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Effect of different land use system and altitude on soil organic carbon and soil fertility of Siang river basin in Arunachal Pradesh, India

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ABSTRACT

The land use (LU) change from forest to cropland and orchards are major causes that decrease soil organic carbon (SOC) and soil fertility of Siang river basin area. Hence proper understanding of the SOC storage in the process of LU system change, altitudinal zones and vertical distribution is crucial for planning and designing appropriate LU system. We examined the vertical distribution of SOC under different land use types and altitudinal zones aspects in Siang river basin of Arunachal Pradesh. Soils were sampled based on slope and soil properties. The results showed that LU system significantly influenced mean SOC per cent following an order forest>mandarin > rice-fallow system. An inverse effect was found in SOC across the altitudes and soil depths. LU system influence the mean soil available N content significantly and followed the order forest=mandarin>rice-fallow while mean soil available P, K, S and B content followed the order forest>mandarin>rice-fallow land use systems. Variation in altitude zone affected the mean soil available N, P, K, S and B content in the order low>high altitudes. Soil depth variations influenced the soil available N, P, K, S and B content in the order 0-15 >15-30 cm. Two factor interaction effects between LU systems, altitudes and depth was also studied. The two factor interaction effect was significant for SOC, soil pH, soil EC, soil available N, P, K, S and B. In all land use systems, SOC showed no significant relationship with soil pH whereas soil SOC was significantly and positively correlated with soil EC, soil available pool of N, P, K, S and B. Across the altitudes, soil available N, P, K, S and B was positively and significantly correlated to SOC whereas soil pH an EC showed no significant relationship. Our study indicates that appropriate LU system and management practices according to altitude zone and slope will improve the SOC sequestration and soil productivity.

Keywords : Altitude, forest, land use system, SOC, soil available nutrients

Soil is the largest pool of organic carbon (c) in the biosphere, containing about 2300 Pg of carbon in the top three meters (Jobbagy and Jackson, 2000). The soil organic carbon pool is influenced by the intake in CO_2 from the atmosphere by plant and soil CO_2 efflux by decomposition and degradation. Soil organic matter plays a key role in shaping the physical structure of the soil, mainly through the formation of organo-mineral complexes that determine the arrangement and stability of soil aggregates. The organo-mineral complexes are the cementing agents which prevent the soil carbon from losses and microbial attack. The conversion to cropland leads to reductions in soil C and N content (Durigan *et al.*, 2017). LUC altered soil organic matter (SOM) quality, and silt and clay remained the combined fraction that contributed the most to soil C storage (Durigan *et al.*, 2017). The organic matter associated with the clay and silt fraction constitutes the recalcitrant fractions that stabilize the soil organic carbon (SOC) and improve the soil quality. The cementing agent are disintegrated and CO_2 is released into the atmosphere with the disruption of forest land to agricultural or settlement area. The annual CO_2 efflux from soil is 8-10 times the amount derived from fossil fuel combustion (Lal, 2008). The labile pool of soil carbon when exposed on the surface is lost easily with clearing of forest vegetation, tillage in rice cultivation and erosion. Despite the potential changes in the SOC pool and its effect on the global carbon cycle, from the agriculture sector, we continue to lack robust estimation of the spatial and temporal variability of SOC content.

Arunachal Pradesh extends from the snow covered Himalayas to the Brahmaputra plains, covering an area of 8.37 m ha. Arunachal Pradesh has the third largest forest cover in India with 82.26 per cent (6.86 m ha) out of the total geographical area (CWC, 2013). The Siang river basin of Arunachal Pradesh has a total forest cover of 22.15 per cent (1.52 m ha) as compared to state's average forest cover of 80.26 per cent. Siang river basin constitutes different kind of forest cover which is tropical evergreen, tropical semi-evergreen, subtropical deciduous, subtropical semi-evergreen and evergreen and wet temperate forest. The major cropping system practiced in the plains and hills is rice-fallow system with terrace or without terracing across or along the slope. The practice of rice-fallow system in hills without terrace along the slope causes loss of SOC and soil available nutrients with runoff water. The other cropping system with few pockets adopted in the recent past are mandarin cultivation, bamboo plantation, tea plantation,

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rubber plantation, vegetables and spices like brinjal, colocasia, ginger, large cardamom *etc*. Land use conversion associated with management practices plays a key role in the distribution and origin of C in different soil organic matter (SOM) fractions (Six *et al.*, 2001; Six *et al.*, 2002; Lee *et al.*, 2009). Few studies addressing land use conversion impact on SOC was done in the lowland subtropical plains of Siang river basin due to its easier accessibility, although contemporary land use changes have been occurring in the higher altitudes. Land use change, logging and deforestation and low intensity agricultural transformation (Roy, 2016) remove bulk of carbon along with the fertile top soil. The amount of total P exported out as timber from the ecosystem by heavy selective logging was estimated at 24.0 kg ha^{-1}, while the amount of labile P in the top soil was 12.8 kg ha^{-1}, indicating labile P might become deficient by more than 12 kg ha^{-1} for biomass recovery (Imai *et al.*, 2017). Many research have been conducted to study the impact of land use (LU) system and altitude on SOC and soil fertility, but little research on the combined effect of LU system change and altitude on the changes in SOC and fertility was done till date. To address the single and combined effect of LUS altitudes and depths, we selected Siang river basin located at Arunachal Pradesh to investigate the changes occurring for SOC and soil available nutrient.

MATERIALS AND METHODS

Study area

Siang river basin is a rugged mountain terrain consisting of deep valleys flanked by highland plateaus and ridges that rise to the peaks of the Great Himalaya. The elevation of the hills varies from 305 to 3050 m. Siang river basin are characterized by the occurrence of depositional terraces of large boulders of quartzite, gneisses, schist, *etc*., bedded in sandy matrix. The Siang river basin is situated $28^0 27' 21.9'' \pm 3$ N and $95^0 14' 14.7'' \pm 3$ E. The Districts in the Siang basin area that are at a higher altitude (>500 m msl) experience temperate subtropical climate. The areas at the lower altitude of Siang river basin (<500 m msl) experience humid sub tropical climate with hot summers and mild winters. The minimum average temperature in the winter was 13.66 ^{0}C and the maximum average summer temperature was 30^0C. The area receives heavy rainfall of 1000 mm upto 4000mm annually. The relative humidity (RH) of the area varies from 66.6 per cent in the winter to 89.75 per cent in the rainy season. The soil is under Ultisols and Inceptisol soil orders, with kaolinite as the dominating clay mineral. The soil is acidic (pH 4.1-5.8) and sandy loam having low soil moisture holding capacity. The area has very low base saturation of less than 40 per cent and lime application showed improvement of soil available nutrients.

Soil sampling

The study site was selected based on its soil properties, slope and distance. Soil samples were collected at three different depths (0-15 and 15-30 cm) from three different land-use system at high (500-1000m msl) and low (<500m msl) altitude of Siang basin districts of Arunachal Pradesh. In high altitudes, forest and mandarin land use system were located juxtapose one another. In the low altitude, rice-fallow was located at a distance of 5 km away from the other two land use system in the plains. On the other hand the rice-fallow land use system in the high altitude was 2-3 km away from the two land use system. Each land use system selected was divided into three sections. In each section soil were sampled from four spot in zig zag soil sampling procedure ((Dwivedi *et al.*, 2005) from 0-15 and 15-30 cm depths using a core sampler. The soil collected from each spots was mixed together with hand to make a composite sample soil for each depth separately in three replicates (36 samples). The soil samples were packed in poly bags and brought to the laboratory from the field. The wet soil samples were air dried and grounded in a wooden mortar and pestel and passed through 0.2mm sieve for laboratory analysis. The grounded soil samples were labeled precisely *viz*. treatment combination in depth wise, and put into an air tight plastic container. Samples were collected between February and March 2015. The land use systems identified for the study was rice-fallow, mandarin and forest. The details of the LU system are briefly given in table 1.

Laboratory analysis

The soil carbon content (SOC) was estimated by Walkely and Black wet oxidation (Jackson, 1967)). The available nitrogen (N) was estimated with 0.32% alkaline $KMnO_4$ (Subbiah and Asija, 1956), available phosphorus (P) with 0.5 M $NaHCO_3$ (pH 8.5), available potassium (K) with Neutral N NH_4OAc (Jackson, 1967), available sulphur (S) with turbidometric (Williams and Steinbergs (1959) and available boron (B) with hot $CaCl_2$ extraction Azomethine-H estmaion (John *et al.* (1975). Soil pH and soil $EC_{(1:2.5)}$ (electrical conductivity) was measured with a pH meter and EC meter as per Jackson (1973) procedure.

Statistical analysis

Mean values for different layers, land use system and altitude were compared using one-way ANOVA with a Tukey's Studentized Range test to indicate between-group differences. ANOVA analysis of means was performed to analyse the effect of different factors and quantify the difference between land use systems, between altitudes and among depths. The correlation between SOC with pH, EC, available N, available P, available K, available S and available B for altitudes and land use systems were also studied. Differences were considered statistically significant at *P<0.05* and correlation were considered statistically significant at *P<0.01* and *P<0.05*. Statistical analysis was performed using SAS9.1.

RESULTS AND DISCUSSION

SOC percent change in different LU systems, altitudinal zone and soil depth

LU system significantly influenced mean SOC percent following an order forest>mandarin> rice-fallow system. We observed a decrease in SOC with increase in altitudes and soil depths (Table 1).

Means of SOC per cent was significant in the two factor interactions between LU systems, altitudes and depths (Table 2). Among the altitudes and LU system interaction, the highest SOC was estimated in the low altitude-forest LU which was at par with low altitude-mandarin land use. The high altitude-forest LU system interaction estimated second highest in SOC accumulation. The high altitude- mandarin LU system estimates the third highest SOC per cent. The 0-15 cm depth interaction with forest LU estimated the highest SOC percent, followed by mandarin LU. The 0-15 cm depth-rice fallow interaction showed lower SOC content than the 0-15 cm depth interaction mandarin and forest LU systems. It was also found that the 0-15 cm depth interaction with low altitude was significantly highest in SOC per cent followed by interactions with high altitude (Table 2).

In this selected study site the forest land was undisturbed; litter fall contributed to the high amount of SOC at 3.43 per cent whereas rice cultivation reduced the SOC due to tillage and runoff along the slope (Singh and Munda, 2008) (Table 2). The study showed the SOC decreased linearly with increase in altitude from 500 to 1000 m confirming findings of some earlier forest transect study (Girardin *et al.*, 2010). The majority of longer tropical transects (spanning >1000 m in altitude) that established their sites on gentle slopes (<25°) with similar soil properties (Girardin *et al.*, 2010; Kitayama and Aiba, 2002) also reported an increase of SOC stocks with increasing altitude. Similarly, other finding of forest

Table 1: Description of selected LU system in the study

LU System		Description
		Low altitude (<500m)
Rice-fallow	:	Rice-fallow LU system was adopted for the past 20-40 years and the rice variety cultivated is indigenous cultivar (Itanagar). The area was an open forest before it was cleared for rice cultivation. The topography is plain and surrounded by rice field in all sides.
Mandarin	:	The area was established into a mandarin orchard in the year 1987. The variety cultivated is Khasi mandarin. The area was an open forest before 1987. Before independence it was a settlement area. Interculural activities like weeding is done three times annually, liming is done during winters after harvest of the crop, pruning is done once annually in the winter season after harvest. Application of FYM- 25 kg tree^{-1}, NPK- 200:500:500 (g tree^{-1}) is applied in three split during March, June and September, annually. Rain fall is the only source of irrigation. The orchard is situated in a slightly slope area.
Forest	:	The forest is a mixture of evergreen and deciduous trees with dominance of evergreen trees. The forest is composed of trees like hollock (*Terminalia myriocarpa*), Bonsun (*Phoebe gualparensis*), hingori (*Castanopsis indica*), dhuna (*Canarium resiniferum*), selling *etc*. the forest area is situated in a slope gradient.
		High altitude (>500-1000 m)
Rice-fallow	:	The area was under jhum cultivation before 2005. Rice-fallow land use system is being practiced in terrace for the past 10 years from 2005. The rice variety cultivated is indigenous cultivar called Itanagar. Before jhum cultivation the land area was under dense forest cover.
Mandarin	:	The land was an open forest till 2009. Before the plantation of mandarin in 2011, the land was used for pineapple cultivation from 2009.The mandarin cultivar grown is khasi mandarin. Rainfall is the only source of. Intercultural activity like weeding is done manually, twice in a year during the month of July-August and October. The mandarin fruit is harvesting starts from November till January. The orchard is situated in slope area facing the sun
Forest	:	The forest is densely covered with evergreen deciduous trees. Some of the tree species found are jutuli (*Altingia illoc*), 3 illock (*Terminalia myriocarpa*), Bonsun (*Phoebe gualparensis*), jamuk (*Syzygium cumin*) *etc*. The forest land is situated in slope area.

transect showed SOC stocks increased with increasing altitude (Dieleman *et al.*, 2013; Girardin *et al.*, 2010; Kitayama and Aiba, 2002; Raich *et al.*, 2006; Townsend *et al.*, 1995). However, in other forest transect there were no changes with altitude (Raich *et al.*, 1997; Soethe *et al.*,2007; Zimmermann *et al.*, 2010), or no consistent pattern was found (Schawe *et al.*, 2007;Schrumpf *et al.*, 2001).

The low altitude region experience warmer temperature which accelerates the enzymatic breakdown of the labile soil organic matter pool than in the high altitude with colder temperature. The buildup of a thicker organic layer due to litter fall in the soil surface (0-15 cm) and presence of beneficial soil micro-organisms in the active root zone of LU systems might have supported the high level of SOC in the surface layer than lower depths (Dieleman *et al.*, 2013; Graefe *et al.*, 2008; Leuschner *et al.*, 2007; Wilcke *et al.*, 2008; Zimmermann *et al.*, 2010). Our study showed significant interaction combination between altitude and LU system on SOC change as climatic conditions varied slightly across the altitude which is in confirmation with previous studies (Han *et al.*, 2010; Post and Kwon, 2000). The significant interaction effect between depth and LU system confirm with the studies that root concentration in different depth influences the SOC percentage (Han *et al.*, 2010).

Soil reaction change in different LU systems, altitudinal zone and soil depth

The mean soil pH of rice-fallow system (6.28) was significantly higher than forest LU (5.06) and mandarin LU (4.93) system (Table 3). Mean soil pH increased numerically with increase in altitude and decreased numerically with increase in depth but statistically altitude and depth effect was not significant (Table 3). The mean soil EC of rice-fallow system was significantly higher in comparison to other two LU systems (Table 4). The means soil EC also responded to altitude and soil layer variation with a decrease in increasing altitudinal tract and depth.

Though, the single factor effects of LU systems, altitudes and depth factor was not significant for mean soil pH, but mean soil pH observed in all two way interactions was significant between the factors (Table 3). It was found that the high altitude-rice-fallow system (6.38) interaction estimated significantly highest in soil pH among all the interaction combination (Table 3). The mean soil pH and EC was significantly highest in 0-15 cm-rice-fallow system among all the interaction combinations (Table 3 and 4). There was no significant interaction recorded between altitude and depth for mean soil pH, while low altitude-0-15cm recorded significantly highest mean soil EC.

Table 2: Effects of land use systems and altitudes on changes on soil organic carbon percentage along the soil depth in Siang river basin districts of Arunachal Pradesh.

	Land use			
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	1.55^{c}	3.76^{a}	3.78^{a}	3.03^{a}
500-1000 m	1.24^{d}	3.15^{c}	3.52^{b}	2.64^{b}
Mean	**1.40^{c}**	**3.46^{b}**	**3.65^{a}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	1.84^{e}	4.08^{b}	4.39^{a}	3.44^{a}
15-30	1.08^{f}	3.02^{d}	3.41^{c}	2.50^{b}
Mean	**1.46^{c}**	**3.55^{b}**	**3.90^{a}**	

	Soil Depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**
<500 m	3.91^{a}	2.96^{c}	3.44^{a}
500-1000 m	3.30^{b}	2.64^{d}	2.97^{b}
Mean	**3.61^{a}**	**2.80^{b}**	

Table 3: Effects of land use systems and altitudes on changes on soil pH$_{(1:2.5)}$ along the soil depth in Siang river basin districts of Arunachal Pradesh.

	Land use			
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	5.98^{abc}	4.47^{d}	4.72^{cd}	5.06^{a}
500-1000 m	6.21^{ab}	5.09^{bcd}	4.95^{bcd}	5.42^{a}
Mean	**6.10^{a}**	**4.78^{b}**	**4.84^{b}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	**6.54^{a}**	**5.27^{abcd}**	**5.21^{bcd}**	**5.67^{a}**
15-30	6.38^{ab}	5.09^{bcd}	4.97^{cd}	5.48^{a}
Mean	6.46^{a}	5.18^{b}	5.09^{b}	

	Soil Depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**
<500 m	5.27^{ab}	5.17^{ab}	5.22^{a}
500-1000 m	5.66^{ab}	5.44^{ab}	5.55
Mean	**5.47^{a}**	**5.31^{a}**	

In our study, rice-fallow system showed significant and highest soil pH and EC among the LU systems confirming the finding with certain studies (Simeon, 2014). Tillage practices in rice cultivation accelerate soil organic matter oxidation; inundation of rice field causes the consumption of active hydrogen ions which increased the pH in rice-fallow LU system in our study (Table 3). Mean soil EC was found to be highest in rice-fallow (0.90dSm^{-1}) that significantly varied from all two LU systems (Table 4). Rice-fallow system water need was provided with flooding irrigation which might be the cause for slightly higher soil EC than the rest of the LU system. The variations of bulk density, soil texture and concentration of root growth in soil layers might be the reason for decrease in soil EC in lower depths (Aini *et al*., 2014). In our study, the <500m altitude was warm and humid while the >500m was colder and humid and soil EC decreased with increase in altitude is in confirmation with previous study that states soil EC decrease with increase of temperature due to decrease of soil resistivity in lateritic soil (Bai *et al.*,2013).

Table 4: Effects of land use systems and altitudes on changes on soil EC$_{(1:2.5)}$ (dSm^{-1}) along the soil depth in Siang river basin districts of Arunachal Pradesh.

	Land use			
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	0.11^{a}	0.06^{de}	0.07^{cde}	0.08^{a}
500-1000 m	0.09^{b}	0.05^{de}	0.06^{de}	0.07^{b}
Mean	**0.10^{a}**	**0.06^{b}**	**0.07^{b}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	0.12^{a}	0.07^{cd}	0.10^{b}	0.10^{a}
15-30	0.08^{bc}	0.05^{def}	0.04^{fg}	0.06^{b}
Mean	**0.10^{a}**	**0.06^{c}**	**0.07^{b}**	
	Soil Depth (cm)			
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	0.10^{a}	0.07^{cd}	0.09^{a}	
500-1000 m	0.09^{ab}	0.06^{de}	0.08^{b}	
Mean	**0.10^{a}**	**0.07^{b}**		

Soil available nutrient change in different LU systems, altitudinal zone and soil depth

The mean soil available N, was significant in LU system and followed the order forest=mandarin>rice-fallow while mean soil available P, K, S and B concentration was significant in LU system and followed the order forest>mandarin>rice-fallow land use systems (Table 5 and 6). Altitude variation affected the mean soil available N, P, K, S and B concentration and followed an order low>high altitudes. Depth factor affected soil available N, P, K, S and B concentration and followed an order 0-15 >15-30 cm. The two factor interaction effect among LU system, altitudes and depths were significant for the soil available N, P, K, S and B (Table 5 and 6). Mean soil available N was highest in low altitude-forest LU that was at par with low altitude-mandarin LU (Table 5). Mean soil available P was highest and significant in low altitude-mandarin LU interaction while mean available K, S and B was highest and significant in low altitude-forest LU interaction. Among the depth and LU system interaction, 0-15 cm-forest LU interaction recorded the highest which was at par with 0-15 cm-mandarin LU interaction in mean soil available N content. The 0-15cm-forest LU interaction recorded highest mean soil available P, K, S and B among other treatment combinations. In our study, the low altitude-0-15 cm depth interaction recorded the highest soil available N, P, K, S and B (Table 5 and 6).

Soil fertility is directly affected by the labile SOC concentration. In our study, we found LU system variation influenced mean SOC in the order forest>mandarin>rice-fallow, likewise soil available P, K, S and B were also influenced by LU change in the same order (Table 5 and 6). Though, mean SOC of mandarin LU was lower than forest LU, mean soil available N was recorded highest in mandarin LU. It suggests that application of fertilizer complements SOC in increasing soil available N. Soil nutrient are present in ionic form and availability increases with increase in pH to neutral in acidic soils. In rice-fallow system though the pH was higher (6.38) than other LU system the available nutrients was found the least due to low SOC in all soil depths.

Correlations of SOC and soil parameters in different land use system

SOC was positively correlated with the soil EC in all land use system while forest land use system have the strongest correlation (r = 0.83) whereas SOC and soil pH showed no significant relationship in all land use systems (Table 7). Soil SOC was significantly and positively correlated with soil available pool of N, P, K, S and B while mandarin land use showed the highest positive correlation between soil available N and SOC (r=0.90), K and SOC (r = 0.91), B and SOC (r = 0.90), rice-fallow-fallow land use showed highest positive correlation between soil available P and OSOC (r=0.90) (Table 7).

Table 5 : Effects of land use systems and altitudes on changes on primary soil available nutrients (N, P and K) along the soil depth in Siang river basin districts of Arunachal Pradesh.

		Soil available N (kg ha^{-1})		
		Land use		
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	268^{cd}	402^{a}	413^{a}	361^{a}
500-1000 m	223^{de}	373^{ab}	355^{ab}	317^{b}
Mean	**246^{b}**	**388^{a}**	**384^{a}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	253^{bc}	441^{a}	408^{a}	367^{a}
15-30	224^{cd}	367^{a}	366^{a}	319^{b}
Mean	**239^{b}**	**404^{a}**	**387^{a}**	
		Soil depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	409^{a}	335^{bc}	372^{a}	
500-1000 m	367^{ab}	315^{bcd}	341^{b}	
Mean	**388^{a}**	**325^{b}**		
		Soil available P (kg ha^{-1})		
		Land use		
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	35.3^{e}	166^{a}	161^{b}	121^{a}
500-1000 m	28.7^{f}	107^{d}	124^{c}	86.6^{b}
Mean	**32.0^{c}**	**137^{b}**	**143^{a}**	
Depth (cm)	**Rice-fallow**	**mandarin**	**Forest**	**Means**
0-15	36.2^{e}	142^{b}	153^{a}	110^{a}
15-30	28.7^{f}	118^{d}	133^{c}	93.2^{b}
Mean	**32.5^{c}**	**130^{b}**	**143^{a}**	
		Soil depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	126^{a}	112^{b}	119^{a}	
500-1500 m	108^{c}	86.5^{d}	97.3^{b}	
Mean	**117^{a}**	**99.3^{b}**		
		Soil available K (kg ha^{-1})		
		Land use		
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	202^{d}	314^{b}	353^{a}	290^{a}
500-1000 m	168^{e}	275^{c}	320^{b}	254^{b}
Mean	**185^{c}**	**295^{b}**	**337^{a}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	202^{e}	350^{b}	397^{a}	316^{a}
15-30	174^{f}	265^{d}	283^{c}	241^{b}
Mean	**188^{c}**	**308^{b}**	**340^{a}**	
	Soil depth (cm)			
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	365^{a}	283^{c}	324^{a}	
500-1500 m	340^{b}	251^{d}	296^{b}	
Mean	**353^{a}**	**267^{b}**		

Table 6 : Effects of land use systems and altitudes on changes of secondary soil available nutrient (S and B) along the soil depth in Siang river basin districts of Arunachal Pradesh.

		Soil available S (kg ha^{1})		
		Land use		
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	3.04^{c}	3.66^{a}	3.54^{b}	3.41^{a}
500-1000 m	2.33^{f}	2.59^{e}	2.86^{d}	2.59^{b}
Mean	**2.69^{c}**	**3.13^{b}**	**3.20^{a}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	**2.84^{c}**	**3.26^{b}**	**3.54^{a}**	**3.21^{a}**
15-30	2.38^{e}	2.75^{d}	2.82^{c}	2.65^{b}
Mean	**2.61^{c}**	**3.01^{b}**	**3.18^{a}**	
		Soil Depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	3.75^{a}	3.50^{b}	3.63^{a}	
500-1000 m	3.08^{c}	2.47^{d}	2.78^{b}	
Mean	**3.42^{a}**	**2.99^{b}**		
		Soil available B (kg ha^{1})		
		Land use		
Altitude (above msl)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
<500 m	0.305^{d}	0.400^{b}	0.474^{a}	0.39^{a}
500-1000 m	0.261^{e}	0.340^{c}	0.411^{b}	0.34^{b}
Mean	**0.28^{c}**	**0.37^{b}**	**0.44^{a}**	
Depth (cm)	**Rice-fallow**	**Mandarin**	**Forest**	**Means**
0-15	0.303^{d}	0.403^{b}	0.453^{a}	0.39^{a}
15-30	0.262^{e}	0.355^{c}	0.416^{b}	0.34^{b}
Mean	**0.28^{c}**	**0.38^{b}**	**0.43^{c}**	
		Soil Depth (cm)		
Altitude (above msl)	**0-15**	**15-30**	**Means**	
<500 m	0.433^{a}	0.391^{b}	0.41^{a}	
500-1000 m	0.369^{c}	0.329^{d}	0.35^{b}	
Mean	**0.40^{a}**	**0.36^{b}**		

Table 7 : Correlation coefficient of SOC with soil parameters from two altitudes and soil depths among three different land use system.

		Percent SOC	
Soil Parameters	**Rice-fallow**	**Mandarin**	**Forest**
pH	0.10^{ns}	-0.13^{ns}	0.19^{ns}
EC	0.74***	0.62***	0.83***
Available N	0.80***	0.90***	0.87***
Available P	0.90***	0.79***	0.82***
Available K	0.84***	0.91***	0.88***
Available S	0.83***	0.81***	0.84***
Available B	0.85***	0.89***	0.74***

Note: Significance level $P<0.01$-*** , $P<0.05$- **, $P<0.10$-*, not significant- ns

Table 8 : Correlation coefficient of SOC with soil parameters from three different LU system in two soil depths among two altitude range.

	Per cent Soil Organic Carbon	
Soil Parameter	**Low altitude**	**High altitude**
pH	-0.28*	-0.22ns
EC	-0.17ns	-0.01ns
Available N	0.84***	0.93***
Available P	0.84***	0.94***
Available K	0.92***	0.91***
Available S	0.76***	0.78***
Available B	0.82***	0.88***

*Note: Significance level P<0.01-*** , P<0.05- **, P<0.10-*, not significant- ns*

Correlation of SOC percentage and soil parameter across the altitude

In all the altitudes soil available N, P, K, S and B was positively and significantly correlated to SOC whereas soil pH an EC showed a negative and no significant relationship with SOC (Table 8). Our study found soil available N showed highest relation with SOC in the high altitude (r = 0.93) while soil available K showed the highest correlation with SOC in the low altitude (r = 0.92) and while soil available S showed the highest correlation with SOC in the high altitude (r = 0.78). Hence, soil available P and B showed significant positive and highest relationship with SOC in high altitude (Table 8).

The high correlation of the available nutrients as the altitude increase shows that at higher altitude the availability of nutrients depend on the SOC (Table 8). The soil reaction not correlated with the differences in altitude which indicates that SOC will not vary much within the altitude range of 500m to 1000m msl transect. The soil reaction is an inherent property influenced by parent material and climatic condition. The climatic condition and parent material of Siang river basin was similar in the altitudinal transect.

Siang river basin area is rich in SOC and soil available K but with changing LU and management practice the SOC and fertility of the soil is decreasing. It is observed that mandarin orchard sequestered more SOC. Thereby, increasing the soil available nutrient content. Rice-fallow LU system was found to slightly increase the soil pH to 6.6 but sequestered the least SOC and soil nutrients. The altitude below 500m msl and soil surface upto 15 cm depth had the highest SOC and available nutrient content. SOC was positively and strongly correlated with available nutrient across the altitude and among the LU systems. This indicates that suitable LU system and management practices increase the carbon sequestration and soil productivity.

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