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Impact of Land Use Management on Soil Organic Carbon Content at Varying Slope Gradients of North East India

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ABSTRACT

The topographic setting and subsistence farming of North East India are important factors affecting the soil organic carbon (SOC) stock. We attempted to assess the SOC stock and simulated SOC under different crop management regimes at varying slope gradients in Meghalaya, India. The SOC stock at surface layer (0-15 cm soil depth) and subsurface layer (15-30 cm soil depth) was decreased in the order of potato-potato system (PPS) at 32% slope gradient of CPRS > upland rice base system (URS) at 12% slope gradient of Sawkilo > lowland rice-fallow system (LRFS) at Bhoirymbong > URS at 32% slope gradient of Pyllun. The higher SOC stock and total nitrogen (TN) was found at the surface layer whereas the soil inorganic carbon (SIC) stock was higher in the subsurface layer. The CENTURY model-simulated SOC declined at the rate of 0.1 kg m^{-2} yr^{-1} at 12% and 32% slope gradient in URS of Sawkilo and Pyllun village and at the rate of 0.05 kg m^{-2} yr^{-1} in LRFS of Bhoirymbong village. However, the SOC would remain above 6 kg m^{-2} in PPS at 32% slope gradient on CPRS in long run with continuation of present management practices.

Key Words: CENTURY; Potato-Potato, Rice-Fallow, Terrace Cultivation, Soil Carbon

INTRODUCTION

The topographical settings and subsistence farming significantly influence the soil organic carbon (SOC) stock (West et al. 2010) which is important for the mitigation of greenhouse gases (GHGs) and is an important indicator of soil fertility, productivity and quality (Swarup et al. 2000). The overexploitation of existing soil and horizontal expansion of deforestation is necessary for increasing the crop production to feed the ever growing population in North East India. The subsistence farming in NE India would affect the existing SOC stock (Saha et al. 2012). Hence, maintaining and improving of SOC level is a pre-requisite to ensure soil quality, crop productivity and sustainability of agricultural ecosystems (Wang et al. 2010). The phyto-biomass is one of the most important renewable sources that enrich the soil with organic carbon. More than 8.5 million Mg (tons) of phyto-biomass is burned annually at the rate of 10 Mg ha^{-1} from shifting cultivation alone (Ghosh et al. 2009). The magnitude of variation in SOC content and stock depends on the type of land-use and management (West et al. 2010).

Carbon models are used for analysing and predicting changes in the content of soil organic matter (SOM) based on current understanding of soil carbon dynamics. Modeling provides a means by which the overall feasibility of a variety of land management technologies and practices can be assessed. Modeling of soil carbon dynamics helps in selecting the most promising soil management practices for further investigation. Field experiment coupled with simulation models is useful for understanding the dynamics of SOC as influenced by complex interactions of soil, land use and management, and climate (Poussart et al. 2004, Pretty et al. 2006). SOM models are recognized as important tools for the study of long-term effects of intensive cultivation on soil C dynamics. SOM models

(CENTURY and ROTH C model) can be important for study the long-term effect of rice cultivation on soil C dynamics in hill agriculture system. Since the NE India is highly variable in climatic conditions, topography, rainfall pattern, vegetation, land use and cultural diversity and ethnicity, the SOC content is expected to be highly variable across the entire region. The understanding of SOC stock and its' simulation under different slope gradients with traditional agrarian cultivation system may help in identifying the promising soil management practices for such diverse topographical settings. Therefore, it was of growing interest to assess and simulate the soil carbon stock under different crop managements at the different slope gradients.

STUDY AREA

The study was conducted at different locations of Ri-Bhoi and East Khasi Hills district of Meghalaya, North East India. The Ri-Bhoi district is at an altitude of 980 m above mean sea level, and experiencing mild tropical climate (2439 mm mean annual rainfall, daily temperature during a year varies between 2.5 to 32.5 °C). The soil is clay loam texture *Typic paleudalf* and is highly acidic and rich in organic C content. The rainfed agriculture is confined from mid hills (sloppy land) to plain (lowland). The Central Potato Research Station (CPRS) is located at 1,800m altitude in East Khasi Hills district and received an annual rainfall of 2850 mm. The average temperature varies from a minimum of 1.3°C in January to a maximum of 25.4°C in July. The relative humidity ranges from 38% in February to 96% in November. The information on land use changes of sampling sites in Ri-Bhoi and East Khasi Hills of Meghalaya is given Table 1.

MATERIAL AND METHODS

Soil Sampling, Processing and Analysis

Soil samples were collected at surface layer (0-15cm) and subsurface layer (15-30cm) after the harvest of *kharif* rice from the upland rice-base system (URS) at 32% slope gradient of Pyllun village (cultivation along the slope), 12% slope gradient of Sawkilo village, and lowland rice-fallow system (LRFS) at Bhoirymbong village, and soil samples at similar depth were also collected from potato-potato system (PPS) at 32% slope gradient of CPRS (terrace cultivation) before cultivation of potato (January to March). The slope of each site was divided into upper slope position (L1), middle slope position (L2) and lower slope position (L3). The LRFS at Bhoirymbong village was divided into terrace land (L1), lowland between gentle hill slope (L2), and low-land (plain) (L3). The ccomposite soil samples were made from random soil samples of each location (L1, L2 and L3). Soil samples were air dried, crushed and ground to pass through 2 mm sieve for analysis of pH (Jackson 1973), soil texture (Baruah and Barthakur 1999), bulk density (Blake and Hartge 1986), soil inorganic carbon (Jackson 1973), Total Nitrogen (Bremner and Mulvaney 1982), and Cation Exchange Capacity (Cochrane and Desouza 1985) and soil samples were further grinded and pass through 0.5 mm sieve for oxidisable organic carbon (Chan et al. 2001). The above (standing dead rice straw) and belowground (root) of crop (paddy) residues in the field were collected after crop harvesting using unconfined destructive methods (Amos and Walters 2006). The number of plants per square meter was recorded to estimate the carbon addition at the field from crop residue which was an input parameter for running CENTURY model.

The soil inorganic carbon (SIC) was obtained from $CaCO_3$ equivalent by multiplying with 0.12 (the mole fraction of carbon in the substrate). The sum of SOC and SIC stock gives the total soil carbon (TC) stock. Soil carbon stock was computed using the equation suggested by Singh and Lal (2005):

$$\text{SOC stock (g m}^{-2}) = \text{SOC concentration (\%)} \times \text{Bulk density (g cm}^{-3}) \times \text{soil depth (cm)} \times 10^4$$

Computer simulated model CENTURY uses a monthly time step utilizing monthly average maximum and minimum temperatures and monthly precipitation data. The CENTURY model was validated with the measured SOC. Modelling efficiency was computed from measured and simulated SOC using the equation given by Vereecken et al. (1991). The modelling efficiency was 0.85 and 0.704 for NPK-100% @80:60:40 kg ha^{-1} and NPK-100% @80:60:40 kg ha^{-1} + FYM @ 5 Mg $ha^{-1}yr^{-1}$ treatments, respectively. A modelling efficiency of 1 means perfect fit and a positive value signifies closer fit. The correlation coefficients (r^2) between the simulated and measured SOC values for NPK-100% @80:60:40 kg ha^{-1} and NPK-100% @80:60:40 kg ha^{-1} + FYM @ 5 tonnes $ha^{-1}yr^{-1}$ treatments were 0.997 and 0.88 (Table 2).

Table 1. Information on changing land use of sampling sites in Ri-Bhoi and East Khasi Hills of Meghalaya

Location	Year	Month	Land use	Management practices and source of nutrients	Sequence/ Repetition
Pyllun (32% slope land at 1188 m elevation)	Before 1999			Pine forests	Every two years
	2000-2012	March-December	Ginger cultivation	Clearing and burning of forests, preparation of bun, ploughing with local spade, manuring FYM@1Mg ha^{-1} (no fertilizer added)	
		January- May		Fallow	
		June- November	Upland Rice cultivation	Preparation of raised bed, ploughing with local spade, manuring	
Sawkilo (12% Slope gradient at 906 m elevation)	Before 2006			Permanent Grass/Pasture	
	2007	April-December	Ginger cultivation		
	2008	June- November	Upland Rice (Local variety Bhalum)	Preparation of land for cultivation, ploughing with local spade, manuring FYM @1 Mg ha^{-1} only in growing of Upland Rice before sowing.	
	2009 to 2010	March/April -July	Maize		
		August- May	Vegetables		
	2010	June- November	Upland Rice (Bhalum variety)		
	2011	April-December	Ginger		
Bhoirym-bong (Lowland at 883 m elevation)	Before 1860			Grassland	
	1900			Cultivation started, growing of vegetables	
	1990-2012	June- November	Rice-fallow	Diamonium Phosphate (DAP)@ 300kg ha^{-1}	Every 1 year
Central Potato Research Station (CPRS) (32% slope land at 1800 m elevation)	Before 1965			Pine Forest	
	1965			Clearing of forest for cultivation, land is left without disturbance	
	1972 – 2011	March-June	Cultivation of Potato (main crop)	Preparation of raised bed, ploughing , addition of fertilizers (N P_2O_5 and K_2O) @ 125:120:60 per ha, FYM @ 10 Mg ha^{-1}	1 year
		August-October	Cultivation of Potato (autumn crop)		

Table 2. Comparison of CENTURY simulated and measured soil organic carbon (SOC) for the effect of two treatments in a long term experiment of maize-fallow system at ICAR-NEH region, Umiam, Meghalaya), using maize variety RCM-1-1)

Year	Bulk density (g cm^{-3})	Measured SOC (g m^{-2})	Simulated SOC (g m^{-2})	Model Efficiency	Correlation coefficient (r^2)
Treatment: NPK-100% (80-60-40 kg N, P_20_5, K_20) + FYM @ 5 Mg ha^{-1} yr^{-1}					
2009	1.25	4875	4878	0.704	0.886
2010	1.22	4978	5114		
2011	1.19	5236	5280		
Treatment: NPK-100% (80-60-40 kg N, P_20_5, K_20)					
2009	1.25	4000	3973	0.85	0.997
2010	1.22	4148	4182		
2011	1.19	4260	4316		

Table 3. Variation of soil physico-chemical properties under upland rice base system (URS), lowland rice-fallow system (LRFS)and potato-poptato system (PPS) at different slope positions

Study sites /	Bulk Density (Mg m^{-3})		Texture (%)			pH (1:2.5)		CEC (cmol (P+) kg^{-1})		Total N (%)	
Sample locations	0-15cm	15-30cm	Sand	Silt	Clay	0-15cm	15-30cm	0-15cm	15-30cm	0-15cm	15-30cm
Pyllun (URS)											
L1 (upper slope)	1.22±0.02	1.23±0.02	52.3±0.75	23.0±1.01	24.6±1.11	4.86±0.13	4.85±0.01	10.59±1.1	7.58±2.32	0.22±0.02	0.22±0.02
L2 (middle slope)	1.22±0.02	1.22±0.02	51.2±0.93	24.6±1.27	24.2±0.38	4.91±0.14	4.72±0.08	9.93±1.74	9.03±2.80	0.19±0.01	0.17±0.02
L3 (lower slope)	1.21±0.01	1.22±0.01	52.7±0.30	24.3±1.27	22.9±2.10	4.7±0.28	4.91±0.22	10.73±1.0	10.37±0.39	0.21±0.02	0.15±0.02
Sawkilo (URS)											
L1 (upper slope)	1.23±0.01	1.24±0.01	51.1±0.68	18.1±0.18	30.8±0.56	4.89±0.03	4.78±0.14	12.71±0.42	12.35±0.31	0.22±0.03	0.13±0.07
L2 (middle slope)	1.21±0.01	1.22±0.01	51.0±0.34	17.7±0.89	31.2±1.22	5.18±0.22	5.28±0.9	12.66±0.26	12.36±0.41	0.27±0.01	0.22±0.03
L3 (lowland)	1.26±0.01	1.26±0.02	46.1±1.61	20.6±2.31	33.2±1.72	4.70±0.28	4.91±0.22	12.32±0.64	11.67±0.33	0.32±0.03	0.24±0.04
Bhoirymbong (LRFS)											
L1 Terrace land)	1.39±0.02	1.44±0.02	45.9±0.58	21.1±2.81	32.9±2.28	5.34±0.09	5.15±0.06	10.05±1.02	7.12±1.18	0.22±0.01	0.17±0.04
L2 (Lowland*)	1.38±0.04	1.38±0.03	43.6±0.98	25.5±1.59	31.0±1.78	4.93±0.07	4.99±0.09	10.41±1.25	7.89±2.19	0.25±0.02	0.20±0.01
L3 (Lowland)	1.42±0.02	1.44±0.02	45.5±2.74	19.9±1.59	34.6±1.17	4.99±0.12	5.03±0.06	13.18±2.13	11.96±1.176		0.22±0.01
	0.18±0.03										
CPRS (PPS)											
L1 (upper slope)	1.08±0.04	1.09±0.03	56.1±0.49	20.9±0.57	22.9±0.27	4.21±0.11	4.40±0.09	12.65±2.82	7.02±0.46	0.26±0.04	0.24±0.04
L2 (middle slope)	1.12±0.04	1.13±0.03	57.7±4.32	18.4±2.05	23.9±2.33	4.33±0.21	4.2±0.30	11.8±1.67	10.14±1.19	0.30±0.02	0.26±0.08
L3 (lower slope)	1.13±0.03	1.13±0.07	61.9±1.53	15.8±0.69	22.3±0.97	4.21±0.074.2±0.04		11.35±1.5	8.5±1.9	0.30±0.02	0.26±0.05

Note: data represent mean ±standard deviation; * Lowland between gentle hills slope)

Table 4. Effect of upland rice base system (URS), lowland rice-fallow system (LRFS)and potato-poptato system (PPS) on soil carbon stock (kg m^{-2}) at varying slope gradient

Study sites /	SOC stock (kg m^{-2})		SIC stock (kg m^{-2})		Total C stock (kg m^{-2})	
Sample locations	0-15 cm	15-30 cm	0-15 cm	15-30cm	0-15 cm	15-30 cm
Pyllun (URS)						
L1 (upper slope)	4.50±0.83	4.47±0.68	0.41±0.04	0.50±0.07	4.99±0.53	4.97±0.16
L2 (middle slope)	4.37±0.16	4.24±0.16	0.40±0.04	0.44±0.06	4.78±0.17	4.68±0.11
L3 (lower slope)	3.68±0.13	3.16±0.27	0.54±0.08	0.58±0.08	4.23±0.19	3.74±0.35
Sawkilo (URS)						
L1 (upper slope)	4.91±0.20	4.35±0.22	0.61±0.28	0.80±0.20	5.52±0.46	5.15±0.33
L2 (middle slope)	4.88±0.13	4.45±0.05	1.28±0.28	1.33±0.24	6.16±0.22	5.78±0.28
L3 (lowland)	5.59±0.28	5.54±0.40	1.62±0.22	1.75±0.12	7.21±0.44	7.29±0.50
Bhoirymbong (LRFS)						
L1 (Terrace land)	4.59±0.36	4.17±0.36	0.51±0.07	0.73±0.10	5.10±0.36	4.90±0.27
L2 (lowland *)	5.43±0.28	4.77±0.55	0.41±0.14	0.83±0.19	5.84±0.39	5.60±0.43
L3 (lowland)	4.33±0.62	3.79±0.08	0.61±0.13	0.68±0.08	4.94±0.55	4.47±0.06
CPRS (PPS)						
L1 (upper slope)	6.38±0.45	4.92±0.68	0.36±0.08	0.44±0.12	6.74±0.38	5.37±0.57
L2 (middle slope)	6.59±0.16	5.60±0.34	0.49±0.04	0.87±0.49	7.08±0.19	6.47±0.57
L3 (lower slope)	6.87±0.17	6.41±0.48	0.79±0.49	1.00±0.48	7.67±0.35	7.41±0.92

Note: Data represent the mean±standard deviation

RESULTS AND DISCUSSION

Soil Physico-chemical Properties

The soil physico-chemical properties were varied with slope gradients and management practices (Table 3). The BDs were found higher at the lower slope position (L3) than other slope positions (i.e L1 and L2). Maximum BD was found at LRFS of Bhoirymbong village (1.38 to 1.42 and 1.38 to 1.44 Mg m^{-3} at 0-15 and 15-30cm soil depth, respectively) and minimum BD at 32% slope gradient of PPS at CPRS (1.08 to 1.13 and 1.09 to 1.13 Mg m^{-3} at 0-15 and 15-30cm soil depth, respectively). The BD might be influenced by soil texture, organic matter content and anthropogenic interventions like tillage, use of heavy implements as traffic etc. The longer period of cultivation (>150 years) in LRFS of Bhoirymbong village without periodic balanced replenishment of plant nutrients might destroy the soil organic matter and weakens the natural stability of soil aggregates. The livestock and agricultural equipments exert pressure on soil cause compaction of soil and reduce porosity, especially on wet soils. It was cleared from the result that the slope gradient and subsistence farming would increase the BD of URS at Pyllun and Sawkilo village. The sand, silt and clay content were ranged from 43.6 to 61.9%, 15.8-25.5% and 22.3-34.6% respectively. The content of sand, silt and clay were different with the position of slope (i.e. L1, L2 and L3). Interestingly, it was found that the content of sand (46.1%) at L3 was comparatively less but high in clay content (33.2%). This finding was opposite to other slope positions (i.e. L1 and L2). The sloppy lands (i.e. Pyllun and CPRS) have more sand percent whereas lowland (Bhoirymbong) and 12% slope gradient (Sawkilo) have high clay percent (30.8 - 34.6%). The soil pH was ranged from 4.20 to 5.34 in all the study sites (table 3). There was no significant effect of slope position on soil pH. However, the lowest soil pH value was observed at PPS of CPRS. It might be attributed to acid released from the decomposition of organic manures and pine roots under high rainfall conditions (average annual rainfall 2439-2850 mm). The acid released from pine tree roots might enhance leaching of soil bases under intensive rainfall. The CEC in all the study sites were ranged from 9.93 to 13.18 Cmol (p+) kg^{-1} at 0-15 cm and 7.12-12.35 Cmol (p+) kg^{-1} at 15-30 cm. Patton et al. (2007) also reported less CEC values (7.4-14.4 Cmol (p+) kg^{-1}) in the acid soils of Nagaland. There was no significant effect of slope position on CEC, but little higher CEC was observed at strong acidic soils of URS at Sawkilo and PPS at CPRS. It might be due to recent conversion of grassland to agriculture, addition of organic manures and also clay percentage. There were relationship between CEC, clay and organic carbon content (Sharma and Kumar 2003), and also found higher CEC in grassland system than that of pinus forests (Alfredsson et al. 1998). The total nitrogen (TN) content were ranging from 0.19-0.32 (%) and 0.15-0.26% at 0-15 and 15-30cm soil depth, respectively. It was clearly observed that the content of TN was higher at the surface layer (0-15cm) as compared to sub-surface layer (15-30cm) in all the locations. The highest TN was found in PPS of CPRS and URS of Sawkilo (Table 3). The wash out TN from the upper slope (L1) was deposited to the middle (L2) and lower (L3) slope position and also found significant effect of nutrient management. The URS of Sawkilo was recently converted into agricultural land from grass land. The decomposition of grass biomass might release more amount of nitrogen in soil.

Soil Organic Carbon Stock

Soil organic carbon (SOC) content at 0-15 and 15-30 cm soil depth was found in the order of PPS at 32% slope gradient of CPRS (terrace cultivation) >URS at 12% slope gradient of Sawkilo >LRFS at Bhoirymbong >URS at 32% slope gradient of Pyllun (cultivation along the slope). The SOC was found higher at the surface layer (0-15 cm) as compare to sub-surface layer (15-30 cm) (Table 4). The URS at 12% slope gradient of Sawkilo village was converted to agriculture from the permanent grassland in the year of 2007. The physical characteristics of the soils in grassland were comparatively better than the pinus forest soils (Nissanka and Sakalasooriya 2003). The SOC stock was found higher at lower slope position (L3) of PPS at CPRS and URS at 12% slope gradient of Sawkilo but it was minimum at L3 in URS of Pyllun (3.68 kg m^{-2}). It might be attributed to recent conversion of agricultural land from the pine forest soil in the year of 2007 and pine litter fall decomposition was slow because of acidic root exudates of pine trees and high C:N ratio. Therefore, the pine letter fall might also act as protecting material for soil erosion. The longer period of agricultural activities were carried out at L1 (lower slope) and L2 (middle slope) of Pyllun village. These locations (L1 and L2) were prone to soil erosion loss with anthropogenic activities under 32% slope gradient. It was understood that SOC content was affected by the land location also. The L2 (lowland between gentle hill slope) of LRFS at Bhoirymbong was observed to be the higher SOC content site at both soil depth (5.43kg/m^2 at 0-15cm and 4.77 kg/m^2 at 15-30cm) as compared to L1 and L3 of the same land use at this village. The SOC content might be affected by long period of agricultural activity and subsistence farming. Similar result was reported that 20-50% of SOC was depleted with repeated cropping periods (Keeny et al. 2002) and rainfall (Martin et al. 2010). The SIC content in the study sites were ranged from 0.36-1.62 and 0.44-1.75 kg m^{-2} at 0-15 and 15-30 cm soil depth respectively (table 4). Maximum SIC content was found in L2 (1.28 and 1.33 kg m^{-2} at 0-15 and 15-30 cm) and L3 (1.62 and 1.75 kg m^{-2} at 0-15 and 15-30 cm) of URS at 12% slope gradient (Sawkilo village). SIC content was increased with soil depth due to accumulation of leached carbonates in the subsurface layer. Higher SIC stock was also found in PPS of 32% slope gradient at CPRS (terrace cultivation). This might be attributed to application of NPK @ 125:120:60 per hectare and FYM @ 10 Mg ha^{-1} in PPS. Ouyang et al. (2008) found that addition of nitrogenous fertilizer might have increased the release of inorganic soil carbon. The TC content was also followed the similar trend of SOC.

CENTURY Simulation of Soil Organic Carbon

About 6 kg soil C m^{-2} could be maintained at PPS in long run with following the present management whereas other management systems were shown the declining trend of SOC. The SOC at LRFS of Bhoirymbong village was found more than the SOC of URS of 12% and 32% slope gradient of Sawkilo and Pyllun village (Figure 1). The subsistence farming for a long period (>150years) with LRFS at Bhoirymbong village might have lowered SOC than PPS. The soil moisture of LRFS at Bhoirymbong might induce the anaerobic condition and reduced the decomposition of SOC whereas the soils of URS of 12% and 32% slope gradient of Sawkilo and Pyllun village might induce aerobic condition and help in faster decomposition of SOC. Therefore, the SOC of LRFS at Bhoirymbong was showing higher than that of URS at 12% slope gradient (Sawkilo) and 32% slope gradient (Pyllun village) (Figure 1). Similarly, higher SOC was found at continuous flooded rice (rice-rice) and rice-wheat systems (Benbi and Brar 2009). The SOC might have also lost through runoff from the sloppy land of URS at Sawkilo and Pyllun village. The trend of SOC declining in URS of 12% and 32% slope gradient of Sawkilo and Pyllun village were very rapid at the rate of 0.1 kg m^{-2} SOC per year whereas in LRFS of Bhoirymbong, it declined at the rate of 0.05 kg m^{-2} SOC per year. The SOC showed gradual increase in all the slope positions (i.e. L1, L2 and L3) for PPS at 32% slope gradient of CPRS (terrace cultivation) till 2060 and start declining thereafter, highest SOC was found at L3 (lower slope position) and minimum at L1 (upper slope position). The simulated SOC for other locations were also followed the similar trend of declination. The L2 (middle slope position) of URS at 12% slope gradient (Sawkilo village) had lower SOC than that of L1 and L3 (Figure 2).

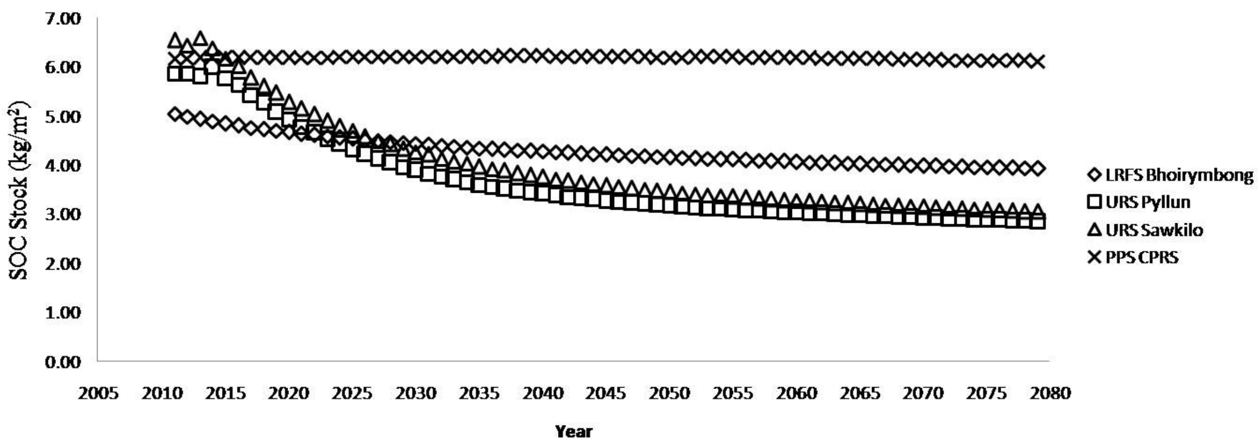

Figure 1. CENTURY simulated soil organic carbon (SOC) stock (kg m^{-2}) of different management sites.

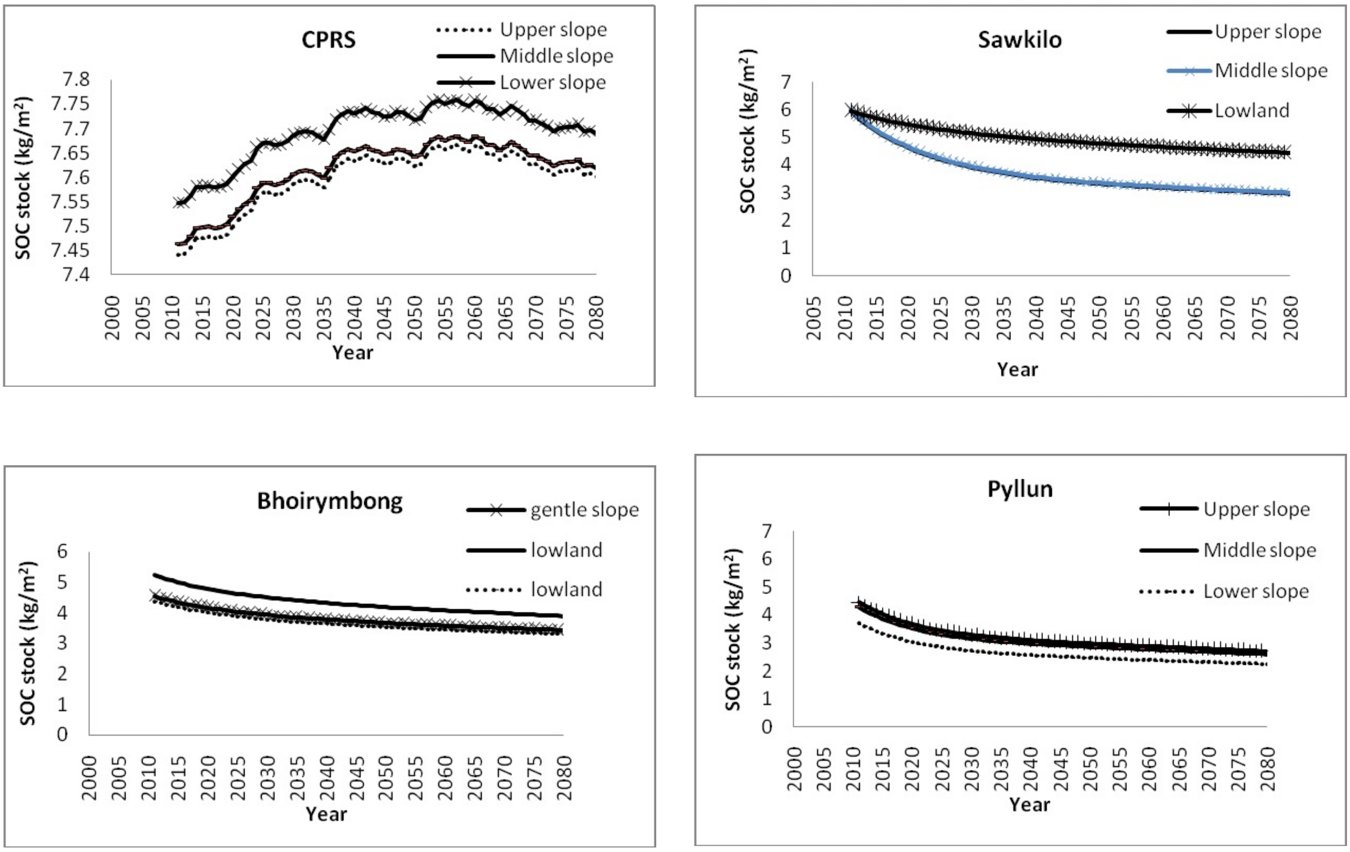

Figure 2. Simulated soil organic carbon (SOC) stock (kg m^{-2}) at varying slope gradient for each study sites.

CONCLUSION

This study could conclude that the clay movement along the slope gradient (high to low) was influenced the soil physico-chemical properties. The lowlands could preserved more SOC stock than the sloppy lands under subsistence farming. The interaction between the clay movement, crop management and native vegetable could control the soil organic carbon (SOC) stock in the hill ecosystem.

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REFERENCES

Alfredsson, H.; Condron, L. M.; Clarholm, M. and Davis, M. R. 1998. Changes in soil acidity and organic matter following the establishment of conifers on former grassland in New Zealand, Forest Ecology and Management 112: 245–252.

Amos, B. and Walters, D.T. 2006. Maize root biomass and net rhizodeposited carbon: an analysis of the literature. Soil Science Society of America Journal 70: 1489-1503.

Baruah, T. C. and Barthakur, H. P. 1999. A Text Book of Soil Analysis, 2nd edition. Vikas Publishing House, New Delhi.

Benbi, D.K. and Brar, J.S. 2009. A 25 year record of carbon sequestration and soil properties in intensive agriculture. Agronomy and Sustainable Development 29: 257-265.

Blake, G.R. and Hartge, K.H. 1986. Bulk density. Pages 363–376, In: A. Klute (Editor) Methods of Soil Analysis. Part 1, 2nd edition. Agronomy Monograph 9. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Bremmer, J.M. and Mulvaney, C.S. 1982. Nitrogen-Total. Pages 595-613, In: .Page, A.L.; Miller, R.L. and Keeny, D.R. (Editors)

Methods of Soil Analysis. Part-2. (2nd edition. Agronomy Monograph 9. American Society of Agronomy and Soil Science Society of America, Madison, WI.

Chan, K.Y.; Bowman, A. and Oates, A. 2001. Oxidizable organic carbon fractions and soil quality changes in an oxic paleustaff under different pastures leys. Soil Science 166: 61–67.

Cochrane, T.T. and Desouza, G.D.M. 1985. Measuring surface charge characteristics in Oxisols and Ultisols. Soil Science 140: 223-229.

Ghosh, P. K.; Saha, R.; Gupta, J. J.; Ramesh, T.; Anup, D.; Lama, T. D.; Munda, G.C.; Bordoloi, J. S.; Verma, M.R. and Ngachan, S.V. 2009. Long term effect of pastures on soil quality in acid soil of North-East India. Australian Journal of Soil Research **47:** 372-379.

Jackson, M.L. 1973. Soil Chemical Analysis. Prentice-Hall of India, New Delhi.

Keeny, E.A.; Hall, J.W. and Wang, C. 2002. Temporal trends in soil properties at a soil quality benchmark site in the lower Fraser valley, British Colombia. Canadian Journal of Soil Science 82: 499–509.

Martin, D.; Lal, T.; Sachdev, C.B. and Sharma, J.P. 2010. Soil organic carbon storage changes with climate change, landform and land use conditions in Garhwal hills of the Indian Himalayan mountains. Agriculture, Ecosystems and Environment 138: 64-73.

Nissanka, S.P. and Sakalasooriya, M.B. 2003. Vegetation and soil properties of *Pinus caribaea* plantation, grassland and semi natural forest in Sri Lanka. Paper presented to the XII World Forestry Congress, Quebec city, Canada.

Ouyang, X.J.; Zhou, G. Y.; Huang, Z.L.; Liu, J.X.; Zhang, D.Q. and Li, J. 2008. Effect of simulated acid rain on potential carbon and nitrogen mineralization in forest soils. Pedosphere 18: 503–514.

Patton, S.; Sharma, S. K. and Singh, P.K. 2007. Characterisation of the acidity of soils under different land use patterns in Nagaland, Journal of the Indian Society of Soil Science 55 (2): 134-138.

Poussart, J.N.; Ardö, J. and Olsson, L. 2004. Effects of data uncertainties on soil organic carbon in the Sudan. Environmental Management 33: S405–S415.

Pretty, J; Noble, A.D.; Bossio, D.; Dixon, J.; Hine, R.E.; Penning de Vries, F.W.T. and Morison, J.I.L. 2006. Resource-conserving agriculture increases yields in developing countries. Environmental Science and Technology 40 (4): 1114–1119.

Saha, D.; Kukal, S.S. and Bawa, S.S. 2012. Soil organic carbon stock and fractions in relation to landuse and soil depth in degraded Shiwalik of lower Himalayas, Land Degradation and Development. DOI: 10.1002/ldr.2151.

Sharma, V.K. and Kumar, A. 2003. Characterization and classification of the soil of upper Maul Khad catchment in wet temperate zone of Himachal Pradesh. Agropedology 13: 39-49.

Singh, B.R. and Lal, R. 2005. The potential of soil carbon sequestration through improved management practices in Norway. Environment Development and Sustainability **7:** 161-184.

Swarup, A.; Manna, M.C. and Singh, G. B. 2000. Impact of land use and management practices on organic carbon dynamics in soils of India. pages 261–281. In: Lal, R.; Kimble, J.M. and Stewart, B.A (Editors) Global Climate Change and Tropical Ecosystems. CRC/Lewis Publishers, Boca Raton, FL.

Vereecken, H.; Jansen, E. J.; Hack-ten Broeke, M. J. D.; Swerts, M.; Engelke, R.; Fabrewitz, S. and Hansen, S. 1991. Comparision of simulation results of five nitrogen models using different datasets, pages 321-338. In: Commission of European Communities Soil and Groundwater Research Report II Nitrate in soils, Luxenbourg: Commission of the European Communities.

Wang, Y.; Liua, F.; Mathias, N.A. and Christina, R.J. 2010. Carbon retention in the soil-plant system under different irrigation regimes. Agricultural Water Management 98: 419-424.

West, P.C.; Gibbs, H.K.; Chad, M.; Wagner, J.; Barford, C.C.; Carpenter, S.R. and Foley, J. A. 2010. Trading carbon for food: global comparison of carbon stocks vs crop yields on agricultural land. Proceedings of National Academy of Sciences, USA 107: 19645–19648.

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