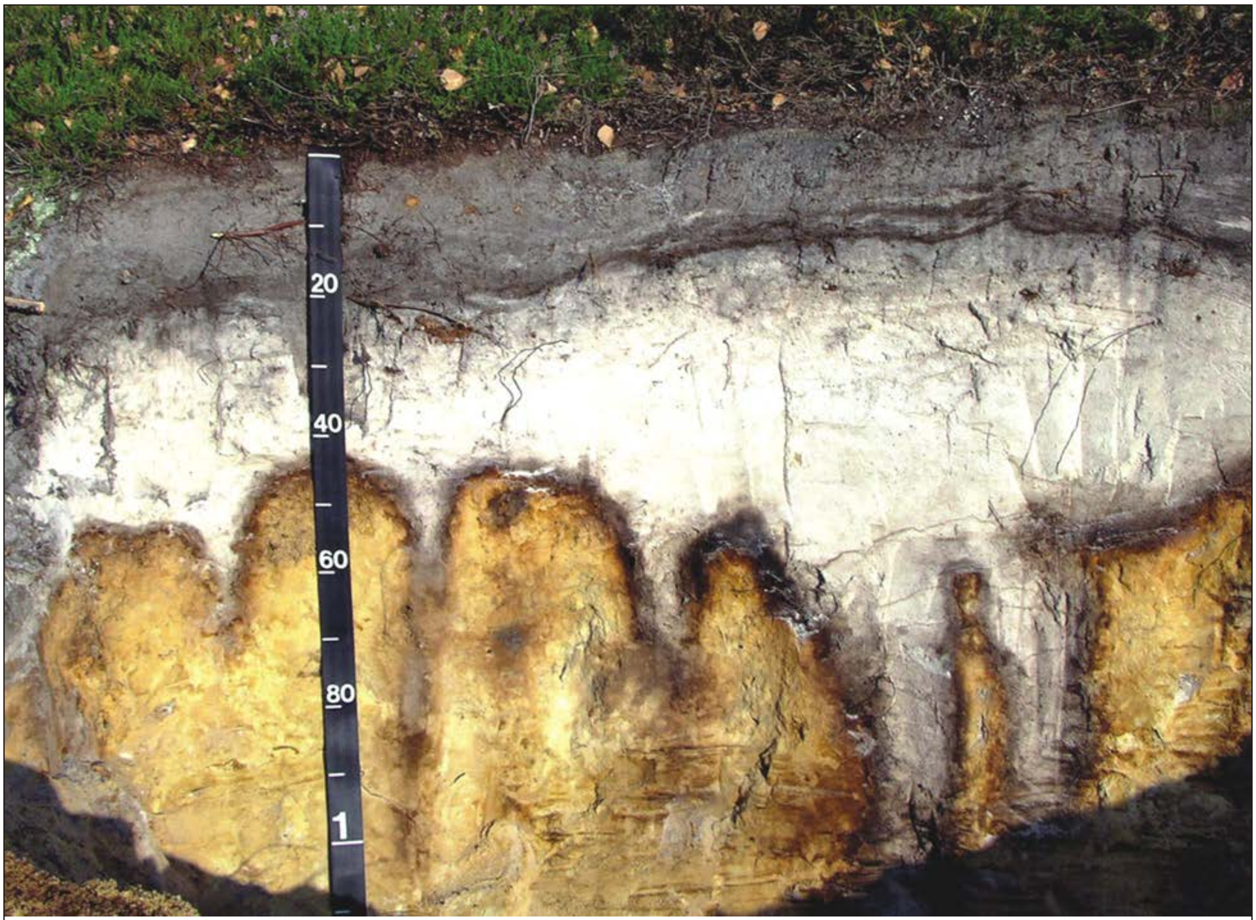

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Comparison of Physical, Chemical and Microbial Properties of Soils in a Clear-cut and Adjacent Intact Forest in North Western Himalaya, India

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ABSTRACT

Soil physical, chemical and microbial properties were compared between two paired forest sites (clear-cut vs adjacent intact forest) in coniferous forests of Kashmir Himalaya. Soil samples were drawn at 0.5, 5-10 and 0-10 cm depths at both the sites. The results indicated that the mean values (0-10 cm) of air and soil temperature, moisture content, water holding capacity, organic carbon (OC), exchangeable Calcium (Ca) and potassium (K) were significantly higher while bulk density and exchangeable magnesium (Mg) were significantly lower at clear-cut site than at intact forest site. With respect to depth, pH, conductivity, moisture content, organic carbon and organic matter (OM) were significantly higher while exchangeable sodium (Na) was significantly lower in the surface soil 0-5 cm depth than 5-10 cm depth at both the sites. Bacterial populations did not show any significant difference with respect to depth at both the sites however, fungal populations significantly ($p<0.05$) increased with depth at clear-cut site from 62.0×10^3 (0-5 cm) to 111.4×10^3 CFU g^{-1} soil (5-10 cm) and decreased at forest site from 157.7×10^3 (0-5 cm) to 65.6×10^3 CFU g^{-1} soil (5-10 cm). The study suggests that clear-cut site had significantly higher nutrient content than the adjacent forest site suggesting that thick herbaceous vegetation and stump roots left at clear-cut site have maintained the fertility of the soil.

Key words: Kashmir valley, soil fertility, deforestation, degradation, conifers

INTRODUCTION

The effects of clear-cutting on soil physical, chemical and biological properties have been studied in both temperate and boreal forests around the world, especially from North America (Covington, 1981; Burns and Murdoch, 2005; Thiffault *et al.*, 2008; Nkongolo and Plassmeyer, 2010) and Europe (Pennanen *et al.*, 1999; Smolander *et al.*, 2001; Palviainen *et al.*, 2005). Clear-cutting is known to cause severe disturbances, including changes in microclimatic conditions and light availability that affect plant growth (Xu *et al.*, 2008). The availability of nutrients in soil usually increases after clear-cutting (Palviainen *et al.*, 2005). Although, the intensity and period of effect may vary depending on the soil fertility (Prescott, 2002). It also causes subtle changes in soil structure and nutrient dynamics that are detectable both immediately after logging and after several years of logging (Schwendenmann, 2000; Malgwi and Abu, 2011). However, these findings were observed at a fairly large scale and hence various environmental conditions may co-vary.

A number of authors have observed decrease, no change or increase in most of the soil nutrients especially pH, moisture, organic carbon and nitrogen after clear-cutting (Giardina and Rhoades, 2001; Ma *et al.*, 2004; Westbrook and Devito, 2004; Belleau *et al.*, 2006; Hwang and Son, 2006; Bradley and Parsons, 2007), indicating that effects of clear-cutting on soil are system specific and vary with respect to climatic regions as well as type of vegetation. Clear-cutting is also reported to affect soil biological properties.

Soil microorganisms are responsible for organic matter decomposition, nutrient cycling and maintenance of soil structure and degradation of pollutants and thus have great role in long-term sustainability of forest ecosystems (Duffkova and Macurova, 2011). Arunachalam *et al.* (1999) observed that soil disturbed by tree removal often have reduced microbial diversity compared with undisturbed areas. Clear-cutting is known especially to decrease the fungal biomass and cause changes in the bacterial community structure (Pennanen *et al.*, 1999). Despite continued focus on the interaction between clear-cutting and soil processes, relatively little is known about the relationship between clear-cutting and soil microbial diversity or whether clear-cutting changes in soil microorganisms influence soil ecosystem functioning.

While forest clearing is rampant in the coniferous forests of the Kashmir Himalaya, no information exists on the effect of these changes on soil properties (Dar and Kaul, 1987; Bhat and Wani, 2003). Such studies are particularly important in view of the role of soil properties in the regeneration and growth of conifers. The present study has compared the effects of clear-cutting on soil physical, chemical and microbial properties in two paired forest sites (clear-cut vs control intact forest) in the wet and dry season, in coniferous forest of Kashmir Himalaya.

MATERIALS AND METHODS

Study sites: The present study was conducted during 2004 in the coniferous forests of Tangmarg which lie on the northern side of the Pir Panjal forest division in Gulmarg range situated in forest compartment number 0047 of the Kashmir Himalaya (Fig. 1). The study area is located in district

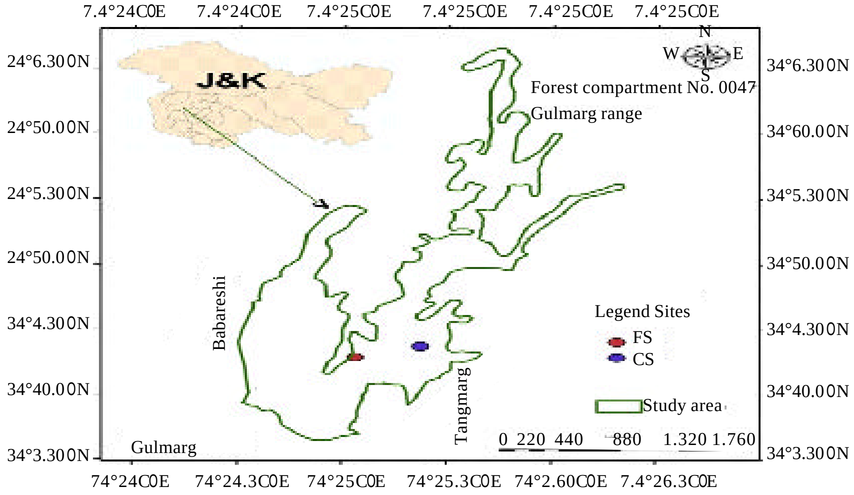

Fig. 1: Map of the study area showing study sites

Table 1: Characteristics of selected study sites

Sites	Clear-cut site (CS)	Intact forest site (FS)
Latitude	34°04' 19.4"-34°04' 30.6"N	34°04' 14.1"-34°04' 24.4"N
Longitude	74°25' 23.7"-74°25' 31.5"E	74°25' 04.9"-74°25' 10.9"E
Altitude (masl)	2142 m	2190 m
Aspect	North-eastern	North-eastern
Slope	15-20°	15-20°
Sand (%)	33.8	24.3
Silt (%)	12.7	14
Clay (%)	54.5	59.7
Soil type	Clayey	Clayey
Tree density 10 m^{-2}	0.8	25.1

Baramulla about 37 km southwest of Srinagar city. The forest vegetation is represented mainly by *Pinus wallichiana* at the lower limits (1600-2500 m) and by *Abies pindrow* and *Picea smithiana* at higher altitudes (2300-3300 m). The climate of the area is temperate with four distinct seasons; spring (March-May), summer (June-August), autumn (September-November) and winter (December-February). The mean monthly precipitation during 2004 was 138.6 mm while mean annual precipitation is 1663.5 mm. The minimum and maximum temperatures during the study year were-5 and 31°C. The mean monthly temperature ranged from -2.5 to 28°C.

The area was covered with dense coniferous forest prior to 1990. In 1990-1992, the area experienced mass deforestation leading to barren patches of about 1 ha devoid of any vegetation. Since, then the area has been under continuous biotic interference and no management was undertaken to regenerate the forest area. Two sites one clear-cut during 1992 and an intact forest were selected (each about 1 ha in area) adjacent to each other, having almost same aspect, climate, topography and parent material (Fig. 1). Before clear-cutting, the forest vegetation at the Clear-cut Site (CS) was same as is present in the adjacent intact Forest Site (FS). The general characteristics of study sites are shown in Table 1.

Soil sampling and analysis: Soil sampling was performed in summer and autumn season during 2004 at both the sites. Within each site 12 to 15 samples were obtained from 0-10 cm depth and then mixed to form the composite sample. Soil samples were also collected similarly from 0-5 and 5-10 cm depths from the study sites. Three replicates from the each composite soil sample were used for further analysis. The soil samples were sieved through 2 mm mesh screen and divided into two parts, one part was used in field moist conditions to determine the soil moisture (MC), pH, conductivity and available-P and the other part was air dried to determine texture, bulk density (BD), organic carbon (OC), organic matter (OM), nitrate nitrogen and exchangeable cations, Ca, Mg, Na, K. Standard methods as given by Page *et al.* (1982) and Jackson (1973), were used to determine the physico-chemical properties of soils. pH and conductivity was determined in 1:2 soil water ratio by digital pH and conductivity meter, OC by wet digestion, nitrate-N by phenol-disulphonic acid method, available-P by ascorbic acid method and exchangeable cations by ammonium acetate method at pH 7. The data are represented on oven dry basis.

Soil samples were also collected aseptically in sterilized polythene bags at both the sites in the same way as stated above and were used for isolation of microbial populations within 24 h by dilution plate technique as given in Page *et al.* (1982). Soil bacteria populations were estimated by using nutrient agar medium and fungal population was estimated by using Martin Rose Bengal agar medium sterilized by streptomycin (30 μg mL^{-1}). Actinomycetes populations were determined by casein medium. The inoculated Petri-plates were incubated at 25±1°C for 48 h for bacteria, 5 days for fungi and 15 days for actinomycetes.

Statistical analysis: Data are expressed as means of three replications for each season. Comparison of means was performed by the one way ANOVA test at 5% level of significance ($p \leq 0.05$). Bivariate correlations (Pearson, two tailed) were used to explore the relationships between different physical, chemical and microbial soil properties. The statistical analysis was performed using the statistical package SPSS (2003).

RESULTS

The changes in physico-chemical properties at the clear-cut and adjacent forest site are presented in Table 2. The mean air temperature was significantly higher at site CS (20.6°C) when compared with FS (17.1°C). Soil temperature also followed the same trend having significantly higher values at CS (20.0°C) than FS (12.5°C). Mean MC values were significantly higher at the CS (16.3%) than at FS (14.2%). The average Water Holding Capacity (WHC) at the CS and FS were 66.8 and 52.7%, respectively. CS (1.04 g cm^{-3}) has significantly lower mean BD values than that of FS (1.18 g cm^{-3}).

The pH was slightly acidic at both the sites. The mean pH was lower at site FS (6.33) than at site CS (6.45) however, the difference was not significant. Conductivity values observed at site CS were greater (196 μS cm^{-1}) than at FS (139 μS cm^{-1}). The mean values of OC (4.32%) and OM (7.45%) observed at CS were significantly higher than the mean values of OC (3.05%) and OM (5.26%) present at FS. Among the base cations, exchangeable Ca and K were significantly higher and exchangeable Mg was significantly lower at clear-cut site with respect to adjacent forest site. The mean concentration of exchangeable Ca, Mg, Na and K at CS were 21.1 and 4.5 meq 100 g^{-1}, 126 and 195 mg kg^{-1} and that at the forested were 15.8 and 6.2 meq 100 g^{-1}, 117 and 115 mg kg^{-1}, respectively.

The changes in physico-chemical properties at the clear-cut and adjacent forest site with respect to depth are depicted in Table 3. Surface (0-5 cm) soil MC at both the sites was significantly higher

Table 2: Mean soil characteristics (0-10 cm depth) at clear-cut and adjacent forest sites (n = 6)

Parameters	Clear cut site (CS)	Forest site (FS)	Sig.
Air temperature (°C)	20.6 (12.0)	17.1 (10.7)	**
Soil Temperature (°C)	20.0 (10.0)	12.5 (7.8)	**
pH	6.45 (0.14)	6.33 (0.05)	ns
Conductivity (μS)	196 (67)	139 (10)	ns
BD (g cm^{-3})	1.04 (0.02)	1.14 (0.02)	**
MC (%)	16.3 (1.1)	14.2 (1.9)	*
WHC (%)	66.8 (5.5)	52.7 (3)	**
OC (%)	4.32 (0.84)	3.05 (0.58)	*
OM (%)	7.45 (1.45)	5.26 (1.01)	*
Available P (μg g^{-1})	14 (5)	18 (5)	ns
NO_3-N (μg g^{-1})	14 (5)	13 (5)	ns
Ca (meq/100 g)	21.1 (1.9)	15.8 (1.0)	**
Mg (meq/100 g)	4.5 (0.5)	6.2 (1.7)	*
Na (mg kg^{-1})	126 (7)	117 (23)	ns
K (mg kg^{-1})	195 (4)	115 (16)	**

*Significant at the 0.05 level, **Significant at the 0.01 level, ns: Non-significant, Values in parenthesis are standard deviation

Table 3: Mean soil characteristics with respect to depth at clear-cut and adjacent forest site (n = 6)

	Clear-cut site (CS)			Intact forest site (FS)		
Parameters	(0-5 cm)	(5-10 cm)	Sig.	(0-5 cm)	(5-10 cm)	Sig.
pH	6.58	6.42	**	6.23	6.12	*
Conductivity (µS)	154	94.0	**	85	63.0	**
BD (g cm^{-3})	0.98	0.99	ns	1.06	1.16	*
MC (%)	16.26	13.39	**	18.9	13.7	**
WHC (%)	74.43	71.24	*	47.8	62.2	**
OC (%)	4.45	3.68	**	3.8	2.60	**
OM (%)	7.67	6.35	**	6.6	4.50	**
Available P (µg g^{-1})	35	14.0	*	20	18.0	ns
NO_3-N (µg g^{-1})	14	15.0	ns	11	14.0	ns
Ca (meq/100 g)	16.4	21.9	**	15.1	15.5	ns
Mg (meq/100 g)	3.2	3.3	ns	4.2	05.4	ns
Na (mg kg^{-1})	92	128.0	**	90	113.0	*
K (mg kg^{-1})	172	143.0	**	107	102.0	ns

*Significant at the 0.05 level, **Significant at the 0.01 level, ns: Non-significant

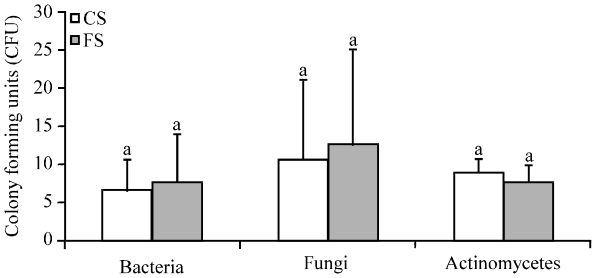

Fig. 2: Population (mean±SD) of bacteria (CFU×10^5), fungi (CFU×10^3) and actinomycetes (CFU×10^4) at clear-cut and adjacent forest site (0-10 cm depth). Bars with different letters show significant ($p<0.05$) difference between the microbial populations with respect to sites

than the subsurface (5-10 cm) soil. The bulk density values at the CS did not change with depth however, at the forested site the BD values showed significant increase with depth from 1.08 g cm^{-3} (0-5 cm) to 1.18 g cm^{-3} (5 -10 cm). The mean pH showed significant decrease with depth at both the sites having values of 6.60 (0-5 cm) and 6.42 (5-10 cm) at the CS and 6.26 (0-5 cm) and 6.12 (5-10 cm) at site FS. The conductivity values at 0-5 cm and 5-10 cm depth at CS (150 and 93 µS cm^{-1}) and FS (84 and 61 µS cm^{-1}) also varied significantly. Organic carbon values also decreased significantly with depth at both the sites from 4.31% (0-5 cm) to 3.65% (5-10 cm) at the CS and from 3.90% (0-5 cm) to 2.64% (5-10 cm) at the FS. There was no significant difference in the concentration of the mean available P and NO_3-N values between the two sites or with respect to depth.

The microbial population at clear-cut and intact forest sites is shown in Fig. 2. Both the sites had higher population of bacteria followed by actinomycetes and than fungi. Highest population of microbial groups was observed during autumn season and lowest in summer season. The mean values of bacterial and fungal populations were slightly higher at adjacent forest site (7.8×10^{-5} and 12.7×10^{-3} CFU g^{-1} soil) when compared to clear-cut site (6.6×10^5 and 10.8×10^3 CFU g^{-1} soil). In

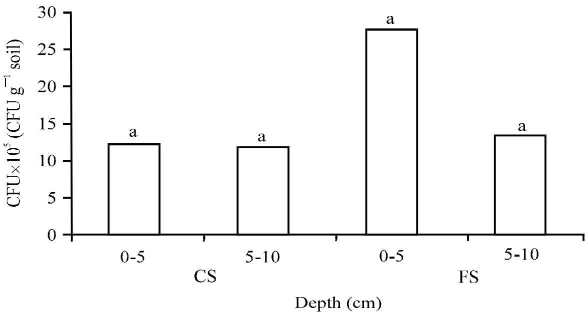

Fig. 3: Bacterial population with respect to depth at Clear-cut (CS) and adjacent Forest Site (FS). Bars with different letters show significant ($p<0.05$) difference between the bacterial populations with respect to depth at respective sites

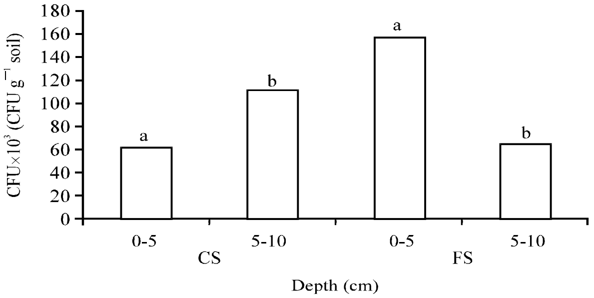

Fig. 4: Fungal population with respect to depth at Clear-cut (CS) and adjacent Forest Site (FS). Bars with different letters show significant ($p<0.05$) difference between the fungal populations with respect to depth at respective sites

Table 4: Correlation coefficients between soil nutrients and microbial populations

Soil nutrients	Bacteria	Fungi	Actinomycetes
pH	0.505	0.428	-0.194
Conductivity	-0.364	-0.39	0.493
BD	0.283	0.25	-0.296
MC	-0.688 (*)	-0.608 (*)	0.242
WHC	0.212	0.288	0.144
OC	0.481	0.557	0.101
OM	0.481	0.558	0.101
Available P	0.246	0.414	0.186
NO_3-N	0.449	0.524	-0.320
Exchangeable Ca	-0.14	-0.021	0.245
Exchangeable Mg	-0.361	-0.587 (*)	-0.558
Exchangeable Na	-0.686 (*)	-0.657 (*)	0.398
Exchangeable K	-0.273	-0.224	0.267

*Correlation is significant at the 0.05 level

contrast, the mean values of actinomycetes were higher at clear-cut site (9.1×10^4 CFU g^{-1} soil) than that of adjacent forest site (7.8×10^4 CFU g^{-1} soil). However, the difference in microbial populations was not significant between the two sites. Bacterial and fungal populations with respect to depth at clear-cut and adjacent forest site are shown in Fig. 3 and 4. Bacterial populations did not show any significant difference with respect to depth at both the sites however, fungal populations significantly increased with depth at CS from 62.0×10^3 (0-5 cm) to 111.4×10^3 CFU g^{-1} soil (5-10 cm) and decreased at FS from 157.7×10^3 (0-5 cm) to 65.6×10^3 CFU g^{-1} soil (5-10 cm).

Pearson's correlation of microbial populations with physicochemical properties of soils is depicted in Table 4. None of the parameters showed significant relation with soil actinomycetes populations. However, both bacteria and fungal population showed significant ($p>0.05$) negative correlation with soil moisture content and exchangeable Na values. Fungal populations also showed significant ($p>0.05$) negative correlation with exchangeable Mg. Rest of the parameters did not show any significant relation with microbial populations in the present study.

DISCUSSION

Clear-cutting results in the loss of interaction between the above-ground vegetation and atmospheric deposition, replaces the continuous flux of litter fall to the soil, disturbs the water influx in the soil and reduces the uptake of nutrients from the soil by trees (Piirainen *et al*., 2004). We observed significant differences in nutrient concentrations and microbial populations between the clear-cut and adjacent forest sites. We also observed high degree of variability with respect to depth within the same site for certain edaphic factors including microbial populations.

The mean values (0-10 cm) of air and soil temperature, moisture content and water holding capacity were significantly higher while bulk density was significantly lower at clear-cut site. Increase in absorption of solar radiation by mineral soil due to removal of forest cover by deforestation has led to the warming of the soil which in turn caused increased air and soil temperatures (Hashimoto and Suzuki, 2004). Increase in soil moisture content may be due to reduced transpiration and no interception in the absence of tree cover which increased the rainfall to the soil surface (Elliott *et al*., 1998; Palviainen *et al*., 2004). Besides high OM content and dense herbaceous vegetation at the CS site may have retained more moisture in the soil than FS site (Tejedor *et al*., 2004). In contrast to many studies which reported increase in BD values due to forest clear-cutting (Hajabbasi *et al*., 1997; Schwendenmann, 2000), present study revealed that clear-cut site had lowest values of bulk density when compared to FS. Lower values of bulk density may be due to presence of high organic matter content at site CS because OM had a significant effect on the bulk density of soils (Adams, 1973; Handayani *et al*., 2012).

The soil OC and OM values at CS were significantly higher than FS site. As CS site had higher soil temperature, moisture content and light intensity than the FS site which may perhaps have increased the decomposition of OM (Reth *et al*., 2005) but presence of thick root mass both from intact cut over stumps and thick herbaceous vegetation at CS could have added enough OM to the soil. Hwang and Son (2006) attributed increase in SOC concentrations after thinning in both Japanese larch and pitch pine plantations due to the increase in OM decomposition and root death, implying that roots added enough soil C to more than compensate for any possible increased loss of soil C after thinning. Further, high cattle grazing at CS may also have contributed to increased soil OC levels due to excreta of animals. Among the base cations, exchangeable Ca and K were significantly higher and exchangeable Mg was significantly lower at clear-cut site with respect to adjacent forest site. However, relatively high levels of exchangeable cations at CS may be due to reduced uptake owing to absence of canopy cover. However, Boerner and Sutherland (1997) reported that thinning increased soil Ca and Mg concentrations due to the increase in temperature and moisture content of the forest floor. Further differences in exchangeable cations between the two sites could be due to soil pH. As clear-cut site had slightly higher pH than adjacent forest site the availability of base cations increases with increase in pH (Sariyildiz *et al.*, 2005; Hwang and Son, 2006; Onweremadu, 2007).

The mean values of pH, conductivity, available P, NO_3-N and exchangeable Na did not show any significant variation between clear-cut and adjacent forest soils (1-10 cm). Similar results have been reported by others (Chidumayo and Kwibisa, 2003; Palviainen *et al.*, 2004; Hwang and Son, 2006) and may be due to long period of deforestation, similar decomposition rates and similar soil texture at the two sites (Sokouti and Mahdian, 2011).

The values of pH, conductivity, moisture content, organic carbon and organic matter were significant higher while exchangeable Na was significantly lower in the surface soil 0-5 cm depth than 5-10 cm depth at both the sites. NO_3-N and exchangeable Mg values did not show any significant difference with respect to depth at both the sites. This is in agreement with other studies which reported high nutrient content in surface soils in comparison to subsurface soils and may be related to high biological activity in the upper soil layers due to accumulation of litter and atmospheric deposition (Arunachalam *et al.*, 1999). Besides, microclimatic conditions (temperature, MC, rainfall, light etc) directly interact only with the surface soil layer and thus could influence the soil physico-chemical properties within this layer. Further leaching of some nutrients (NO_3-N, base cations) may increase their concentration in the lower soil layers.

However, in the present study some of the parameters like available P, exchangeable Ca and K showed significant variation with depth only at clear-cut site. Similarly bulk density values significantly increased with depth only at adjacent forest site while WHC showed opposite trend, increasing with depth at adjacent forest site and decreasing at clear-cut site. These changes may be related to variation in above ground vegetation and soil particle sizes induced due to clear-cutting. Clear-cut site was dominated by herbaceous vegetation while trees roots at forested site may have influenced the nutrients within the soil layers. Piirainen *et al.* (2004) observed that inputs of Ca^{2+}, Mg^{2+} and K^{+} to the forest floor decreased immediately after clear-cutting however, soil pool of base cations increased in mineral soil (E+B horizons) after clear-cutting due to reduced leaching below the B-horizon.

Microbial populations are influenced by a number of environmental factors including temperature, moisture, pH and organic matter (Fierer and Jakson, 2006). Bacterial populations did not show any significant difference with respect to depth at both the sites however, fungal populations significantly increased with depth at CS and decreased at FS. Generally top soil contains high organic matter and soil moisture and hence microbial counts are generally higher in the surface soil layers (Panaiyadiyan and Chellaia, 2011). However, soil depth used in this study may be too less to observe any significant change in bacterial populations. Reciprocal changes in fungal populations with depth may be due to differences in temperatures at the two sites. Clear-cut site had significantly higher temperature while tree canopy at FS buffered temperature extremes. Tangjang *et al.* (2009) also observed higher populations of microbes in topsoil except during rainy season when the population was greater in subsurface soil layer under agroforestry systems in northeast India. However the mean values of soil bacteria, fungi and actinomycetes did not show any significant variation between CS and FS sites. Insignificant variation in microbial populations may be due to similar soil texture (clayey) and narrow range of pH (Fierer and Jakson, 2006; Babalola *et al.*, 2012). Soil pH was the best predictor of bacterial community composition across landscapes while fungal community composition is most closely associated with changes in soil nutrient status (Lauber *et al.*, 2008). Smith *et al.* (2008) also reported that harvesting did not have significant impact on the soil microbial community and suggested that microorganism play an important role in the resilience of forests to disturbances and in the regeneration process.

CONCLUSION

It is concluded that clear-cut site had significantly higher nutrient content than the adjacent forest site except exchangeable Mg. It is also observed high degree of variability with respect to depth within the same site for certain edaphic factors including microbial populations. However, present study did not observe any significant difference between soil pH, available P, NO_3-N and different microbial populations suggesting that thick herbaceous vegetation and stump roots left at clear-cut site have maintained the fertility of the soil. This increased fertility could provide a valuable nutrient supply to the succeeding forest stand, particularly if it is given proper protection.

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