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Soil carbon buildup and bioeconomics of different lanuduses in humid subtropics of West Bengal, India

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Abstract. Long term carbon sequestration in soil had been advocated in almost all the international forum to minimize the global warming. However, the extent of carbon storage in soil will depend on the type of vegetation it supports. The study examined different land use potentiality in sequestering carbon in soil on the basis of extent of tree component. In addition it was also investigated that how soil carbon is related with other physical and chemical parameters of the soil in different land uses. Farmers will adopt a particular land use system only if it fits in his socio-economic frame work. Hence, bioeconomics of different land uses were also calculated and compared. Extent of tree in the land use affected the physical and chemical properties of soil. The pH of the soil decreased from 6.09 to 5.09 and bulk density from 1.55 to 1.21 g/cm^3 as the tree component increased. Available soil nitrogen increased from 97 to 143 kg/ha and organic carbon from 0.39 to 1.77 per cent. Out of the four soil depths surface soil had less pH, bulk density and moisture, however soil nitrogen and organic carbon was higher. Physical characters of the soil were found to be more related with organic carbon in land uses which are devoid of trees or when their number was less. However, as the tree component increases both physical and chemical component needs to be taken simultaneously to get better estimate of carbon. Agroforestry systems (agrihorticulture) seems to be better land use practices as they fulfill the needs of the farmers and can also earn carbon-credits thus increasing their income by 21 per cent.
Keywords land, use soil carbon, soil physical characters, soil chemical characters, bioecomonics.

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Introduction

In wake of global warming and climate change, sequestering carbon from atmosphere has become a major policy issue in all forums world wide. Reduce emission or sequester are the two option to minimize the rate of climate change. Sequestration of carbon seems to be better option as the prior option will have serious implications on industrialization. Biomass and soil are two sinks of terrestrial carbon. Carbon sequestration in soil had been advocated for long term mitigation of carbon. Soil carbon is a component of two important pools: soil organic C (hereafter SOC) and soil inorganic C. SOC pool is predominant form of C in soil of humid and subhumid regions. Worldwide, Soil Organic Carbon (SOC) in the top one meter of soil comprises about $3/4^{th}$ of the earth's terrestrial carbon. IPCC in its Second Assessment Report, 1996 estimated that it may be possible over the next 50 – 100 years to sequester 40 – 80 Pg of C in crop land soils (Paustian et al. 1998). Having said this, it is also known that sequestration capability will certainly differ with the kind of land use, species, edaphic and climatic factors of the specific area. It is thus imperative, before framing region specific policy, to identify location specific suitable land use system which on one hand full fills the objective of carbon sequestration and on the other fit-in within the socio-economic framework of the society. Adoption of a particular land use system by a farmer will depend upon the return which a farmer will get carbon credits are added to the returns obtained from the changed land use. It was with this objective that a comprehensive study was made to come out with a land use which is sustainable in terms of mitigating carbon and simultaneously provides multiple benefits to the farmers.

Materials and methods

Study site

The study site is a *terai zone* (foot hill plains of Himalayas) in West Bengal which lies between 26^{o} $30^{'}$ and 26^{o} $56^{'}$ North latitude and 88^{o}

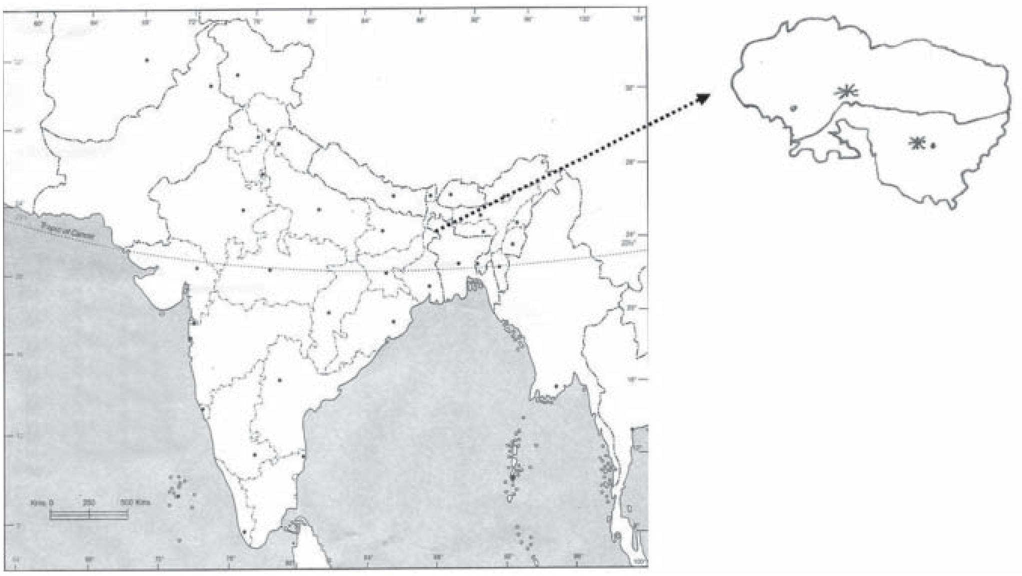


Figure 1 Location of the study area (* are the study sites and points denotes districts headquarter)

7' and 89° 53' East longitude. It covers an area of 12,015 sq. kms covering districts of Cooch behar and Jalpaiguri (Figure 1). The land use pattern of this region can be classified into five broad categories. About 50 per cent of the land is net sown and 22 per cent is under non-agricultural uses. Forests occupy a little over 14 per cent mainly confined to the Jalpaiguri district and Siliguri sub-division of Darjeeling district. Orchards and plantation crops occupy about 9 per cent of the land, tea being the most important commercial plantation crop is dominantly grown in Jalpaiguri district. The area under barren land is about 4 percent and 1 percent falls under fallow and cultivable waste. Climate of *terai* zone is sub-tropical humid. Based on the old system of classification the soils of the study site is broadly classified into Teesta alluvium, terai and brown forest soils. However, according to the modern system of classification, soils are association of Dystrochrepts and Haplaquepts of the order Inceptisols and Udifluvent / Udorthent / Ustorthent of the order Entisol (Paul 2004).

Seven land uses, in order of increasing tree component, representing grassland to natural forest namely fallow land (FL), agriculture (paddy) field (AG), tea garden (TG), agrihorticulture agroforestry system (AHAF), plantation of *Dalbergia sissoo* (PDS), plantation of *Terminalia arjuna* (PTA) and natural Forest of *Shorea robusta* (NFSR) were selected for comparing their carbon sequestration potentials (Table 1). Plots of 1 x 1 m for grasses and 10 x 10 m for tree based land use system were taken for observations. For each land use system five replications were taken.

Collection and preparation of soil samples

Soil samples were collected from four soil depths (0 - 10 cm, 10 - 20 cm, 20 - 30 cm and 30 - 40 cm) in triplicates. Composite samples for each depth were obtained by mixing three samples. Samples were air dried in shade, ground with wooden pestle, passed through 2 mm sieve and stored in cloth bags for analysis of physio-chemical attributes of soils. pH of soil was determined using Potentiometric method (Jackson 1967), bulk density (g cm^{-3}) using core sample method (Piper 1950), organic carbon (%) using potassium permanganate method as suggested by Walkley & Black 1934, available Nitrogen as per Subbiah & Asija 1956 and Soil Moisture Content following Piper 1966.

Soil organic carbon stocks (tonnes ha^{-1}) were calculated by multiplying the organic carbon with weight of the soil for a particular depth and expressed as tones per ha. Soil organic carbon pool inventory expressed as mega grams per ha (Mg ha^{-1}) for a specific depth was computed by multiplying the soil organic carbon (g kg^{-1}) with bulk density (g cm^{-3}) and depth (cm)

Table 1 Details of the land use systems selected

Land use system	Plot size (m)	No. of trees (ha^{-1})	Initial tree spacing (m)	Year of planting
Fallow land/ Uncultivated land	1 x 1	-	-	The land has not been cultivated for the last 15 years
Agriculture field	1 x 1	-	-	-
Tea Garden	10 x 10	400	6 x 6	1996
Agrihorticulture Agroforestry System	10 x 10	400	8 x 8	1996
Pure Plantation of *Dalbergia sissoo*	10 x 10	1800	1.5 x 1.5	1997
Pure Plantation (*Terminalia arjuna*)	10 x 10	2200	1.5 x 1.5	1997
Natural Forest of *Shorea robusta*	10 x 10	700	-	1976

(Joao Carlos et al. 2001).

Bioeconomic analysis

Landholder / farmer who is assessing the possibility of changing land use in the presence of payments for carbon sequestration. The profit function faced by the landholder over a planning horizon of *T* years is: (Wise & Cacho 1999)

$$V_t = \sum\left[(\Delta S_t + \Delta B_1)Pc + H_t P_H - CM_t\right](1+r)^{-t} - CE \quad (1)$$

where S_t soil carbon content, B_t above-ground biomass in year *t*, both measured in tonnes of carbon per hectare (t C/ha); Δ represents change over year *t*. H_t is the amount of products harvested during year *t*. *Pc* is the price of carbon (in present case taken as $5 per tonnes of carbon) and P_H is the price of harvested products. CM_t are annual maintenance costs and *CE* is establishment costs.

The units of H_t depend on the type of output. However, in present study all the out puts were converted to tonnes/hectare. Annual maintenance costs may include any soil tests and other carbon-monitoring expenses required to receive carbon payments. It may also include the cultural operations to be carried out in maintaining and managing the land use. It is important to note that both ΔS_t and ΔB_t can be negative. This is particularly important in the last year of the planning horizon (*T*), when total harvest may occur, thereby reducing standing biomass and requiring the landholder to pay back some of the carbon credits previously received.

Data analysis

The data obtained were subjected to statistical analysis following method suggested by Gomez & Gomez 1984 using the package SPSS. The relationship between soil organic carbon and other chemical and physical properties, influencing carbon content, at given sites were examined using regression analysis.

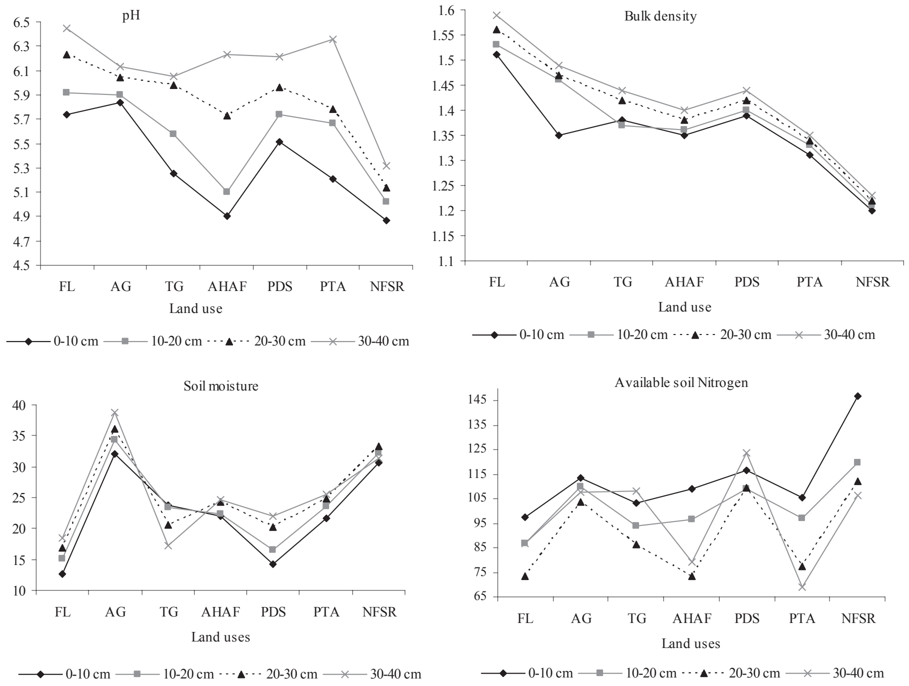
Results

Physical and chemical characters

Decrease of pH was observed as number of tree in the land use increased. In uncultivated land pH was 6.09 and natural forest had a pH 5.09 (Figure 2a). Soil reaction, in each land use, approached toward neutral as the soil depth increased. Among the land uses all the combinations showed high correlation (more than 0.93) except for a combination of tea garden and *Terminalia arjuna* pure plantation where correlation was 0.897.

Presence of tree decreased the bulk density of the soil. In uncultivated soil the mean value was 1.55 g cm^{-3} and it was least 1.21 g cm^{-3} in soil of natural forest (Figure 2b). Bulk density increased as the depth of sampling increased. All land use showed very high correlation with each other for bulk density. Uncultivated land were observed to have more compact soil as they had not been cultivated since many years and are managed in such as way that the grass, what so ever grows, is cut for stall feeding of animal. This leads to less organic matter returned to soil and hence more compactness.

Soil moisture content was higher in paddy field and least in uncultivated land. As the tree cover increased the moisture content of the soil increased. Moisture content also increased with soil depth for all the land uses except tea garden which had a reverse trend (Figure 2c). A high correlation was found among all the possible combination of soil depths, though it was less for deeper layers. Tea garden had a negative correlation with all the other land



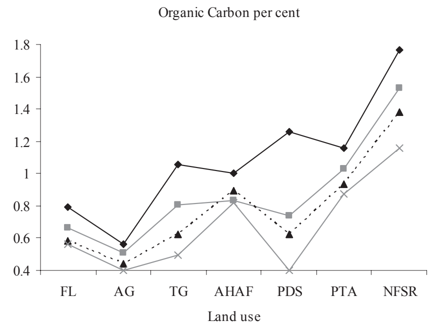


Figure 1 Effect of landuse on physical and chemical characters of soil

uses.

Available soil nitrogen was lower for uncultivated soil and higher for natural forest. Nitrogen content decreased with increase in depth of soil up to 30 cm in all the land use studied. However, in tea garden and pure plantation of *Dalbergia sissoo*, soil nitrogen increased significantly in 30 – 40 cm soil layer (Figure 2d). Nitrogen content of pure plantation of *Dalbergia sissoo* was found to have negative correlation with agrihorticulture, *Terminalia arjuna*, and natural forest land uses. Available soil nitrogen was proportional to the extent of the tree component. As the tree component increased the available nitrogen also increased.

SOC ranged from 0.399 to 1.768 (Figure 2e). It was lower in paddy field, and increased as the tree cover increased and was higher in natural forest. Organic carbon was higher in surface soil and lower in deeper soil layers.

A high degree of correlation, above 0.70, was found among different soil layers and land uses. Soil organic carbon per cent was more in tree based land use and it decreased as the soil depth increased.

Mean minimum C:N ratio was in paddy land and maximum in *Terminalia arjuna* (Table 2). As the soil depth increased the C:N ratio decreased. However, in *Terminalia arjuna* based land use and mango based agrihorticulture

Table 2 Effect of land-use and soil depth on soil C:N ratio

Land use	Soil depth (cm)				Mean
	0-10	10-20	20-30	30-40	
FL	12.27	11.68	12.40	10.30	11.67
AG	7.20	6.70	6.24	5.54	6.43
TG	13.98	12.03	10.27	6.62	10.67
AHAF	12.33	11.65	16.82	14.42	13.53
PDS	15.01	9.57	8.06	4.67	9.29
PTA	14.37	14.03	16.20	17.14	15.23
NFSR	14.46	15.43	15.02	13.40	14.59
Average	12.87	11.58	11.80	9.59	

Table 3 Effect of land-use and soil depth on soil organic carbon stock (t/ha)

Landuse	Soil depth (cm)				Average
	0-10	10-20	20-30	30-40	
FL	11.96	10.15	9.16	8.92	10.05
AG	8.17	7.38	6.47	5.98	6.99
TG	14.44	11.27	8.89	7.16	10.45
AHAF	13.47	11.27	12.36	11.45	12.14
PDS	17.52	10.42	8.84	5.79	10.66
PTA	15.17	13.64	12.53	11.80	13.29
NFSR	21.21	18.46	16.83	14.27	17.69
Average	14.57	11.80	10.73	9.33	

Note: CD $_{(p=0.05)}$, land use - 1.55, soil depth - 0.69, interactions: land use x soil depth $_{1---n}$- 1.82, soil depth x landuse$_{1---n}$ - 2.21

Table 4 Effect of land-use and soil depth on soil organic carbon pool inventory (Mg/ha)

Land use	Soil depth (cm)				Average
	0-10	10-20	20-30	30-40	
FL	119.60	101.52	91.56	89.19	100.47
AG	81.72	73.86	64.73	59.37	69.92
TG	144.46	112.71	88.92	71.66	104.43
AHAF	134.68	112.71	123.58	114.56	121.38
PDS	175.28	104.19	88.41	57.90	108.69
PTA	151.67	136.40	125.35	118.06	132.87
NFSR	212.08	184.64	168.33	142.73	176.94
Average	146.92	118.00	107.26	93.36	

Note: CD $_{(p=0.05)}$, land use - 16.19, soil depth - 6.49, interactions: land use x soil depth $_{1---n}$- 17.18, soil depth x landuse$_{1---n}$ - 22.04

system C:N ratio first decreased and then increased with depth. With increase in depth the correlation among soil depth decreased from 0.72 to 0.30. *Terminalia arjuna* was found to have negative correlation with all the land use except agrihorticulture. Similarly agrihorticulture system was also negatively correlated with all land use except uncultivated lands and *Terminalia arjuna* based land use where correlation was 0.067 and 0.767 respectively.

SOC stock decreased with increase in soil depth, signifying the importance of upper layer in storing SOC (Table 3). Similar trends were observed for SOC pool inventory (Table 4). An increasing trend in SOC stock and pool was found as the number of trees increased. Highest average SOC stock was 17.69 t ha^{-1} in Natural forest of *Shorea robusta* followed by *Terminalia arjuna* plantation (13.29 t ha^{-1}) and least in paddy field (6.99 t ha^{-1}). SOC pool inventory also showed similar trend.

Per cent contribution of SOC to that of total Carbon (above ground biomass and SOC) was worked out. It was found that SOC contributed 98 per cent of total carbon in uncultivated land, 85 per cent in paddy field, 77 per cent in agroforestry system, 32 per cent in *Terminalia arjuna* plantation, 25 per cent in tea garden, 19 per cent in *Dalbergia sissoo* plantation and only 10 per cent in natural forest.

Relationship between soil C with physical and chemical measures of soil

The goodness of fit values for the multiple regressions between soil organic carbon and measure of chemical and physical properties in different land uses studied differed between the sites for same variable (Table 5). Relationship between OC and pH; OC and Nitrogen was highest in natural forest, R^2 value for OC and Bulk density was highest in PTA (0.541), OC and soil moisture it was 0.784 in AG and OC and carbon pool R^2 was 0.982 also in AG. Relationship of organic carbon with two soil physical factors (soil moisture and bulk density), chemical factors (pH and nitrogen) and mix (pH and moisture; Bulk Density and Nitrogen) were observed. It was found that in land use which supports less number of trees soil moisture and pH together shows more close relationship with organic carbon. Land uses where tree component are dominant, either only physical or chemical parameter gives higher R^2 value.

Different statistical models were fitted for organic carbon and other physical and chemical parameters as independent variables in all the seven land uses, to arrive at the best model which can be applied for such diverse land uses. The models fitted were linear, logarithm, Inverse, Quadratic, Cubic, Power, Compound,

Table 5 Relationship between soil organic carbon and measure of chemical and physical property of soil

Organic carbon	R^2 values						
	FL	AG	TG	AHAF	PDS	PTA	NFSR
pH	0.606	0.801	0.752	0.007	0.643	0.394	0.868
Available Nitrogen	0.179	0.331	0.003	0.196	0.000	0.525	0.545
Bulk density	0.166	0.254	0.058	0.432	0.145	0.541	0.246
Soil Moisture	0.724	0.784	0.652	0.005	0.727	0.357	0.037
Carbon pool	0.798	0.929	0.919	0.484	0.982	0.470	0.840
Bulk density and soil moisture	0.726	0.801	0.706	**0.503**	0.733	0.568	0.298
BD and nitrogen	0.215	0.654	0.059	0.464	0.147	**0.598**	0.552
pH and Nitrogen	0.690	0.821	0.772	0.270	**0.758**	0.543	**0.880**
pH and soil moisture	**0.748**	**0.901**	**0.839**	0.007	0.728	0.483	0.870
All parameters	0.890	0.946	0.956	0.758	0.993	0.657	0.911

Sigmoid, Logistic, Growth and Exponential. Highest R^2 value among the model fitted for each combination of parameter in different land use is given in table 6. It was observed that there was no particular trend neither within nor among land use. However, higher order models particularly cubic and quadratic equations were the best fit.

To confirm that the variation in physical and chemical parameters of the soil, as seen in above sections, is because of presence of trees, land use were converted to numerical value by associating weightage to the trees and associated crops. Number of trees present in the land use was converted to decimal fraction by dividing number of trees by 100. Associated crops having annual nature (e.g. paddy) were given a value of 5 and perennial associated crops were given a value of 10 (e.g. grass as they have more potential in soil carbon accumulation). The trees and associated values were added to get the weightage of particular land use (Table 7). Weightage obtained were fitted in different models for all the physical and chemical parameters taken under study. Third and fourth order polynomial equations were found to be best fit. Organic carbon, carbon pool, moisture and nitrogen were found to have increased as the tree component increased. pH and bulk density decreased with increase in tree component (data not shown).

Bioeconomics of carbon sequestration

The economic returns from land use are also affected by the carbon-credit regime; in particular, the carbon pools that are eligible for payment. These carbon-credits influence the financial attractiveness of the project. Three pools may be eligible: standing biomass, soil carbon and harvested biomass. Four accounting methods were considered in the economic analysis: (i) no carbon credits, (ii) carbon credits on standing biomass only, (iii) carbon credits on soil carbon only, (iv) carbon credits on standing biomass and soil carbon.

To obtain the carbon credits which can be earned, over a period of time by altering the land use from paddy to other tree based land use, soil carbon and average carbon produced through biomass in paddy field was deducted from the carbon sequestered in other land uses. This was done because the previous land use of the area was monocropping of paddy. Assumption was that the carbon in soil and quantity of biomass produced in paddy field on per hectare area remains the same over a period of time because no much change in variety used and management practice had been observed in this period.

Using equation 1, four possible accounting systems for land use comparison were calculated and are given in table 8. The contribution of carbon credits to overall income of the land use was 71.46 per cent for uncultivated lands, 0.77 per cent for tea gardens, 20.61 per cent for Agrihorticulture, 88.80 per cent for *Dalbergia sissoo* plantation, 90.72 per cent for *Terminalia arjuna* plantation and 100 per cent income was contributed through carbon credits in natural forest of *Shorea robusta*. It is interesting to note that in accounting system two, income generated in uncultivated land is negative. It is because the biomass produced in these lands is much less then paddy field and hence signifies loss in income if we convert paddy lands to uncultivated lands.

Discussion

Decrease in soil pH with increase in the tree component is because of the addition of more organic matter which results in production of organic acid during decomposition (Fig. 1a). Similarly extent of organic matter was more in surface layers and less in the deeper layer as a result the pH in deeper layer approached to neutral. Chavan et al. 1995 and Contractor & Badnur 1996 have also reported low soil pH under forest plantation which is attributed to leaching of bases and enhancement of weathering process giving rise to high Al levels (Chakravarty & Barthakur 1997).

Decrease in bulk density with increase in tree component (Fig 1b) is correlated to more organic matter which leads to better soil structure and hence more porosity. Bulk density had also been observed to inversely related to tillage intensity (Halvorson et al. 2002, Baruah & Barthakur 1997).The same is applicable to the present study because as the tree component increased the area for tillage decreases. Decrease in bulk density with increase in soil depth had also been supported by Christine, 2006 (a).

Higher soil moisture in paddy field is due to the management practices followed for rice cultivation. Increase in moisture with increase in tree component (Fig 1c) is attributed to

Table 6 R^2 values for different models fitted between OC and other chemical and physical property of soil

	FL	AG	TG	AHAF	PDS	PTA	NFSR
OC and pH	0.54895^{C}	0.73399^{C}	0.70896^{C}	$0.60022^{C,Q}$	0.74377^{S}	0.74428^{Q}	0.83838^{Q}
OC and N	NS	0.47832^{Q}	NS	NS	NS	0.60653^{C}	0.69900^{C}
OC and BD	NS	0.67155^{C}	$0.40172^{C,Q}$	0.57198^{Q}	0.52702^{CO}	0.78102^{C}	0.42541^{C}
OC and SM	0.85910^{C}	0.89587^{CO}	0.73635^{CO}	NS	0.83678^{S}	NS	0.63913^{Q}
OC and OP	0.90754^{P}	0.99685	0.97309^{P}	0.98911^{P}	0.99082^{P}	0.99675^{C}	0.99171^{P}

Note: Letters in superscripts represents the best fitted model C = Cubic ; Q = Quadratic; I = Inverse; CO = Compound; S = Sigmoid; P = Power; OC = Organic Carbon; BD = Bulk Density; N = Nitrogen; SM = Soil Moisture; OP = Organic Carbon Pool; NS = Non Significant

Table 7 Weight age of extent of coverage of land

Land use	Number of trees	Weightage for trees	Weightage for associated crop	Total
FL	0	0	10	10
AG	0	0	5	5
TG	277	2.77	10	12.77
AHAF	156	1.56	5	6.56
PDS	1800	18	0	18
PTA	2200	22	0	22
NFSR	700	7	10 + 10	27

Table 8 Income generation (Net Present Value) in different land use using four accounting systems

Land use	Accounting System: No carbon credits	Carbon credit * on biomass only	Carbon credit on soil carbon only	Carbon credit on both biomass and carbon
FL	363.47	-132.15	1769.26	1273.64
AG	-	-	-	-
TG	2027620.00	2041724.00	2029214.00	2043317.00
AHAF	13516.52	14645.55	15896.18	17025.21
PDS	2725.99	22649.11	4413.18	24336.29
PTA	1580.75	14120.56	4491.92	17031.73
NFSR	0	71696.56	4952.70	76649.26

Note: * Carbon credit value taken as $5 per tones and converted to Indian Rupees taking value of 1$ as Rs 50. Rate of interest *r* in equation 1 is taken as 8 per cent and t is 10 years for calculations conservation of water by increase in organic matter and better soil structure. Increase in carbon results in more pore space, lower bulk density and hence greater ability of the soil to hold water (Anon. 2002). Tree cover also helps conserve moisture by reducing the evaporation from the soil surface. Christine 2006 (b) had also reported that by increase in 1 per cent of soil organic carbon 14.4 liters of extra available water can be stored per square meter in top 30 cm of soil. Higher soil moisture in deeper layer is attributed to the fact that the water table in the region is high which keeps the soil moist. In tea garden deep drainage channels are prepared to avoid stagnation of water at root zone of tea bushes which may go up to 2 to 3 feet. The deep drainage results in quick removal of water from deeper layer and hence less moisture.

The increase of nitrogen with tree component (Fig 1d) is because of the return of nitrogen through leaf fall. Nitrogen content decreased with increase in soil depth in all the land uses except tea garden and *Dalbergia sissoo* plantation where nitrogen content increased at 30 – 40 cm depth. This is attributed to the presence of nitrogen fixing trees in both the land uses which fixes nitrogen at lower depth. Land use change also alters the inputs of organic matter thus affect soil nitrogen stores Zhiyong et al. 2007. Gupta et al. 2001 reported that organic carbon, N and C: N ratio values were lowest in barren land and highest in forest. High available N in paddy land is due to continuous N fertilizer addition and rapid turn over of organic matter by tillage operation.

Higher organic carbon in tree based land use system (Fig. 1e) is due to return of more organic matter to the soil in form of leaves, bark, fruits and flowers. The present results are in conformity with the results obtained by Ladegaard et al. 2005 who reported that SOC stocks differed significantly between tree species. Jha et al. 2003 also reported that miscellaneous forest has the maximum SOC storage capacity compared to pure plantation. Moreover, carbon storage potential of soils increases which are tilled less (Subramanian et al. 2006, Marland et al. 2004, Deen & Kataki 2003, Qian et al. 2001) this had been attributed to oxidative loss of SOC and change in soil physical and biological conditions in soil which are tilled regularly. Bauhus et al. 2002 also reported that concentration of carbon was highest in undisturbed areas. Zhiyong et al. 2007 were also of the view that land use change altered the inputs of organic matter thus affecting SOC stores.

The accumulation of more organic matter in tree based land use leads to higher carbon and hence higher C:N ratio (Table 2). In agriculture land all the plant residues is removed for its utilization and hence low C:N ratio (Gupta et al. 2001).

While developing co-relationship between soil physical, chemical and land use it was found that the relationship between soil carbon with physical and chemical parameters when taken individually were not robust and consistent across all the sites. Therefore, it will be more appropriate to develop site-specific soil quality indices which should include both physical and chemical measures Burger & Kelting 1999, Rab 1994, Bauhus et al. 2002 as has also been observed in the present study. Taking soil moisture with pH had shown better relationship with organic carbon as compared to when they were taken individually. Similar is the case for bulk density and soil moisture, pH and nitrogen.

Conclusions

Developing region specific strategy to counter global warming is imperative. One of the ways is to change or develop such land use which on one hand are environmental friendly and on the other meet out the requirement of income and food. Of the seven land use studied, agriculture beyond doubt can cater to our food requirement however; it has less potential in carbon storage. Natural forests on the other hand provide less income but are environment friendly. Therefore, need is to take a middle path, a land use which can provide income & food and still has a capability of storing sufficient carbon. Thus integrated land uses seem to be best option like tea garden and other form of agroforestry systems. Since these integrated land use have trees as an essential component they have, beyond doubt, capability of earning carbon credits. Numbers of trees to be retained will *interalia* depend upon carbon credits to be earned and type of associated crop to be grown.

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Assessment of carbon pools in semi-arid forests of India is crucial in order to develop a better action plan for management of such ecosystems under global climate change and rapid urbanization. This study, therefore, aims to assess the above- and belowground carbon storage potential of a semi-arid forest ecosystem of Delhi. Methods. For the study, two forest sites were selected, i.e., north ridge (NRF) and central ridge (CRF).Â Belowground (root) biomass was determined by using a developed equation. For soil organic carbon (SOC), soil samples were collected at 0â€“10-cm and 10â€“20-cm depth and carbon content was estimated. Results. The present study estimated 90.51 Mg ha âˆ'1 biomass and 63.49 Mg C ha âˆ'1 carbon in the semi-arid forest of Delhi, India. Opting different land use for carbon buildup in soils and their bioeconomics in humid subtropics of West Bengal, India. Divy Ninad Koul, Pankaj Panwar. Biology. 2012 (First Publication: 31 July 2012). Long term carbon sequestration in soil had been advocated in almost all the international forum to minimize the global warming. However, the extent of carbon storage in soil will depend on the typeâ€¦ Continue Reading. 3.Â The traditional water harvesting system that existed decades ago in various Indian states is as relevant today as it was then and perhaps even more. Present day India is no stranger to natureâ€™s furyâ€¦ Continue Reading. View PDF. Soil carbon buildup and bioeconomics of different lanuduses in humid subtropics of West Bengal, India. Author(s): Divy Ninad Koul | Pankaj Panwar Volume: 55 Issue: 2 Year: 2012. The relationship between potential solar radiation and spruce bark beetle catches in pheromone traps.Â Forest structure, diversity and soil properties in a dry tropical forest in Rajasthan, Western India. Author(s): J. I. Nirmal Kumar, | Kanti Patel, | Rohit Bhoi Kumar Volume: 54 Issue: 1 Year: 2011. Phytosociological studies of the forests with sessile oak and Norway spruce from South-Eastern Transylvania. The humid forest zone has a large and diverse soil-associated fauna that strongly influence soil properties and development. Data on the invertebrate fauna composition on the different land-use systems were collected above ground and within soil/litter. 2.4.1. Above-Ground Data Collection. Ten different positions were selected randomly on the different sites, and a sweeping net was used to collect the organisms [20] found on the low vegetation (about 0.5 m above soil) found under the main vegetation. The sweep net was swept on the low vegetation, and the organisms captured inside the net were