levels were reduced after fire. Several authors [24,23,11] have documented losses of nitrogen during fires due to volatilization. Nitrogen is essential for growth of soil microflora and fauna which are essential for the growth and development of higher plants, so nitrogen could impact growth significantly. Various studies [27,20] have found that boreal ecosystems are one of the largest terrestrial reservoirs of soil organic carbon and are prone to relatively frequent and severe wildfires. Wildfires that penetrate soil organic horizons reverse the accumulation of surface SOM. Wildfires, through the combustion losses of nitrogen, also affect nutrient content and availability in boreal ecosystems [16] and change in noncombustible element content [5,15]. As soils burn, the chemical structure of SOM can be altered through partial combustion or alteration of SOM and through the production of highly recalcitrant black C [22]. For all these reasons, there is significant variability in the combustion losses of soil C and nutrients during wildfire and estimates of SOM, C and nutrient changes associated with fire remain highly uncertain. Our study found that the existing shrub cover in the forest was very low after fire (Table 3). Rego et al. [32] also assessed the changes in under storey vegetation in maritime pine forests; and observed a decrease in shrub cover after fire. Amounts of nutrients in an ecosystem may be relatively stable or may be changing in quantity depending on the net gain and loss of nutrients by various input and output processes. Fire may cause direct losses through the transfer of the nutrients to the atmosphere as gases and particulates [30] while indirect losses may result from erosion of ash and soil during storms. Kellman and Sanmugadas [21] as the present study showed the losses in the entire nutrient after fire. Similar studies conducted in the West Gulf Coastal Plain of southeastern Arkansas in loblolly pine forests also showed the losses of nutrients (N, P, K, Mg and S) after fire on the forest floor. Several other researchers [2,14,6] also reported the losses in nutrient content after fire.

Various authors have also reported that there is a considerable loss of the total amount of some nutrients such as nitrogen and phosphorus after a fire ([9,31,36]). A reduction in the ability of soil to absorb phosphorus could be due to greater phosphoric mobility, characteristic of the ash-bed-effect, which is produced after a fire [18]. In the case of nitrogen, according to Kellman and Sanmugadas [21], the low proportion lost could be attributed to the capacity of the soil to immobilize rapidly any large quantity of nutrients in solution. This could have happened because slight rains were

Table 3
Effect of fire on the ecological parameter (frequency and density) of under storey vegetation.

Elevation (m asl)	Name of the species	Frequency (%)		Density (plants/m^2)	
		Pre-fire	Post-fire	Pre-fire	Post-fire
700 m	*Acchmanthan gosspina*	80	30	12.2	6.1
	Rhus parviflora Roxb.	80	50	9.8	4.5
	Asparagus racemosus Willd.	100	–	11	–
	Carrissa spinarum auct.nun. L.	20	–	1.2	–
	Mallotus philippensis (Lam.) Muell. Arg.	20	–	0.8	–
800 m	*Acchmanthan gosspina*	100	60	14.8	0.6
	Rhus parviflora Roxb.	100	70	8.2	0.7
	Carrissa spinarum auct.nun. L.	60	–	6	–
	Asparagus racemosus Willd.	80	–	5.2	–
	Mallotus philippensis (Lam.) Muell. Arg.	80	–	7.4	–
	Nepeta hindostana (Roth). Haines	40	–	5.6	–
	Artemisia capillaries Thnub.	60	–	5.8	–
	Colebrookia oppositifolia J. E. Smith	20	–	2	–
1000 m	*Acchmanthan gosspina*	20	–	4.2	–
	Lantana camara L.	20	–	5	–
	Rhus parviflora Roxb.	20	30	4	0.3
	Carrissa spinarum auct.nun. L.	20	–	4	–
	Sapium insigne (Royle) Benth. Ex Trimen	20	–	1.4	–

registered some days after. Gilmour and Cheney [13] suggest that nutrient loss can occur because of rainfalls after fire. It is important to consider that, as a generally accepted model, an initial pulse of increased available nutrients is followed by a decline in the middle- or short-term availability. Chemical effects of fire tend to be favorable for soil fertility in the short-term, but may not be in the long-term, because there is loss of mineral nutrients in ash, smoke articles and gases, and direct volatilization [8]. Knight [23] argues that the amount of nutrients that can be fixed by organisms in forest soil is limited. According to Fagberno [12], nutrient loss during rainfalls after fire, is more notable in the first rainfall events. According to Knight [23] and Raison et al. [30], smoke can contain large amounts of ash material rich in al1 nutrients; therefore very intense fires may remove substantial quantities of al1 nutrients.

5. Conclusion

The present study concludes that fire plays an important role in changing the nutrient status in the Chir pine forests, reducing soil nutrients along the altitudinal gradient at any soil depth and without regardless the type of under storey vegetation. These nutrients can be saved through better management practices, e.g. by early controlled burning and by educating the local villagers about the negative impacts of severe wild fires on soil and vegetation.

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