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Effect of Forest Fires on Soil Carbon Dynamics in Different Land Uses under NW Himalayas

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Abstract: Fires are regarded as features of forest disruption and renovation. The study was conducted to assess the fires effect on soil organic carbon (SOC) and microbial biomass carbon (SMB-C) in four land uses *viz.* forest land, grassland, agricultural land and non-fire site (control). PVC core were used for sampling soils at 0-5, 5-10 and 10-15 cm depths. SOC levels were found to be reduced post fire in all sites. Significant reductions were observed in SMB-C accumulations. However, SOC and SMB-C contents increased again with passage of time in all the sites. Grasslands samples, attained highest values of SOC (1.34 %) followed by 1.29 per cent in agricultural land at 10-15 cm depth. The maximum SMB-C of 172.20 µg C/g soil was in forest land at 0-5 cm depth and later was found to be decreased with increase in depth. Higher rates of carbon and microbial biomass accumulations were observed during the spring and rainy seasons. Therefore, prescribed burning of surface litter at right time could be a superior approach to avoid the fatal loss caused by wildfires and for better re-germination of plant species.

Keywords: Microbial biomass carbon, Forest fire, Organic carbon, Soils, Land uses, Prescribed burning

Severities of forest fires impart significant effect on soil microbial biomass content, therefore high severity of these fires lead to higher rate of reduced microbial biomass over low severity fires (Holden et al 2016, Girona-Garcia et al 2018). Fires do not cause threat only to forest wealth but alter the entire ecology of fauna and flora present in the region. In general, microbial biomass represents the status of numerous microbial communities thriving in the soil responsible for nutrient transformations and maintaining fertility of soil (Mataix-Solera et al 2009, Manral et al 2020). Disturbances caused by fires control the plant community succession and intra competition, ecophysiology and native species genetics, nutrients and rate of erosion and pest behaviour (Brown and Smith 2000). Fires lead to removal of carbon and essential nutrients from the soil pool and therefore a big reason for the reduction of microbial biomass of soil as carbon is utilized as food source by microbes (Zhou et al 2018). Topography of the region is also responsible for varying impacts of forest fires on biomass, land features like valley position, slope gradient, ridge exposure are important (Mabuhay et al 2006). Higher temperatures caused by fires for instance >50°C lead to death of microflora which were heat sensitive, further increase (around 70°C) directly affected the crops and vegetation (Shakesby and Doerr 2006). Fire being a mineralizing agent, plays a vital role in nutrient transformations, therefore, acts as the important soil health indicator. It boosts the nutrient accessibility to flora and fauna for better multiplication and higher activity rates (Hyodo et al 2013). Duration and intensity of forest fires in region also alter the vegetation and landscape of the region and therefore affect the biomass content (Lucas-Borja et al 2019). In some regions, accumulation of heavy fuels in sub surface layers of soil can increase the temperature beyond 500 °C in fire incidence (Neary et al 2005).

Soil microorganisms play various functional roles *i.e.* sources and sink of essential nutrients, maintain soil structure, acts as nutrient transformations catalyst and profoundly establish mutualistic relationships with roots responsible for plant fitness (Van Der Heijden et al 2008; Schmidt et al 2014). Soil microbes are very sensitive to global change including temperature variations (Allison and Treseder 2008; Frey et al 2008), soil nutrients availability (Allison et al 2008, Demoling et al 2008, Allison et al 2010) and moisture availability (Salamanca et al 2003, Hawkes et al 2011). Microbial biomass is a sensitive indicator of soil and thus used to determine the impact of forest fire on soil (Sadeghifar et al 2020, Singh et al 2021). Soil microbial biomass carbon, microbial biomass nitrogen and enzymatic activities are found to alter the post forest fire. In general, fire effects on soils are of two kinds, direct effects *i.e.* burning of soil organic matter, whereas, indirect effects deals with change in other components of ecosystems (Dooley et al 2012, Weber et al 2014). Various intracellular and extracellular enzymes present in microbes are responsible for nutrient transformations. Enzymes are regarded as sensitive indicators for quantifying ecological changes and also plays important role in releasing the essential nutrients and therefore improves availability to plant communities (Sadeghifar et al 2020). In oxidation of soil organic matter (SOM), intracellular enzyme *i.e.* dehydrogenase, plays a vital role in the initial phase by transferring the H^+ & electrons from substrates to acceptors (through co-enzymes). Several research studies showed positive correlation of acid phosphatase activities (ACP) with microbial biomass as ACP activities were reduced after the fire (Hyodo et al 2013, Sadeghifar et al 2020). Proportions of microbial biomass carbon, microbial biomass nitrogen and organic carbon in soils are very important parameters for assessing soil fertility and productivity (Li et al 2016).

In Himachal Pradesh, around 66.52 per cent of total area is occupied by forests. More precisely, out of total geographical area of 55,673 km^2 of state, around 1, 25,885 ha area is covered under Chir-pine forest (Anonymous 2019). In the Himalayan mountainous region of Solan, Himachal Pradesh, biomass burning in the sub-tropical areas, especially in the chir pine forests is a common phenomenon which occurs regularly each year due to which soil composition of the forest is prone to change. Pine (*Pinus roxburghii*) is regarded as the principal species of Himalayan subtropical forest (Zhou et al 2018). Prescribed fires/controlled fires have been commonly practiced in the moist seasons and farmers are performing same from many years. The approach already showed its superiority by lowering the accumulation of heavy fuels in sub surface soils, improving stand quality and recharging soil nutrient pool. Fire resulted in reduction of microbial abundance by an average of 33.2% and fungal abundance by an average of 47.6% (Dooley and Treseder 2012). Prescribed burning lead to minimize the severity of wildfires and its extent, and therefore, facilitated the emergence and germination of desired forest species in the region (Shubham et al 2021). Transformation of essential elements during fire combustion can affect the cycling and availability of nutrients. The combustion of organic matter during fire releases appreciable quantities of available nutrients and thus can be reliable nutrients source for re-growth of forest species. The mineral ash can also influence the soil properties (pH) and microbial activities responsible for nutrient turnover (Deluca et al 2006). Impact of forest fires on the soil microbial biomass carbon has received very less scientific attention in the region till date. Therefore, conducted a field experiment under sub-tropical pine forest areas of Solan, India situated in NW Himalayan region.

MATERIAL AND METHODS

The research investigation was carried out in forest areas of Solan, falls in II^{nd} Agro climatic zone *viz.,* Sub-temperate and Sub-humid zone of Himachal Pradesh, India during 2019. The experimental sites were located at 1196 amsl, with mean annual temperature of 17.4°C with annual rainfall of 1100 mm was recorded during study period. Due to rugged and mountainous topography the climatic conditions in the district vary from place to place. Winter rains were scanty and mostly received during the months of January to March. For the experimentation, four different land uses *viz.* forest land, grassland, agricultural land and non-fire site (control) were selected. All the selected sites were situated at an elevation of 1275 amsl (average). On longitude and latitude basis the study area was situated at 30°51'24" N to 77°09'58"E and all the land uses were nearly adjoining. The minimum distance of 2 km was kept between fire sites and non fire sites for obtaining high accuracy in results. Plot size of 200m×500m was chosen for each land use. In each land use, 3 parallel lines were aligned separating each other by 15 meters, in each line 10 PVC cores were arranged positioned at every 5 meters. PVC cores taken had dimensions of 5 cm diameter and 5, 10 & 15 cm lengths, perforated by holes and driven into the soil and finally capped on top. The collected soil samples were air dried, crushed, and passed through a 2-mm sieve. Soil samples were divided into two parts for the physicochemical and nutrient analysis, and microbial properties. The soil samples were stored at 4 °C until microbial activities were analyzed.

Soil samples were drawn from three depths *i.e.* 0-5 cm, 5-10 cm & 10-15 cm for determining soil physico-chemical properties, organic carbon and microbial biomass carbon analysis. Initial samples were drawn from near the PVC core, while the further monthly successive samples were collected from the cores with least disturbance. One set of samples were drawn from the sites that were burnt by controlled fire, while for the second set samples were taken from non fire region as control treatment. Experimental design taken for the study was completely randomized block design to maintain heterogeneity in results.

Soil organic carbon content of the soils was determined by the wet digestion method (Walkley and Black 1934). For estimation of microbial biomass and soil basal respiration, the soil moisture content was adjusted to 60% and incubated for a week to estimate microbial biomass. Soil microbial biomass carbon (SMB-C) content was determined by fumigation-extraction method given by Vance et al (1987). Soil pH and electrical conductivity were determined as 1:2 Soil: water suspension, measured with digital pH meter (Jackson 2005). Bulk density and particle density was calculated using pycnometer method. Organic carbon of soil was determined by Wet digestion method (Walkley and Black

1934). Soil available N (kg ha^{-1}) was determined by alkaline potassium permanganate method (Subbiah and Asija 1956). Soil available phosphorus (kg ha^{-1}) was determined by Stannous chloride reduced ammonium molybdate method (Olsen et al 1954) and estimated on Spectronic-20D^{+} at 660 nm. Soil available potassium (kg ha^{-1}) was determined by neutral normal ammonium acetate method (Merwin and Peech 1951) and estimated with flame photometer (Table 1).

Statistical analysis: The data generated from the present investigation were subjected to statistical analysis using the statistical package SPSS (16.0) and Microsoft Excel.

RESULTS AND DISCUSSION

Soil characteristics: Soils of the experimental sites were categorized as *Typic Eutrochrept* on sub group level as per USDA soil taxonomy. Soil texture in different sites varies from sandy loam to sandy clay loam. Particle density of the soils varied between 2.32 to 2.35 g cm^{-3}, while bulk density ranged between 1.33 to 1.36 g cm^{-3}. Higher range of soil porosity could be due to presence of sufficient organic matter and higher proportion of fine soil fraction which might have increased the surface area. Available soil nitrogen was in the range of 173.18 as lowest in forest land to 390.28 kg ha^{-1} as highest in the agricultural land use. While soil available phosphorus varied as lowest of 32.59 kg ha^{-1} to highest of 46.90 kg ha^{-1} in agricultural land. Soil available K content ranged between 272.68 kg ha^{-1} in forest land to 431.88 kg ha^{-1} in agricultural site (Table 1). Continuous application of NPK fertilizers in agricultural fields might have increased the soil NPK levels in this land use.

Soil microbial biomass carbon (SMB-C): The inducing fires remarkably reduced the microbial biomass carbon in the land uses to great extent. In forest land, initial SMB-C values was 170 µg C/g soil which was later reduced to 152.44, 137.19 & 121.19 µg C/g soil with a decrease of 10.70, 19.63 & 29.01 per cent in 0-5, 5-10 and 10-15 cm sampling depths, respectively (Table 2). Similarly, in grassland, the per cent decrements were 19.41, 25.24 & 32.95 per cent. In agricultural land fire lowered the SMB-C by 28.19, 35.22 and 37.80 per cent over the pre-fire levels. The un-burnt sites, slight reduction of 1.69, 9.18 and 22.02 per cent. Data showed that highest SMB-C content was recorded in 0-5 cm depth, the microbial biomass carbon content was reduced with increase in soil depth. Amongst the different land uses, highest value of 172.20 µg C/g soil was recorded in forest land (September) and have significant statistical difference over rest of the sites. Monthly variations of SMB-C in post-fire showed a secular variations trend as presented in Figure 1, 2, 3 and 4 in different sampling depths of land uses. The climate had also an direct effect on the SMB-C build up, as higher rates of biomass carbon had been generated during mild winters and rainy period as compared to peak summer months *i.e.* April, May and June. Effect of forest fires have found to have a short time effect on microbial biomass after then they regenerate, multiply and sustain their populations in soil.

Soil organic carbon (SOC %): The forest fire caused a great reduction in SOC under fire induced land uses (Table 3). Amongst the different land uses, maximum of SOC values were recorded in grassland over the rest sites. Comparative results on sampling depths showed soil sampled initially post fire at 0-5 cm, SOC values of 1.09, 1.19, 1.16 and 1.06 per cent were recorded in forest, grassland, agricultural, non fire site, respectively. Later, the SOC content showed secular variations trend with passage of time (on monthly basis) (Fig. 1). Overall highest values of SOC *i.e.* 1.34 per cent was in the grassland (August and October) followed by 1.29 per cent in agricultural land and 1.25 per cent in non fire site. However,

Table 1. Initial physico-chemical properties of soils

Parameters	Land uses			
	Forest Land	Grassland	Agricultural Land	Unburnt site (Control)
Particle density (g cm^{-3})	2.32	2.33	2.35	2.32
Bulk density (g cm^{-3})	1.33	1.34	1.36	1.33
Porosity (%)	42.70	42.48	42.12	42.67
pH (1:2)	5.93	6.05	6.44	6.57
Electrical conductivity (dS m^{-1})	0.22	0.24	0.27	0.25
Soil organic carbon (%)	1.41	1.49	1.40	1.38
Available N (kg ha^{-1})	173.18	179.54	390.28	291.29
Available P (kg ha^{-1})	32.59	35.65	46.90	41.54
Available K (kg ha^{-1})	272.68	319.54	431.88	339.52
SMB-C (µg C/g soil)	170.71	163.38	159.36	157.91

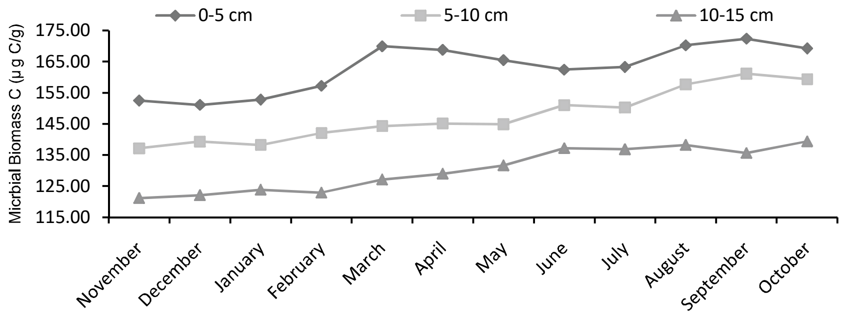

Fig. 1. Effect of forest fire on monthly variations in soil microbial biomass carbon (µg C/g) in different samping depths under forest based landuse

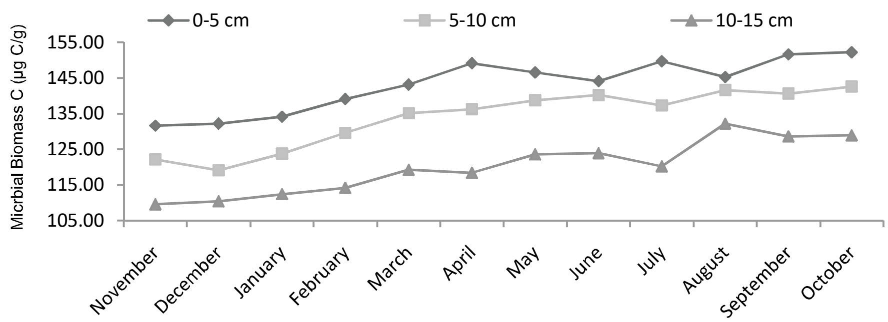

Fig. 2. Effect of forest fire on monthly variations in soil microbial biomass carbon (µg C/g) under different samping depths in grassland based landuse

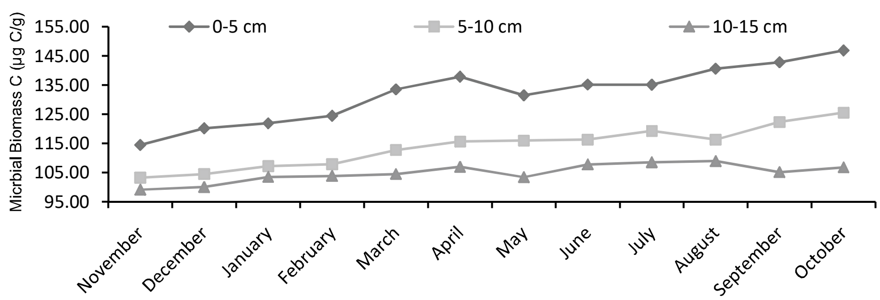

Fig. 3. Effect of forest fire on montly variations in soil microbial biomass carbon (µg C/g) under different samping depths in agricultural based landuse

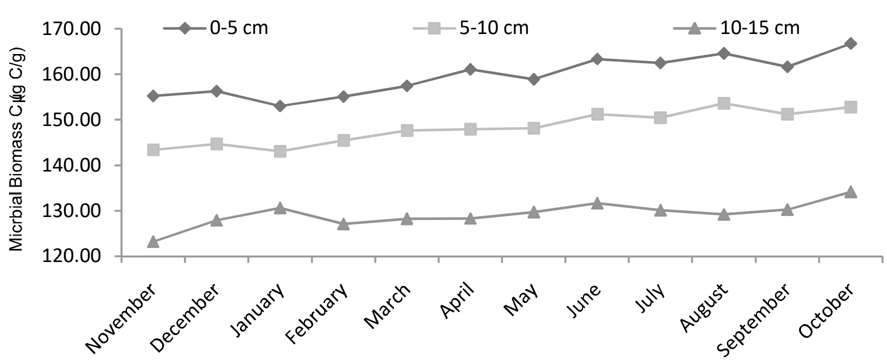

Fig. 4. Effect of forest fire on montly variations in soil microbial biomass carbon (µg C/g) under different sampling depths in unburnt site (Control)

Table 2. Effect of forest fire on soil microbial biomass carbon content (SMB-C) of soil

		Soil microbial biomass C(µg C/g soil)													
Land uses	Depth of sampling	November	December	January	February	March	April	May	June	July	August	September	October	CV (%)	C.D. (0.05)
Forest Land	0-5 cm	152.44	151.06	152.76	157.22	169.90	168.78	165.43	162.41	163.26	170.20	172.34	169.20	0.74	2.08
	5-10 cm	137.19	139.34	138.20	142.04	144.26	145.12	144.88	151.03	150.22	157.64	161.10	159.34	0.59	1.49
	10-15 cm	121.19	122.08	123.86	122.97	127.13	128.99	131.64	137.19	136.83	138.22	135.67	139.42	1.18	2.62
Grassland	0-5 cm	131.67	132.19	134.17	139.09	143.14	149.12	146.56	144.12	149.66	145.24	151.66	152.19	0.77	1.89
	5-10 cm	122.14	119.07	123.77	129.63	135.12	136.21	138.74	140.19	137.25	141.60	140.60	142.56	0.89	2.03
	10-15 cm	109.54	110.37	112.43	114.15	119.22	118.38	123.54	123.88	120.19	132.23	128.54	128.92	0.70	1.44
Agricultural land	0-5 cm	114.44	120.14	121.90	124.44	133.56	137.88	131.44	135.22	135.09	140.66	142.85	146.90	0.72	1.61
	5-10 cm	103.23	104.46	107.21	107.89	112.73	115.62	115.99	116.32	119.26	116.27	122.44	125.57	1.07	2.07
	10-15 cm	99.12	100.03	103.48	103.81	104.52	106.94	103.39	107.76	108.54	108.92	105.17	106.84	1.12	1.99
Unburnt site	0-5 cm	155.23	156.34	153.06	155.14	157.48	161.10	158.93	163.40	162.50	164.60	161.70	166.77	0.69	1.89
	5-10 cm	143.40	144.67	143.03	145.47	147.62	147.91	148.16	151.22	150.49	153.64	151.22	152.80	0.74	1.86
	10-15 cm	123.14	127.90	130.60	127.09	128.20	128.30	129.70	131.60	130.10	129.20	130.20	134.12	0.90	1.98

Table 3. Effect of forest fire on organic carbon content (SOC) of soil

		Soil microbial biomass C(µg C/g soil)													
Land uses	Depth of sampling	November	December	January	February	March	April	May	June	July	August	September	October	CV (%)	C.D. (0.05)
Forest Land	0-5 cm	1.09	1.12	1.12	1.13	1.14	1.1	1.12	1.12	1.13	1.16	1.15	1.16	1.54	0.03
	5-10 cm	1.13	1.12	1.16	1.18	1.19	1.18	1.21	1.2	1.22	1.22	1.21	1.22	1.96	0.03
	10-15 cm	1.14	1.17	1.17	1.21	1.22	1.24	1.22	1.27	1.29	1.3	1.33	1.37	1.79	0.03
Grassland	0-5 cm	1.19	1.22	1.24	1.28	1.3	1.29	1.28	1.32	1.33	1.34	1.33	1.34	1.17	0.03
	5-10 cm	1.16	1.21	1.23	1.22	1.25	1.26	1.24	1.25	1.27	1.29	1.32	1.31	1.25	0.03
	10-15 cm	1.23	1.22	1.25	1.27	1.27	1.28	1.31	1.34	1.36	1.3	1.41	1.44	1.39	0.03
Agricultural land	0-5 cm	1.16	1.15	1.18	1.19	1.19	1.22	1.24	1.24	1.23	1.26	1.29	1.29	1.23	0.02
	5-10 cm	1.2	1.22	1.25	1.24	1.25	1.28	1.26	1.3	1.29	1.33	1.31	1.32	1.33	0.03
	10-15 cm	1.22	1.21	1.24	1.24	1.27	1.28	1.32	1.31	1.3	1.36	1.36	1.35	1.76	0.03
Unburnt Site	0-5 cm	1.06	1.07	1.10	1.14	1.11	1.12	1.14	1.17	1.21	1.25	1.21	1.25	1.41	0.02
	5-10 cm	1.11	1.10	1.13	1.16	1.15	1.17	1.20	1.23	1.22	1.24	1.26	1.28	1.49	0.03
	10-15 cm	1.15	1.17	1.21	1.21	1.23	1.25	1.28	1.30	1.31	1.32	1.35	1.36	1.14	0.02

the least build up in SOC was in forest area with 1.16 per cent organic carbon. Similarly, in sampling depths of 5-10 cm & 10-15 cm, similar trends were observed (Fig. 5, 6 and 7). Amongst all the sampling depths, overall maximum organic carbon content was in 10-15 cm depth, with maximum of 1.44 per cent in grassland (October) which was 6.67 and 5.88 per cent higher than values recorded in October under agricultural and un burnt sites But here, forest area improved the SOC content by 1.48 per cent over agricultural land. On comparison of pre-fire and post fires effect on SOC, very slight change was recorded in un-burnt sites as compared to fire induced ones. It is also have been found that post fire, the soil have showed regeneration of plant species and thereby improved soil organic carbon content.

Forest fires are regarded as one of the utmost elements of climate change which influences the different soil microbial communities to a great extent as these microbes plays a vital role in carbon dynamics of terrestrial ecosystems. Fires cause a great reduction to microbial populations thriving in soils (Dooley and Treseder 2012, Holden and Treseder 2013, Garcia et al 2018). Burning destroys the different microbes which ultimately lead to reduced microbial biomass.

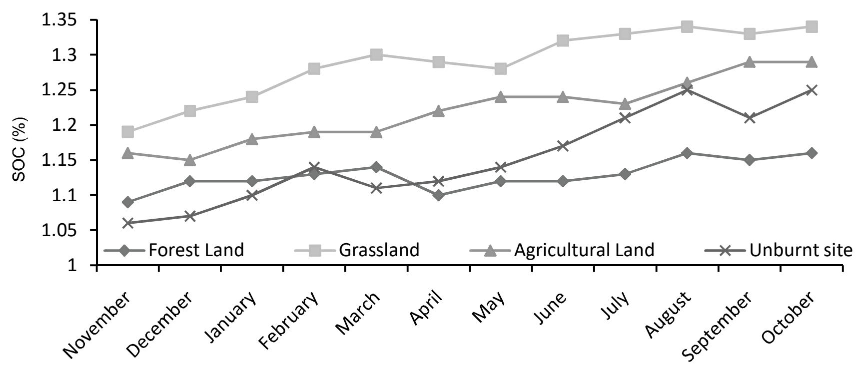

Fig. 5. Effect of forest fire on soil oragnic carbon content (SOC) (Sampled at 0-5 cm depth) under different land uses

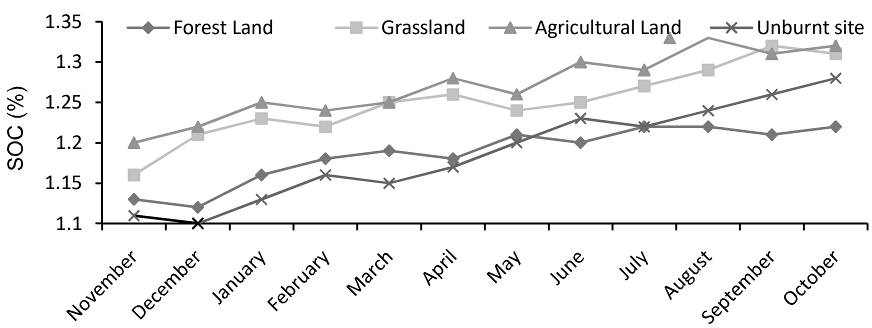

Fig. 6. Effect of forest fire on soil oragnic carbon content (SOC) (Sampled at 5-10 cm depth) under different land uses

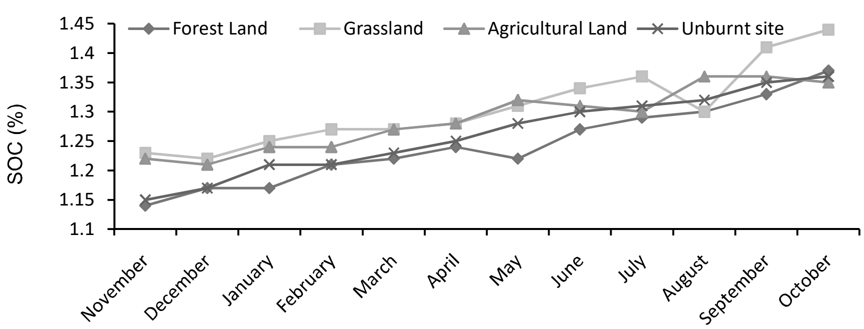

Fig. 7. Effect of forest fire on soil oragnic carbon content (SOC) (Sampled at 10-15 cm depth) under different land uses

Alterations in the nutrient supplies caused by the death of plant species can be a rationale for lower rates of biomass carbon (Mabuhay et al 2003, Hart et al 2005, Smith et al 2008, Shubham et al 2021, Singh et al 2021). Higher soil organic carbon content in grassland could be due to attributed to addition of greater litter as input, which might have provided a substantial carbon to the soil pool for microbial utilization. The results were in line with the findings of Palese et al (2004), Knelman et al (2015), Sadeghifar et al 2020). Forest fires increased the soil temperature to great extent and therefore the soil organic carbon content was reduced. But with the passage of time the microbial biomass carbon and SOC attained their pre fire levels in soil. Higher rates of microbial biomass carbon in mild winters and spring over harsh summers could be attributed to reason that most of the mineralizing microbes favours 25-35°C, beyond this their activity and multiplication restricts. The results were in agreement with the findings of Guerrero et al (2005) and Mabuhay et al (2006). The percentage of organic carbon was found to be decreased at a faster rate immediately after fire incidence and this decrease in organic carbon could be due to decline in the microbial C pool. The results were in line with the findings of Kara and Bolat (2009).

CONCLUSION

Incidences of forest fires are more endemic across the Himalayan region; therefore it becomes very important to study how these fires affect the ecosystem and their capabilities of responding and recovering. The forest fire had imparted a significant effect on reduced microbial biomass carbon. The soil organic carbon content was reduced after the fire incidence but carbon accumulation in soil returned to its pre fire levels with the passage of time. Highest levels of organic carbon were at 10-15 cm depths. Soil microbial biomass carbon contents were higher in forest land (0-5 cm sampling depth). Forest fire has a significant impact on microbial properties and soil enzymatic activity along soil physico-chemical properties. Soil biological properties were more sensitive on surface heating by fires than physico-chemical properties as it provide lethal temperatures for microbes occurring below 100 °C. Effect of fire on organic carbon and microbial biomass carbon was highly dependent on the intensity of the fire, soil moisture content and type of the burned materials. Effect of fires on soil properties and biomass carbon were highly variable and no generalized statements can be suggested for most of the fire-induced changes on soil organic carbon and biomass carbon content. Therefore, prescribed burning of floor litter at right time can be a good choice for avoiding wild fires incidences in region and for better plant regeneration and maximum stockpile of organic carbon in soil pool.

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