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Effect of altitudinal variation on the soil characteristics in sal (*Shorea robusta* gaertn.) forests of eastern Nepal

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Abstract

Physico-chemical properties of forest soil depends on a variety of natural factors, the most important are variation in altitude, vegetation cover and microbial activities. The present study was conducted to understand the effect of variation in altitude in the soil characteristics in Tarai Sal forest (TSF) and Hill Sal forest (HSF), of eastern Nepal. Soil samples were collected from thirty plots randomly in each forest from 0- 15cm and 15-30cm depths in May 2012. Both forests had sandy loam type of soil texture. However, the percentage composition of soil particles varies within the forest sites. Soil moisture was higher in TSF. It was maximum in the rainy season in both forests. Water holding capacity was slightly higher in TSF. Bulk density was higher in TSF and it increased with soil depth in both forests. The pH value was slightly higher in HSF than TSF however, the value increased in lower soil depth in both forest stands. In the upper soil layer (0-15cm) soil organic carbon (SOC) was higher in HSF (2.09%) than TSF (1.6%). Similarly, total nitrogen (TN) was also higher in HSF (0.173%) than in TSF (0.129%) while total phosphorus (TP) was more or less same in both forest stands. The potassium (K) a soil extractable nutrient also showed higher value in HSF (312.13 $\mu g\ g^{-1}$) than TSF (238.47 $\mu g\ g^{-1}$). The values of SOC, TN, TP and K decreased in lower depth (15-30cm) in both forest stands. In conclusion, variation in altitude causes difference in the microclimatic condition which resulted into the alternation in soil characteristics.

Key words: Hill Sal forest, Microclimate, Soil physico-chemical properties, Tarai Sal forest

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Introduction

Physiochemical properties of forest soil vary in space and time depends on a variety of natural factors. Among the natural factors, the most important are variation in altitude, climate, vegetation cover and microbial activities (Bojko and Kabala, 2016). The elevation gradient may affect the microclimate and vegetation cover even over a small area. In the soil the microclimate particularly air temperature and annual precipitation determine the direction and intensity of physical, chemical and biological processes (Schawe *et al*., 2007). The vegetation cover also influences the chemical properties of soil to a great extent. The selective absorption of nutrient elements by different tree species and their capacity to return them to the soil brings about changes in soil properties (Sharma and Sharma, 2004). Plant litter and shed fine roots are main sources of soil organic matter which influence the physico-chemical characteristics of soil. The availability of soil nutrients may change with elevation in tropical ecosystems. Generally, soil organic carbon, nitrogen, available phosphorus, and exchangeable cation concentrations increased with the altitudes (Unger *et al*., 2010).

Information on the status of soil physico-chemical properties in the forests with regard to altitudinal variation is limited. So, in the present study, an attempt has been made to assess the effect on the status of soil physio-chemical properties in Sal forests located in Tarai and Hill regions of eastern Nepal. The work was designed to answer the following questions. (i) What is the status of soil physical and chemical properties of Sal forests located in Tarai and Hill regions? (ii) How does the soil property vary with regards to altitudinal variation?

Materials and Methods

Study area

The study was carried out in the Sal forest of Jhapa and Ilam districts of eastern Nepal. Sal forest of Jhapa district is addressed as Tarai Sal forest and of Ilam district as Hill Sal forest. The main part of TSF is located at Jalthal Village Development Committee (VDC) near kechana (extreme low land of Nepal). The forest floor has ridge and furrows with altitudinal variation from 62 to 129 m msl. It lies in between 87°55′ and 88°03′E longitude and 26°26′ and 26°31′N latitude. In TSF mean monthly minimum and maximum temperature ranged between 17.3°C and 30.6°C. The average annual rainfall of TSF was 2130.4 mm.

The main part of HSF is located at Kiteni of Kolbung VDC. The forest is situated on the southern foot hills (Siwalik Hills) representing the Sub Himalayan tract of Nepal Himalayas (Gansser, 1964). Altitude ranges from 500 to 850 m msl in HSF. It is situated in between 88°02′ and 88°04′E longitude and 26°44′ and 26°47′N latitude. In HSF the temperature range was 15.8°C (minimum) to 22.2°C (maximum). The average annual rainfall of HSF was 1776.07 mm. Both TSF and HSF are Sal *(Shorea robusta* Gaertn.) dominated mixed forests located along altitudinal gradient in moist tropical region in eastern Nepal. The climate of TSF and HSF is tropical monsoon type.

Soil sampling

Soil samples were collected from thirty plots randomly in each forest. At each plot the soil was collected from three pits (10 cm×10 cm×15 cm), mixed and pooled as one replicate. Soil samples were collected from 0-15 cm and 15-30 cm depths for the estimation of physico-chemical properties in May 2012. The air dried samples were sieved through a 2 mm mesh screen and used for Physico-chemical analysis.

Soil analysis

The soil texture, soil moisture (SM) and water holding capacity (WHC) were determined following Piper (1966). Water holding capacity was estimated by allowing perforated brass box filled with compacted soil to stand overnight over water until saturated. Bulk density (BD) was determined by inserting metallic tube of known internal volume in soil and there after estimating dry weight of a unit volume of soil (Brady and Weil, 2013).

Soil pH was measured by using a glass electrode (1:5, soil: water). Soil organic carbon was analyzed by digestion of soil samples with H_2SO_4 along with potassium dichromate and titration with ferrous ammonium sulphate (Walkey and Black, 1934). Total nitrogen was estimated by micro-kjeldahl method (Jackson, 1958). Total phosphorus was determined by calorimetrically by ammonium molybdate-stannous chloride blue color method after digesting the soil in triacid mixture of $HClO_4$, HNO_3 and H_2SO_4 in the ratio of 1:5:1 (Jackson, 1958). Potassium was estimated by atomic absorption spectrophotometer.

Correlation analysis was done to find out the relationship in between soil physico-chemical properties for upper soil depth (0-15 cm) of TSF and HSF. Linear regressions were also carried out between the significantly correlated variables. Student t-test (two samples assuming equal variance) was performed to compare the SOC and TN of TSF and HSF.

Results

Soil physico-chemical properties *viz*., texture, SM, pH, BD, WHC, SOC, TN, TP and K have been analyzed for TSF and HSF and results are presented in Table 1 and 2. Both forests had sandy loam type of soil texture. The soil of TSF was composed of sand (52%), silt (31.4%) and clay (16.6%) while in Hill Sal forest, sand (65.73%), silt (25.93%) and clay (10.73%) in the upper (0-15 cm) depth (Tab. 1). The proportion of sand showed a marked increase with soil depth in both forests but silt increases with depth only in TSF. Clay decreased along the soil depth in TSF. Soil moisture was higher in TSF it was maximum in the rainy season in both the forests. Water holding capacity was slightly higher in TSF. It decreased with soil depth in both forests. Bulk density was higher in TSF than HSF and increased with soil depth while porosity was higher in HSF and decreased with soil depth in both forests.

The pH value was slightly higher in HSF than TSF however, the value increased in lower soil depth in both forest stands. The soil chemical properties generally increased with increasing altitude (Tab. 2). In the upper soil layer (0-15 cm) soil organic carbon was significantly higher in HSF (2.09%) than TSF (1.6%). Similarly, total nitrogen was also significantly higher in HSF (0.173%) than in TSF (0.129%) while total phosphorus was more or less same in both forest stands. The potassium a soil extractable nutrient also showed higher value in HSF (312.13 $\mu g\ g^{-1}$) than TSF (238.47 $\mu g\ g^{-1}$). The value of SOC, TN, TP and K decreased in lower depth (15-30 cm) in both forest stands. The C:N ratio of Tarai and Hill Sal forest was more or less similar.

Table 1. Soil physical characteristics in Tarai Sal forest and Hill Sal forest of eastern Nepal. Values are means ±1 SE.

Soil properties	Tarai Sal forest		Hill Sal forest	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
Soil texture				
Sand (%)	52 ± 1.75	57.66 ± 1.83	65.73 ± 0.77	68.13 ± 0.60
Silt (%)	31.4 ± 1.68	33.93 ± 1.50	25.93 ± 0.86	21.8 ± 0.76
Clay (%)	16.6 ± 0.96	8.46 ± 0.65	10.73 ± 0.62	11 ± 0.44
Soil moisture (%)				
Rainy	38.3 ± 0.14	40.13 ± 0.11	26.32 ± 0.24	28.35 ± 0.25
Winter	18.17 ± 0.219	20.53 ± 0.20	10.56± 0.13	12.13 ± 0.14
Summer	9.11 ± 0.18	10.96 ± 0.18	5.15 ± 0.15	7.21 ± 0.15
Water holding capacity (%)	59.6 ± 1.25	54.58 ± 1.24	58.41 ± 1.53	52.51 ± 1.44
Bulk density (g cm^{-3})	1.3 ± 0.004	1.44 ± 0.004	1.03 ± 0.007	1.13 ± 0.004
Porosity (%)	50	45	60	57

Table 2. Soil chemical characteristics in Tarai Sal forest and Hill Sal forest of eastern Nepal. Values are means ±1 SE.

Soil properties	Tarai Sal forest		Hill Sal forest	
	0-15 cm	15-30 cm	0-15 cm	15-30 cm
pH	5.35 ± 0.03	5.59 ± 0.02	6.42 ± 0.03	6.58 ± 0.03
Organic Carbon (%)	1.6± 0.09	0.908 ± 0.050	2.09± 0.12	1.53 ± 0.11
Total nitrogen (%)	0.129± 0.003	0.106 ± 0.002	0.173± 0.005	0.124 ± 0.004
Soil organic matter (%)	2.76± 0.15	1.55 ± 0.08	3.6± 0.02	2.64 ± 0.18
Total phosphorus (µg g^{-1})	619.95 ± 0.31	617.13 ± 0.19	669.53 ± 9.63	621.55 ± 0.38
Potassium (µg g^{-1})	238.47 ± 0.37	209.11 ± 0.18	312.13 ± 0.14	297.27 ± 0.15
C: N ratio	12.48	8.56	12.09	12.33

Table 3. Pearson's correlation between soil physico-chemical properties in Tarai Sal forest of eastern Nepal.

	Sand	Silt	Clay	WHC	SM	pH	BD	SOC	TN	TP
Silt	-0.843**									
Clay	-0.342	-0.215								
WHC	0.118	-0.233	0.191							
SM	0.107	-0.262	0.262	-0.102						
pH	-0.005	-0.281	0.501**	0.354*	0.167					
BD	0.112	-0.297	0.315	0.123	0.127	0.286				
SOC	0.476*	-0.441*	-0.095	0.355*	0.103	0.109	-0.172			
TN	0.420*	-0.517	0.139	0.530*	-0.074	0.186	0.134	0.640**		
TP	0.323	-0.275	-0.106	0.344	0.045	-0.168	0.126	0.493**	0.551**	
K	-0.093	-0.121	0.382*	-0.025	0.111	0.436*	-0.137	-0.037	-0.213	-0.251

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

Table 4. Pearson's correlation between soil physico-chemical properties in Hill Sal forest of eastern Nepal.

	Sand	Silt	Clay	WHC	SM	pH	BD	SOC	TN	TP
Silt	-0.769**									
Clay	-0.386*	0.259								
WHC	-0.439*	0.321	0.159							
SM	0.159	-0.204	0.023	0.102						
pH	-0.085	0.022	-0.129	-0.348*	-0.083					
BD	0.133	-0.188	0.007	0.096	0.073	-0.377*				
SOC	0.186	-0.216	0.110	0.315	-0.013	-0.436*	0.412*			
TN	-0.002	-0.017	0.293	0.311	-0.230	-0.444*	0.254	0.733**		
TP	0.119	0.168	-0.157	-0.014	-0.023	-0.191	0.054	-0.038	-0.100	
K	0.121	-0.138	0.426*	0.489*	0.056	-0.278	0.243	0.671**	0.603**	-0.219

** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed).

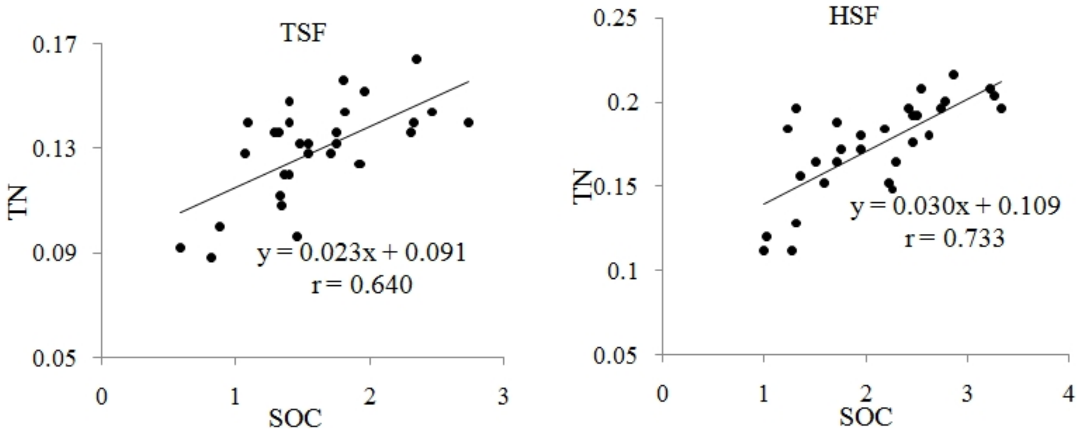

Figure 1. Relationship between soil organic carbon and total nitrogen in Tarai Sal forest and Hill Sal forest of eastern Nepal. (P < 0.001)

Pearson's correlation analysis is presented in Table 3 and 4. Relation in between physico-chemical properties for upper soil layer (0-15cm depth) was assessed for TSF and HSF. Soil variables significantly correlated at 0.01 and 0.05 level are mentioned in the tables for both forests.

Regression analysis was carried out between the significantly correlated soil variables. Relationship between soil organic carbon and total nitrogen in TSF and HSF which were significant at 0.01 levels are shown in Figure 1.

Discussion

Variation in altitude is very common in forest ecosystems in the Southeast Asia due to the wide spread of mountains and this change can influence the microclimate, such as the temperature and moisture (Chang *et al*., 2016). Due to change in microclimatic condition, soil physical, chemical, biological properties especially soil microbial biomass are changed consequently. Altitudinal variation is highly interrelated with the physiochemical properties of soils (Burns and Tonkin, 1982).

In the present study the soil texture in both forests was sandy loam type. This is common in Tarai, Siwalik and Dun valleys which support dense Sal forest and other timber plants (Jackson, 1994). Soil texture plays important role in the vegetation development and nutrient cycling (Robertson and Vitousek, 1981) because of its main role in supply of air, water and nutrients required for root development. The result showed similarity with the result of Paudel and Shah (2003) reported for mixed Sal forest of Udayapur Nepal, mature hill Sal forest of Nepal Himalaya (Singh *et al.*, 2001) and in Siwalik Sal forest located in different altitudes of Kumaun, India (Bohra *et al.*, 2010).

Values of soil moisture and water holding capacity were higher in Tarai Sal forest and showed decreasing trend with increasing altitude. Soil moisture increased while water holding capacity decreased in lower depth (15-30 cm) in the both Sal forests. Higher value of WHC in soil of Tarai Sal forest may be due to presence of relatively higher amount of clay which has large specific area, giving them great capacity to adsorbed water and other substances (Brady and Well, 2013). Moreover, TSF showed higher soil temperature and moisture than HSF (Bhattarai, 2016) which may enhance the decomposition of litter and fine root turnover rate, as a result the soil may be enriched with soil nutrients causing higher water holding capacity of soil (Reth *et al.*, 2005).

The bulk density was higher in Tarai Sal forest than Hill Sal forest and showed increasing trend towards the lower depth in the both Sal forests. Similar finding was also reported by Singh and Kashyap (2006) in Bindhyan region, Utter Pradesh, India and Kidanemariam *et al*. (2012) in Tsegeden highlands, northern Ethiopia. Griffiths *et al*. (2009) also found an opposite relationship between elevation and bulk density in Oregon Cascade Mountains. The relatively lower value of bulk density in HSF might be due to presence of higher organic matter accumulation in the soil than the TSF. The soils with high organic matter accumulation are higher in percent pore space despite of the amount of soil particles in the soil and results in lower bulk density. On the other hand the soils with low organic matter are lower in percent pore space and results in higher bulk density. The bulk density of soil increased in lower depth which may be due to compaction of soil and decrease in organic matter in the lower horizons of the profiles with time.

Soil pH affects a wide range of soil chemical and biological properties (Brady and Weil, 2013). Acidification of forest soil might be due to formation of weak organic acid by dissolving the carbon dioxide in soil water which is produced during root respiration and decomposition of soil organic matter by micro-organisms. Tarai Sal forest had relatively acidic soil than Hill Sal forest and acidic nature decreased along soil depth as the pH values increased in both the forests. Similar trend was reported as the effect of altitude on soil pH in the forest of Firtina River Basin (Yüksek *et al.*, 2013) and in Oregon Cascade Mountains (Griffiths *et al*., 2009). Singh and Kashyap (2006) reported more or less similar value of pH in Bindhyan Sal forest located in different topography. Soil pH increased along the soil depth which may be concluded that leaching of alkaline cations (such as Ca, Na, K, Mg) from upper layer to lower layer might have affected to increase soil pH. On the other hand, the decreasing soil organic matter may lead to increase the soil pH along the soil depth.

Soil organic carbon is the main terrestrial carbon pool (Bates, 1996) which increases the ion exchange capacity (Johnston, 1986), water holding capacity (Salter and Williams 1969) and availability of nutrients (Schnitzer and Khan, 1978). Tarai Sal forest had lower value of soil organic carbon than Hill Sal forest. However it decreased along the increasing soil depth. Griffiths *et al*. (2009) and Tsui *et al*. (2013) also found a positive relationship between elevation and soil organic matter. Similarly, DFRS (2015) also showed that SOC stock in forest was found to increase with increasing altitude. Relatively higher amount of soil organic carbon accumulation in the Hill Sal forest might be due to lower soil temperature and moisture which reduce the decomposition rate of organic matter (Griffiths *et al*., 2009; Moore, 1986). On the other hand higher concentration of organic carbon in the upper layer of soil may be due to higher microbial activities releasing more carbon in upper layer of soil.

Total nitrogen in Hill Sal forest was higher than Tarai Sal forest. Similar relationship was also found by Sigdel *et al*. (2015) on Shivapuri Nagarjun National Park, central Nepal and Li *et al*. (2013) in the Gongga mountain of western China. Lower temperature together with high atmospheric humidity of Hill Sal forest may cause slow rate of mineralization and nitrogen turnover thus accumulation occurs at high rate. On the other hand, high turnover rate of leaf litter and fine root and N-mineralization rate at TSF (Bhattarai, 2016) may be the cause of less organic matter accumulation at TSF. Moreover, there is a longer residence time of nitrogen in the litter and a decrease in soil N losses at higher altitude than lower (Smith *et al*., 2002). Another cause of high soil nitrogen storage in HSF may be the presence of *Cassia* species a dominant legume tree of second story vegetation which fixes atmospheric nitrogen in root nodule. Further, its nitrogen rich leaf litter and fast decomposition rate are also the source of more nitrogen addition in the soil (Mandal, 1999). In the present study the C: N ratio became more or less same indicating the stabilization in nutrient concentration in plant parts and domination of the site by a single species i.e. *Shorea robusta* (Singh *et al*., 2001). In conclusion, variation in altitude causes the difference in microclimatic condition, which resulted into the alternation in soil characteristics. The less organic matter accumulation at TSF may be due to its fast turnover and mineralization rate indicating a fast nutrient cycling essential for high production rate of forest.

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