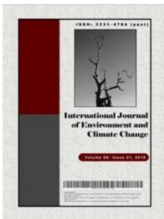

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Carbon Sequestration in Relation to Topographic Aspects and Land Use in Northeast of Thailand

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Authors' contributions

This work was carried out in collaboration between all authors. Author KKI designed the study, literature searched, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author SA guided in designing, managed the analyses and editing of the study. Authors IK and ST helped in editing. All authors read and approved the final manuscript.

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ABSTRACT

With the aim of investigating carbon sequestration and its relationship with land use in different topographical conditions, the present study carried out during March-November/2013 in mixed vegetation cover areas under forest condition, eroded bare land and cultivated lands of corn, cassava and paddy rice in Nakhon Ratchasima province, Northeast of Thailand. A total number of 72 samples {3(transects) X 6 (sampling points spreading over different land uses along toposequence) X 4 (different depths)} together with 72 undisturbed soil samples using Soil Core Samplers for the determination of soil bulk density were collected from four different depths, 0-15, 15-30, 30-45 and 45-60 cm with each comprising six spot of mini soil pit located from three transect (tran-1, tran-2 and tran-3) for laboratory analysis in this study. The estimation of soil organic carbon and calculation of the amount of carbon sequestration on the basis of transects and landscape positions up to 60 cm soil depth revealed a positive significant correlation (r = .66**) between carbon sequestration and elevation. A non-significant but positive correlation (0.269 ^{NS}) was also observed between carbon sequestration and slope but the combined effect of slope and elevation was found to be significant with C_{Seq} (r = .56*). Among land uses, the highest amount of carbon sequestration was observed in trees and forest followed by corn, cassava, paddy rice while the lowest being in bare land with respective values of 26.10, 23.70, 19.50, 16.80 and 6.20 Mg C ha^{-1}. Carbon sequestration was also found to be significantly correlated with depth within soil

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profile, showing the highest amount in surface soil and decreased gradually with increasing depth in all land use types. The highest concentration of organic carbon (4.74 g kg^{-1}) and rate of carbon sequestration (11.07 Mg C ha^{-1}) was found in native forest at the surface soil (0-15 cm depth) and the lowest (1.84 g kg^{-1} and 4.37 Mg C ha^{-1}) mostly at the lowest depth (45-60 cm) studied. Variation in soil organic carbon under different land uses and topographic condition along toposequence are of significance for understanding the process of soil carbon sequestration.

Keywords: Carbon sequestration; relationship; land uses; transect; toposequence; topographic aspects.

1. INTRODUCTION

Food insecurity and underprivileged population is now a growing threat throughout the world that envisages the need to enhance and sustain productivity while ensuring climate change mitigation, biodiversity improvement and soil and water resources quality resilience. Carbon sequestration contributes increased carbon stocks in soil which can be achieved by sustainable land use and improved management practices. Soil, being an important carbon source plays a vital role in maintaining balanced global carbon cycle and sustainable crop production. In recent time soil carbon has gained great attention due to the implication of carbon fluxes and pools in global climate change and the maintenance of soil health and quality. The interactions between residue inputs to soil and the subsequent transformations done by soil microorganisms modifies carbon content in soil through changes in land-use [1]. Determination of soil-plant systems whether it would be a source or sink of CO_2 depends on the rate of soil organic matter formation and decomposition [2]. Increasing rate of carbon sequestration in the vegetation results more organic matter add to the soil which is essential for productivity and long-term sustainability of the ecosystem.

The global soil Carbon Sequestration is estimated at 0.4-1.2 Pg C $year^{-1}$ which is equivalent to 6%-20% of the CO_2 released annually from fossil fuel combustion [3]. Soil contains 1500 Pg (1 Pg = 10^{15} g) of carbon [4] which is 4.5 times more than carbon content of all living beings and 3 times more than Carbon present in the atmosphere [5]. Plants take up carbon from atmospheric CO_2 through photosynthesis and by using sunlight of which they convert CO_2 into organic carbon in their body parts such as roots, stems and leaves. A significant amount of soil organic carbon (SOC) is resulted from decomposition of both above ground and below ground plant tissues. In the process of carbon sequestration, CO_2 is, thus, extracted from the atmosphere and thereby stored in the soil for a long time through different processes.

A number of environmental factors that interact with land use change to control soil carbon pools mentioned by scientists are as, climate [6], topography [7], elevation [8] and land use [9]. It is essential to have an adequate amount of SOC for sustainable agriculture and mitigating carbon flux to the atmosphere. A decrease in SOC generally decreases crop productivity and alters the capacity of the soil to act as a sink for atmospheric CO_2 and thus play significant role in global climate change [10]. Global carbon balance is affected by the change of land-use or the land cover and in determining soil carbon storage, land use recognized as the main factor [11]. In complex landscapes, especially, when diverse environmental conditions interact with different land uses, a great variation in soil carbon pool as well as soil carbon storage and turnover is found to be existed. Therefore, understanding SOC under different land uses along toposequences is crucial to understanding of ecosystem functioning and agricultural sustainability. Information regarding how much carbon is sequestered or lost over time, where carbon is stored and how much in quantity and in course of time how shifts in land use affect the amount of carbon sequestered and stored is crucial in managing landscapes for carbon sequestration and storage. Therefore, the present study has been undertaken with the aim of evaluating how carbon sequestration in soil changes in relation to different agricultural and natural land use types in comparison with different topographical conditions.

2. STUDY SITE AND METHODOLOGY

2.1 Study Site

The study was carried out in a mixed vegetation cover area between latitude 0810270^0 and 0811887^0 under forest condition, eroded and cultivated lands of degraded area at Nong Suang Village in Kham Thale Sor district, Nakhon Ratchasima province, Northeast of Thailand. The site was categorized with low to medium terrace in gentle slope providing wide-ranging light textured non-saline, saline, saline sodic and heavily salt affected soils. Three nearby transects with a variety of land uses such as native forest, plantation forest, cassava, corn and paddy rice as well as some part of bare land were selected for sample collection (Fig. 1).

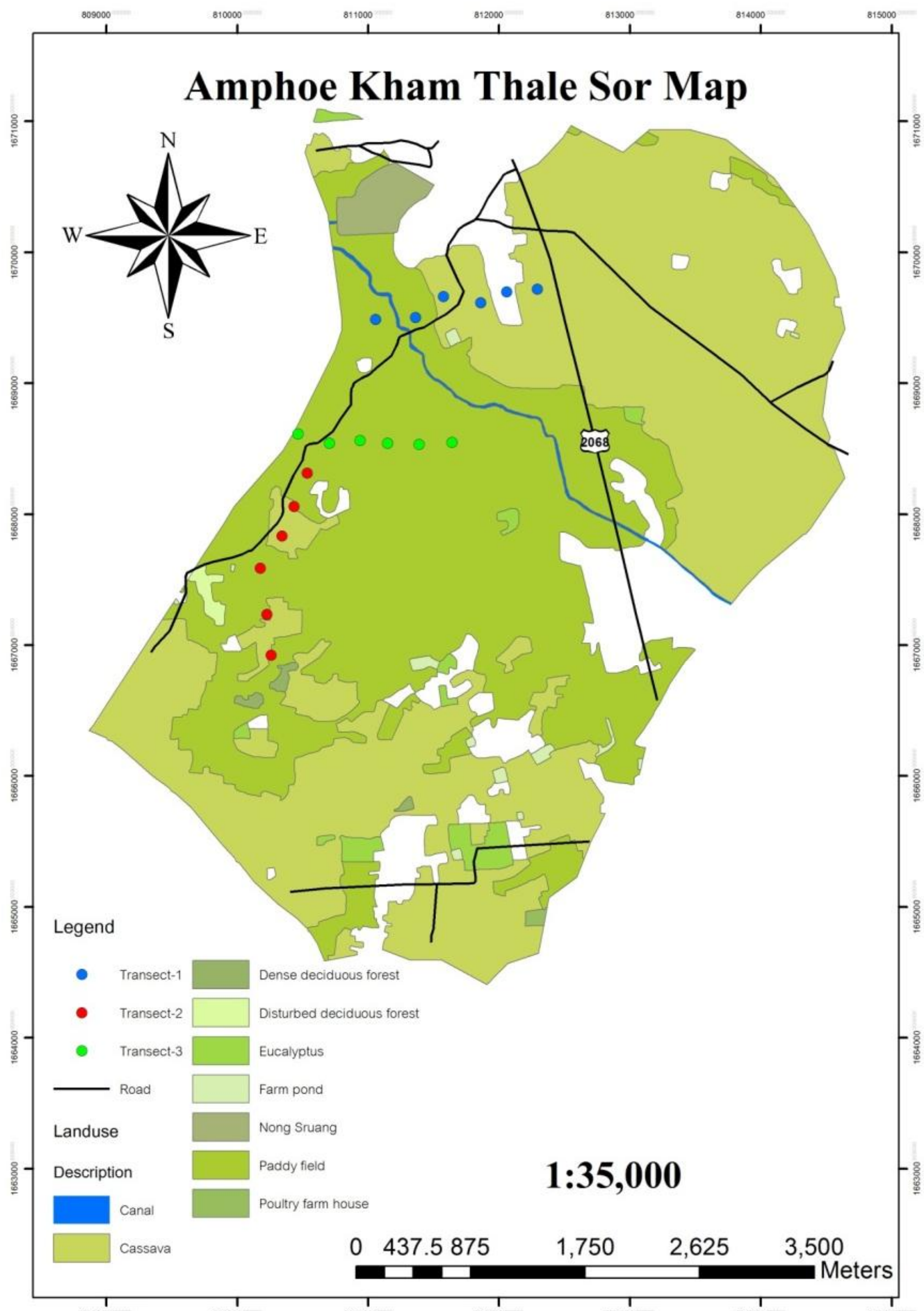

Fig. 1. Map showing sampling location of the study site along with land uses

2.2 Field Analyses

At the time of collecting soil samples data related to field morphology, elevation, slope %, aspect, land use (Fig. 2) and management practices, constrains and potentiality prevailed over the areas were observed and noted to correlate these features with carbon sequestration.

2.3 Sampling, Transportation and Storage

From each transect, 6 spots were identified along with land slope considering land use prevailing over the area (Fig. 2) and from each spot 4 composite soil samples were collected from 4 different depths of 0-15, 15-30, 30-45 and 45-60 cm increments from each pit at the study sites.

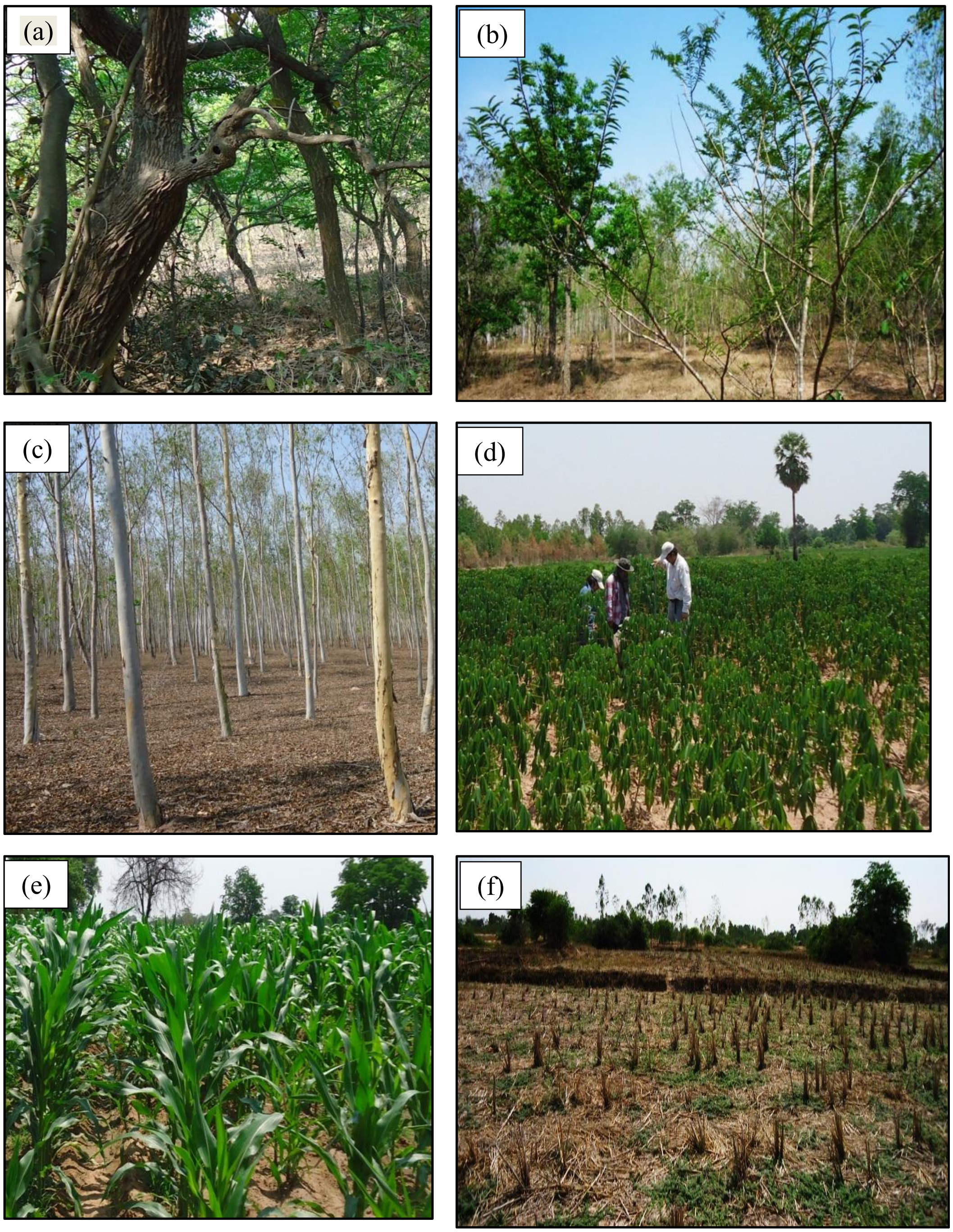

Fig. 2. Photograph showing Land Uses of the study site; a) Native forest, b) Degraded plantation forest, c) Eucalyptus plantation, d) Corn field, e) Cassava field, f) Paddy rice field and g) Bare land

For each aggregate sample, soils from pits of randomly selected 3 different spots were mixed together and a composite soil sample was prepared for each depth following the standard procedure [12]. A total number of 72 samples {3(transects) X 6 (sampling points at different land uses along toposequence) X 4 (different depths)} together with 72 undisturbed soil samples using **soil core sampler** for the determination of soil bulk density were collected for the study. Each of the composite soil samples thus prepared was taken into plastic bags, gathered all together and was transported immediately to the shade house for air drying and further prepared for laboratory analysis.

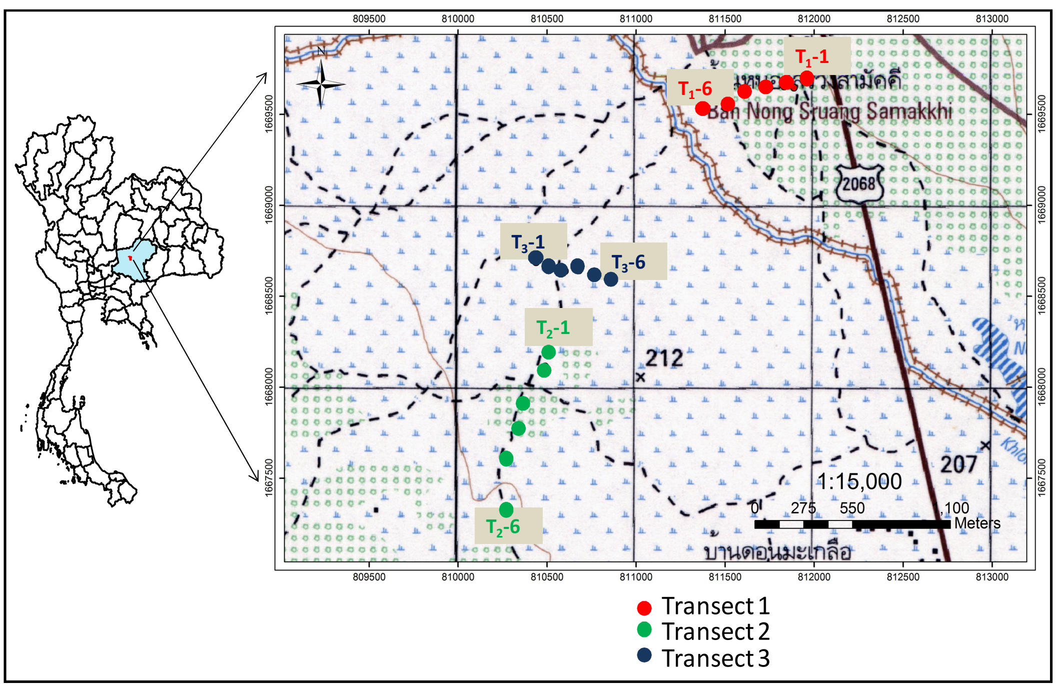

Fig. 3. Map showing position of the transects and sampling points of the experimental site

2.4 Preparation of the Soil Samples for Laboratory Analyses

The soil samples were air dried, crushed and sieved passing through a 2 mm sieve prior to analysis at the laboratory of Department of Soil Science, Kasetsart University. A small amount of soils from each 2 mm sieved samples were grinded and passed through 0.5 mm sieve for analysis of organic matter content. Care was taken in every step of drying, crushing and sieving so that all processes were done without mixing soils from each other. Prepared samples were kept in sealed plastic bag and stored in a cool and dry location for laboratory analysis.

2.4.1 Laboratory analysis

Soil samples were analysed for the determination of soil bulk density, soil organic carbon and total nitrogen as follows.

Bulk Density: Undisturbed soil samples were weighed and dried in an oven at a temperature of 105°C for 48-72 hrs. until they have a constant weight and soil bulk density was calculated from the sample volume and the mass of the oven-dried sample following procedures of Blake and Hartge [13].

Total Nitrogen (TN): TN content was determined via the semi-micro Kjeldahl digestion procedure [14].

Organic Carbon: The organic carbon was determined by wet oxidation method using potassium dichromate and concentrated sulfuric acid [15] followed by distillation and titration according to the procedure of Nelson and Sommers [16].

Calculation of Soil Carbon Sequestration or Soil Organic Carbon Pool: The soil organic carbon pool of a specific soil depth was calculated using the following equation as mentioned by Lal et al. [17].

$$\mathrm{Mg\ C\ ha^{-1}} = \frac{\%\ \mathrm{OC} \times \mathrm{BD}\ (\mathrm{Mg\ m^{-3}}) \times \mathrm{depth\ (m)} \times 10^4\ \mathrm{m^2\ ha^{-1}}}{100}$$

2.5 Data Analysis

Statistical analysis of data was done through correlation and regression analysis by using SPSS-16 statistical software and Microsoft Excel-2010 software.

3. RESULTS AND DISCUSSION

3.1 Topographical Factors Affecting Carbon Sequestration

The elevation of the study area was low and the values of the elevations varied between 194 and 212 m above mean sea level. A difference of elevation of only 18 m was found between the highest and the lowest sampling points. Even though the studied soils showed a significantly positive correlation (r = 0.66**, Table 1) between the amount of C_{Seq} (Carbon Sequestration) and elevation. This relationship indicates that with the increase of elevation the concentration of SOC increases positively which contributes incremental rate of C_{Seq} in soils. This result is consistent with the findings of Wang et al. [18], Zhang and McGrath [19], Martin et al. [4] and Chuai et al. [20]. The causes behind this result may be that differences in elevation affects the rate of decomposition of soil organic matter by changing micro-climate. In higher elevation the temperature is low that decreases the rate of decomposition of soil organic matter which results in higher accumulation of organic carbon in soil [21]. Additionally, the forest and trees were located at the higher elevations while the field crop sites were at the lower elevation which was the driving factor of showing incremental rate of carbon sequestration in higher elevation of the study area.

A positive correlation was also observed between slope and C_{Seq} which is consistent with the finding of Hontoria et al. [22] in Peninsular Spain. Although, the relationship of slope and C_{Seq} found in the present study was not to be correlated significantly between these two parameters. The studied area was located in a gentle topographic area. There was no steep slope in the studied area. The slope classes of the studied soil sites were only 1 and 2%. The situation is not so prominent because of a slight difference in slope of the area as well as coarse texture of soils that favors high infiltration rate of soil and thereby reducing soil erosion, especially in transect-1 and transect-2. Table 1 shows a significantly positive correlation between slope and elevation which is an indication of the influence of multicollinearity among these two topographic parameters. This multicollinearity effect of slope and elevation is responsible for strongly significantly positive correlation between C_{Seq} and elevation.

Table 1. Pearson's correlation among carbon sequestration and topographic factors

Sl. No.	Sample	C_{Seq} (Mg C ha^{-1})	Elevation (m MSL)	Slope (^{0})	Aspect (Azi.)	Correlation Coefficient *r*			
						Elevation and C_{Seq}	Slope & C_{Seq}	Aspect& C_{Seq}	Elevation & Slope
1	T_1-1	34.95	210	2	280				
2	T_1-2	23.22	209	2	268				
3	T_1-3	27.60	212	2	270				
4	T_1-4	23.79	207	1	264				
5	T_1-5	10.21	196	1	262				
6	T_1-6	16.30	194	1	262				
7	T_2-1	20.83	206	1	20				
8	T_2-2	23.12	203	1	22				
9	T_2-3	19.69	206	2	10				
10	T_2-4	19.22	200	1	190	0.66^{**}	0.27^{NS}	$-.05^{NS}$	0.56^{*}
11	T_2-5	28.73	205	1	0				
12	T_2-6	23.65	209	1	350				
13	T_3-1	7.96	203	1	100				
14	T_3-2	10.56	204	2	90				
15	T_3-3	7.68	205	1	282				
16	T_3-4	7.81	199	1	290				
17	T_3-5	4.61	199	1	290				
18	T_3-6	29.52	207	1	300				

**. Correlation is significant at the 0.05 level*
***. Correlation is significant at the 0.01 level*
NS. Non-significant
T_1=Transect-1, T_2=Transect-2, T_3=Transect-3; {T_1-, T_2-, T_3- (1-6)} = Soil sampling points

The increasing trend of the amount of C_{Seq} with increasing slope percentages in Fig. 4 is indicative of positive correlation between slope and soil organic carbon concentration. An inference can be drawn from these findings that removing of organic matter along with finer particles from the upper position and depositing at relatively lower areas causes higher concentration of organic carbon of the lower areas [23]. The highest C_{Seq} (29.52 Mg C ha^{-1}) in the lowermost area of paddy rice field of transect-3 proved this type of erosion and accumulation of organic carbon to the lower most part of the studied area.

The aspect was found to show a negative correlation with the amount of carbon sequestration, although the correlation was not found to be significant in the studied soils (Table 1). Aspect affects the moisture and vegetation of an area that indirectly affects carbon sequestration. A similar type of explanation had been given by Piender et al. [24] and Serdinero [25] who observed that topographic aspect and vegetation altogether affect the rate of carbon sequestration in soil.

3.2 Landscape Position and SOC Concentration and C_{Seq}

Sampling position also showed a variation in the concentration of organic carbon and amount of C_{Seq} of the studied soils in the same transect as well as among different transects (Fig. 5). The trend of organic carbon concentration in transect-1 and transect-3 was just opposite from each other. In transect-1, the highest concentration of carbon was found in sampling position-1 and then it decreased gradually from sampling position 1→6 direction with sudden decrease at point-2. On the other hand, the highest concentration of organic carbon in transect-3 was at sampling position 6 and decreased drastically at point-5 then started to increase gradually up to point-2 and again sudden decrease at point-1. In Transect-2 the variation of concentrations of organic carbon was not as high as it was found in transect-1 and transect-3. On the contrary it was more or less similar at all sampling points with little bit high at points 2 and 5.

The above variations of organic carbon concentration among transects and in between sampling points were due to land use variation as well as differences in slope class. The highest concentration of organic carbon at sampling point-1 in intransect-1 was due to native forest with slope percentage of 2 whereas, in transect-3, the highest concentration of organic carbon was at sampling point 6 for being of the lowermost position with paddy rice. Deposition of the eroded finer materials with organic matter into the lowermost part was the reason to give higher organic carbon at the lower position. The slope percentage of the sampling points in transect-2 was similar (1% with only one exception i.e. at sampling point-3 which was 2%) in all cases that contributed more or less similar concentration of organic carbon at all landscape positions, especially in the same vegetation.

In the case of field crops, soil samples in the paddy field areas accounting nearly 45% of the total samples (32 out of 72) was widely distributed in all three transects (two sampling points in transect-1, 2 in transect-2 and 4 in transect-3). Therefore, it is quite logical to know the amount of C_{Seq} by paddy rice in each of the 3 transects to know the effect of sampling position or landscape position on C_{Seq}. It was found that in the surface soil (0-15 cm) the amount of C_{seq} was 6.3 and 9.1 Mg C ha^{-1} in sampling positions 5 and 6, respectively in transect-1 whereas, in transect-2 it was 9.12 and 10.12 Mg C ha^{-1} in sampling positions 2 and 5, respectively. On the other hand, in transect-3 the amount of C_{Seq} was 3.04, 5.69, 3.39 and 11.55 Mg C ha^{-1} in sampling positions 1, 2, 3 and 6,

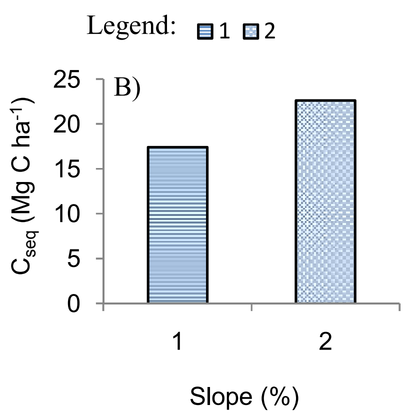

Fig. 4. Variation of C_{Seq} (mean value) with differences in Slope % in whole soil

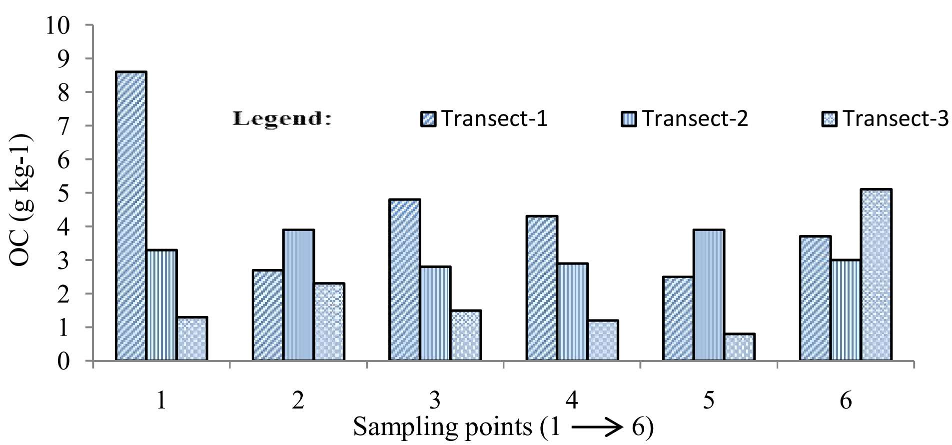

Fig. 5. Variation of the concentration of organic carbon in different topographical position among 3-transects in surface soil (0-15 cm)

respectively. These results showed that rate of C_{Seq} in paddy rice field of transect-2 is higher than that of transect-1 and transect-3 but the highest rate (11.5 Mg C ha^{-1}) of C_{Seq} was found at the lowermost area of transect-3. In most cases, sampling from the lower areas showed comparatively higher C_{Seq} than the upper areas with the only exception of sampling from position 3 at transect-3 that was lower (3.39 Mg C ha^{-1}) than that in its upper area (5.69 Mg C ha^{-1}, at sampling position 2). This indicates a positive interaction of landscape position and land use on the amount of C_{Seq} in the study area. The eroded finer particles along with organic matter from the upper areas being deposited at the lower position contributed higher rate of carbon sequestration at comparatively lower positions in the same transect as well as in between transects.

3.3 Land Use as a Factor of Affecting Carbon Sequestration in Soil

Land use greatly influenced carbon sequestration in soil. The increase of organic matter through the addition of litter fall, dead roots, root exudates and crop residues depend on the vegetation grown in a particular land. On the other hand, the magnitude and rate of decomposition of the added organic matterial depends on the nature and type of the source of organic matter, intensity of land use, climate and topography. In this study, the estimation of the organic carbon concentration and total nitrogen as well as amount of carbon sequestration within the soil depth up to 60 cm showed that soil organic carbon varied strongly with land use in each transect and among transects, indicating that the land use itself is a significant factor that controls soil organic carbon concentration and carbon sequestration of the area concerned.

Soil organic carbon content and total nitrogen in the studied soils varied widely showing a clear difference of C/N ratio among land uses (Fig. 6). Soil organic carbon concentration ranged from 1.00 (g kg^{-1} soil) in bare land to 4.74 (g kg^{-1}) in native forest and total nitrogen was found from 0.06 (g kg^{-1}) in bare land to 0.41 (g kg^{-1}) in surface soils of paddy rice field (Table 2). In the surface soil (0-15 cm), the highest C/N ratio (16.66) was observed in soil of bare land and the lowest (7.39) was in the paddy rice field. Soils of uncultivated land are compacted and sealed, which reduces the rate of decomposition and increases storage of more resistant organic carbon in the surface soil giving the highest C/N ratio [20]. In addition, surface soils of paddy rice field repeatedly cultivated gave rise to a high decomposition rate of rice straw or crop residues with low C/N ratio rather than accumulation. Again, the rate of decomposition of crop residues with comparatively higher C/N ratio of cassava and corn was slower than that of rice. In the surface soil (0-15 cm), the order of C/N ratio among the vegetation was tree and forest > cassava > corn > paddy rice (Fig. 6).

Variation of C/N ratio was also observed to be varying among depths within soil profile (Table 2). The highest C/N ratio (17.85) was found in corn at the depth of 15-35 cm and the lowest was (5.00) found at the depth 0f 30-45 cm in corn. The C/N ratio of tree and forest at each depth fractions was found steadily and comparatively higher than the other types of vegetation in the study area but the result did not show consistency in terms of an increase or a decrease of C/N ratio among the types of vegetation when compared among different depths within soil profile.

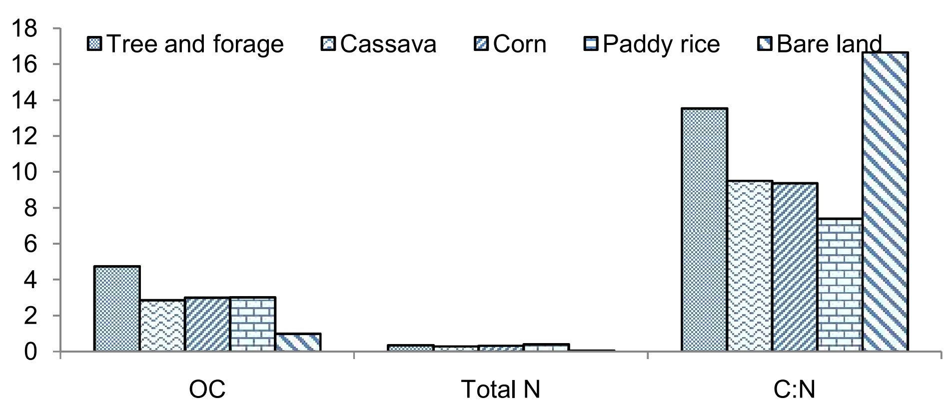

Fig. 6. Variation of C:N ratio as per different land uses found in the study area (0-15 cm depth)

A significantly positive correlation (R^2=.91**, Fig. 7) was observed between land use and the amount of carbon sequestration in soil. The highest C_{Seq} (26.07 Mg C ha^{-1}) was found in trees and forest areas, whereas the lowest one (6.22 Mg C ha^{-1}) was found in bare land. The order of the amount of C_{Seq} was as follow; trees & forest > corn > cassava > paddy rice > bare land (Fig. 7). Observation of the highest rate of C_{Seq} in trees and forest vegetation agrees well with a previous study of Lichaikul et al. [26] conducted in a similar type of study in Northeast of Thailand. They found that the highest stock of total carbon was in natural forest while the lowest being in the cereal crop fields. The result also supports the findings of Lorenz and Lal [27], Puget and Lal [28], Paustian et al. [29], in which croplands generally contributed lower soil organic carbon in comparison with forest and grassland due to soil physical disturbance and land intensification. The ultimate source of organic carbon in soil is plant leaves, roots, root exudates and plant residues. For this reason, land use plays an important role in adding organic carbon to the soil. The closed canopy trees and woody perennial vegetation of the trees and forest category of vegetation ensure litter fall, dead roots and root exudates throughout the year which contributes more organic matter added to the soil [30]. At the same time soils under forest or trees do not experience cultivation or ploughing which ensures more organic carbon to be stored in soil as decomposition rate of soil organic matter by microorganisms is low. On the contrary, there is no scope of adding organic matter through crop residues in bare land as no crops were grown there which was the ultimate cause of having the lowest organic carbon concentration in the soils [31]. The variation of cropping intensity in field crop areas was another reason of being differences in rate of C_{Seq}. Among the field crops, corn field always has straw residue left on soil surface in every cropping, as a consequence, higher organic matter is annually added to the soil than that of cassava and paddy rice. Irrigation facility in the fields of corn and cassava is another reason for comparatively higher rate of C_{Seq} than paddy rice field. The only one rain fed paddy cultivation due to shortage of water is the main factor of having lower C_{Seq} rate in the less productive paddy field than in other field crops in the study area.

On the other hand, the present result is inconsistent with the findings of several studies, such as, Jiao et al. [31], Laopoolkit et al. [32] where it has been reported that the land use of trees or trees and forage crop contributed lower concentration of organic carbon as well as lower rate of C_{Seq} than did paddy rice field and also from uncultivated land. The reason behind these differences mentioned in that case is the paddy rice fields were best fertile lands with irrigation facilities and using nitrogen-rich organic fertilizers ensured high production of biomass and contributed the highest rate of C_{Seq} and the sites of the forest and the trees were marginal lands with steep slope thereby giving lower productivity and lower rate of C_{Seq} in that cases. The highest rate of C_{Seq} observed in uncultivated land in that case being the fertile productive land just kept without cultivation which stored more carbon in the soil protecting faster decomposition due to less disturbances. Whereas, in the present study, the bare land was unproductive and barren land was incapable of producing any crop due to high inland salinity.

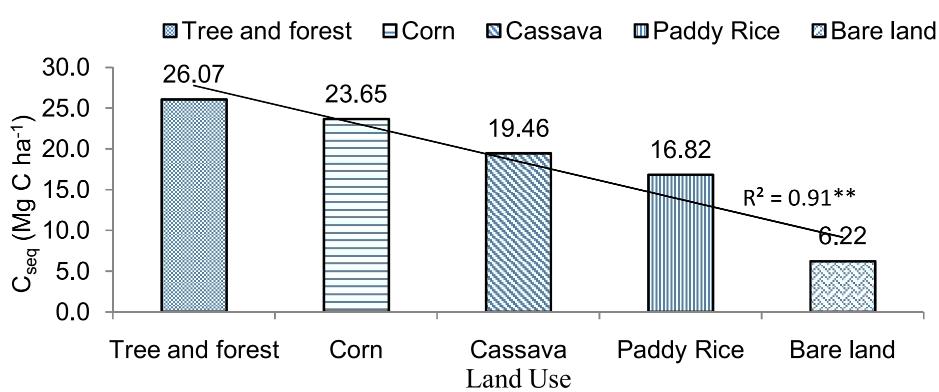

Fig. 7. Variation of amount of C_{Seq} according to land use in whole soil depth (0-60 cm)

Among tree and forest land use types, the native forest soil showed the highest amount of C_{Seq} (34.95 Mg C ha^{-1}) and the secondary forest plantation showed the lowest (23.22 Mg C ha^{-1}). The average rate of C_{Seq} in the eucalyptus tree plantation was 24.07 Mg C ha^{-1} which was higher than that of the secondary forest. In the native forest, there was dense vegetation with a variation of plants and shrubs that contributed the highest rate of C_{Seq}. The ecosystem of native forest with high biodiversity is another reason of contributing high rate of C_{Seq} in this case. Transformation of natural forest to secondary forest caused a substantial loss of carbon from the soil. Again in the secondary forest plantation dominated by Neem (*Azadiracta indica*) and some fruit plants, these plants were scattered throughout the area with ample open dry spaces, resulting in an addition of organic matter through litter fall and dead roots being comparatively much lower than in the native forest, whereas the rate of decomposition was faster due to warmer condition which contributed the lowest rate of C_{Seq} for the secondary forest type of land use. Canopy of eucalyptus plantation was very dense that prevented sun to dry up the ground and thereby protecting soil organic matter loss from rapid decomposition, which was the reason of having comparatively higher rate of carbon being sequestered by eucalyptus plantation than by the secondary forest. Substantial litter fall of eucalyptus trees was another cause , contributing higher C_{Seq}.

A significantly positive significant correlation (R^2= 0.77**, R^2= 0.84**, R^2= 0.65** and R^2= 0.66** for soil at depths of 0-15, 15-30, 30-45 and 45-60 cm, respectively) was found between the depth within soil profile and the amount of carbon sequestration according to land use in the studied soils (Fig. 8). The highest concentration of soil organic carbon as well as rate of carbon sequestration was observed in the surface soil and diminished accordingly with depth in every case except for paddy rice and bare land, which showed a slight increase of both

Table 2. Mean values of bulk density, organic matter, organic carbon, total n, c:n ratio and carbon sequestration with soil depths for land use type

Depth (cm)	Land use	BD Mg m^{-3}	OC (g kg^{-1})	Total N (g kg^{-1})	C:N Ratio	C_{Seq} (Mg C ha^{-1})
0-15	Tree and forest	1.56	4.74	0.35	13.54	11.09
	Cassava	1.49	2.85	0.30	9.50	6.37
	Corn	1.58	3.00	0.32	9.37	7.11
	Paddy rice	1.61	3.03	0.41	7.39	7.32
	Bare land	1.75	1.00	0.06	16.66	2.63
	STD	0.09	1.18	0.12	3.35	2.69
15-30	Tree and forest	1.54	2.52	0.23	10.95	5.82
	Cassava	1.66	2.15	0.28	7.67	5.35
	Corn	1.71	2.5	0.14	17.85	6.41
	Paddy rice	1.80	1.54	0.19	8.10	4.16
	Bare land	1.69	0.5	0.07	7.14	1.27
	STD	0.09	0.76	0.07	3.98	1.82
30-45	Tree and forest	1.63	1.98	0.15	13.20	4.84
	Cassava	1.78	1.6	0.23	6.95	4.27
	Corn	1.66	2.1	0.42	5.00	5.23
	Paddy rice	1.71	0.98	0.17	5.76	2.51
	Bare land	1.8	0.4	0.07	5.71	1.08
	STD	0.07	0.64	0.12	3.00	1.55
45-60	Tree and forest	1.58	1.84	0.20	9.20	4.36
	Cassava	1.67	1.4	0.25	5.60	3.51
	Corn	1.82	1.8	0.14	12.85	4.91
	Paddy rice	1.75	1.13	0.14	8.07	2.97
	Bare land	1.59	0.5	0.05	10.00	1.19
	STD	0.09	0.49	0.07	2.37	1.29

BD= Bulk Density, OC= Organic Carbon, Total N= Total Nitrogen, C:N Ration= Carbon Nitrogen Ratio, C_{Seq} = Carbon Sequestration, STD= Standard Deviation

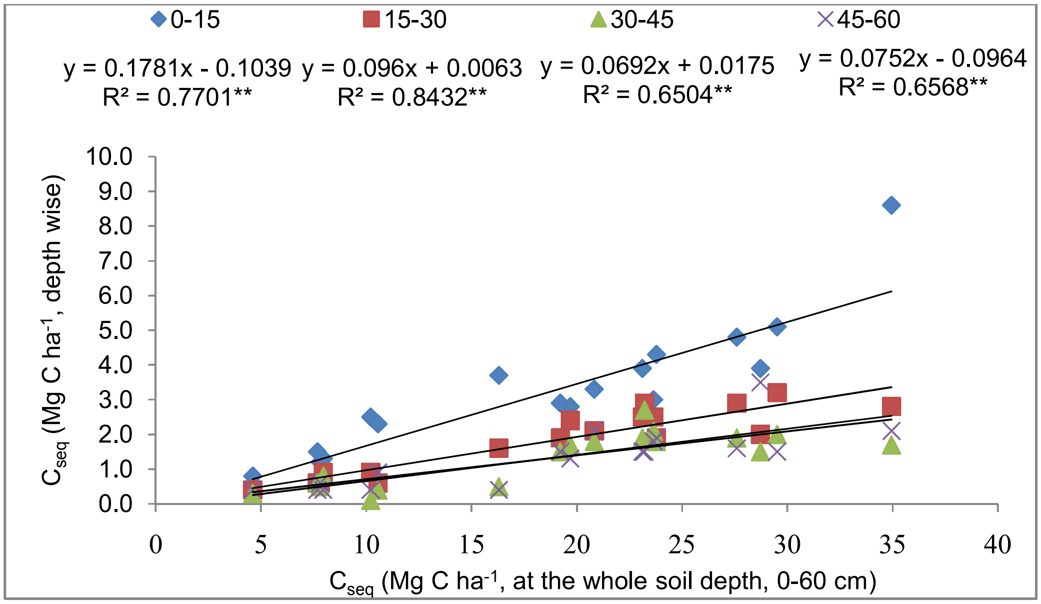

Fig. 8. Relationship of C_{seq} of the whole soil (0-60 cm) with that of specific depth of soil
*Carbon sequestration: significant with soil depth, ** $P < 0.001$*

parameters from 30-45 cm depth to 45-60 cm depth. Similar observations have been made by Jobbagy and Jackson [33] and Wang et al. [34]. The highest concentration of organic carbon (4.74 g kg^{-1}) and rate of carbon sequestration (11.07 Mg C ha^{-1}) was found in native forest at surface soil (0-15 cm depth) which was nearly 3 times more than the lowest (1.84 g kg^{-1} and 4.37 Mg C ha^{-1}) at the lowermost depth (45-60 cm) studied (Table 2). This result is consistent with the observation of Sheikh et al. [35]. The addition of organic matter through litter fall, crop residues mainly remains at the surface soil and becomes a major contribution of higher rate of carbon sequestration to the surface soils.

4. CONCLUSION

In complex landscapes, especially, when diverse environmental conditions interact with different land uses, a great variation in soil C pool as well as soil C storage and turnover is found to be existed. The addition of organic matter through litter fall, dead roots, root exudates and crop residues depend on the type of vegetations grown in a particular land. On the other hand, the magnitude and rate of decomposition of the added organic materials depends on the nature and type of the source of such material, intensity of land use, climate and topography. In the present study, estimation of the organic carbon concentration and total nitrogen as well as the amount of carbon sequestration of soils in three different transects under different land uses along toposequences, measured to 60 cm depth from the soil surface revealed that topographical factors and land use had great impact on C_{Seq}. The elevation and C_{Seq} were significantly correlated with each other, whereas, slope of land had a weakly positive correlation with C_{Seq} as a single factor but slope and elevation were significantly positively correlated with each other indicating a strongly significantly positive correlation with C_{Seq}. Landscape position also showed variation in the amount of C_{Seq}, giving higher value at the lower position as compared to its higher position in the same transects and in between transects.

Land use greatly influences carbon sequestration in soil. There is no clear difference found to be existed for bulk density in the studied soils but soil organic carbon varied strongly with land use in each transect and among transects, indicating that the land use itself is an important factor that controls soil organic carbon concentration and carbon sequestration in the area chosen for the study. The highest amount of C_{Seq} was observed in trees and forest followed in order by corn, cassava, paddy rice and bare land. Among tree and forest type, natural forest contributed the highest amount of C_{Seq}, whereas, eucalyptus plantation comparatively had higher values than did secondary forest. Depth within soil profile also showed significant variation in the amount of C_{Seq} with the surface soil having the highest amount and its decreases gradually with increasing depth in all land use types.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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