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Comparative analysis of soil organic carbon storage under different land use and land cover in Achanakmar, Chhattisgarh

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Abstract

In context to the India's climate pledge and the goal of limiting global warming below 2°C to reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level and to create an additional carbon sink of 2.5 to 3 billion tons of CO_2 equivalent through additional forest and tree cover by 2030. Forest vegetation and forest soils represent a significant sink for atmospheric CO_2, soil biota functioning, reduction of greenhouse gases, modification of pollutants and maintenance of soil quality. The great importance of carbon sequestration emphasizes the need to understand the role of soil carbon dynamics and quantitative changes as affected by different land use pattern and vegetation cover management. However, knowledge on the impact of different land use and vegetation cover on soil carbon dynamics in India is very limited. To address this problem the present study was undertaken in Achanakmar, Chhattisgarh to estimate soil carbon sequestration potential of four land uses (forestland, grassland, agricultural land and wasteland) and five land covers (sal, teak, bamboo, mixed, open and scrub). The highest soil carbon storage potential was found in forestland (118.14 t ha^{-1}) followed by grassland (95.54 t ha^{-1}), agricultural land (75.70 t ha^{-1}) and least was found in the wasteland (57.05 t ha^{-1}). Among the different land covers, maximum soil carbon storage potential was found in the soils under mixed land cover (118.18 t ha^{-1}) followed by teak (76.64 t ha^{-1}), bamboo (67.21 t ha^{-1}), sal (64.28 t ha^{-1}) and least under soils of open and scrub (48.72 t ha^{-1}) land cover.

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Introduction

The world's population is expected to reach 9.6 billion by 2050 (United Nations, 2013). This enormous demographic pressure creates four major global challenges for earth's soils over the coming four decades. The challenge for global soils is to meet the anticipated demands of population to double the food supply worldwide, double the fuel supply including renewable biomass, increase by more than 50% the supply of clean water, all while acting to mitigate and adapt to climate change regionally and worldwide (God fray *et al.,* 2010). Recent assessments from the Intergovernmental Panel on Climate Change (IPCC) conclude that net anthropogenic carbon emissions must be eliminated before the end of this century in order to limit increase in mean global surface temperatures to less than 2°C (Moss *et al.,* 2010; Edenhofer *et al.,* 2014). Soil carbon sequestration is a key component of the soil-plant ecosystem and is closely associated with soil properties and processes, as well as emission and storage of greenhouse gases (Kasel and Bennett, 2007; Yang *et al.,* 2009; Wu and Cai, 2012). The SOC is an important factor affecting soil quality (Nsabimana *et al.,* 2004). Besides being a source and sink of nutrients for plants, the SOC has an important function in the carbon cycle, accounting for the major terrestrial pool of this element.

The amount of Carbon (C) stored in soils worldwide is estimated more than 3000 Pg (1 Pg =1 billion ton) among which, 70% exists as soil organic C (SOC) in the top 1 m of the soil. (Jansson *et al.,* 2010). Tropical soils contain about 496 Pg of C, accounting for 32% of the total global pool (Lal, 2002).

Soils not only contain C but also can represent a significant sink for atmospheric carbon dioxide (CO_2) and play an important role in the C cycle in terrestrial ecosystems and in the global C balance (Post *et al.,* 1982; Eswaran *et al.,* 1993; Batjes, 1996). Evidence for rapidly changing SOC pools has been shown for different ecosystems and continued warming may lead to strong climate-induced SOC loss (Bellamy *et al.,* 2005; Cox *et al.,* 2000; Rumpel and Chabbi, 2010; Post and Kwon, 2000; West *et al.,* 2004). Changes in soil C stocks may thus significantly influence the atmospheric carbon dioxide (CO_2) concentration. The SOC concentration is an indicator of soil fertility and strongly affects soil physical and biological properties (Eswaran *et al.,* 1993; Karlen *et al.,* 1999; Smith *et al.,* 2005). SOC is more sensitive to land management when compared with total SOC and better suited to predict changes in soil quality (Cambardella *et al.,* 1992; Chan, 2001; Fang, 2006). Land management practices can markedly affect the soil carbon sequestration in different vegetation types (Li *et al.,* 2014; Zhang *et al.,* 2014; Li *et al.,* 2013; Baritz *et al.,* 2010). Activities for mitigation of climate change include soil preserving management practices (Ogle *et al.,* 2005; Powlson *et al.,* 2011).

Thus, Soil carbon sequestration is strongly affected by the different land use adaptation and vegetation cover management regimes, in addition to being affected by biophysical factors, such as climate, hydrology and parent geological material (Eswaran *et al.,* 1993). Changing land use, particularly the removal of forest cover has a major and widespread impact on soils (Ellis and Ramankutty, 2008; Don *et al.,* 2011).

Therefore, a clear understanding and quantification of the amount of C stored in soils under different land uses and vegetation cover is essential for an improved understanding of the global C cycle and how this will be altered in the near future by human activities.

The effect of a certain land use change or soil management practice on atmospheric CO_2 needs thus to be considered in a broader context. There is, however, great potential for increasing the soil C sequestration through adoption of forest land use and mixed vegetation cover land management practices that will increase soil carbon, the win–win strategy of increased C storage and soil fertility advocated by Lal (2004) and others. Activities for mitigation of climate change include soil preserving management practices (Ogle *et al.,* 2005; Powlson *et al.,* 2011). The objective of the study was to determine the carbon storage potential under different land use and land cover in Achanakmar Chhattisgarh.

Materials and methods

Study Area

The present study was carried out in Achanakmar, Chhattisgarh which lies between East longitudes 81°29′02″ & 82°27′44″ and North latitudes 21°42′40″ & 23°06′58″. The annual temperature varies from 9.2°C to 42.1°C. The hottest months are May and June and the minimum temperature is observed in the months of December and January. The maximum temperature in May is 46°C and means minimum temperature is 9°C in December. May is the hottest month and December is the coldest.

The months of July and August are the heaviest rainfall months and nearly 95% of the annual rainfall is received during June to September months. The rainfall is unevenly distributed and also the amount of rainfall varies from year to year and experiences a hot and semi-humid climate. The average rainfall is 130.04 cm. The relative humidity is higher during the monsoon season, being generally over 75%. After monsoon season, humidity decreases and during the winter season, air is fairly dry.

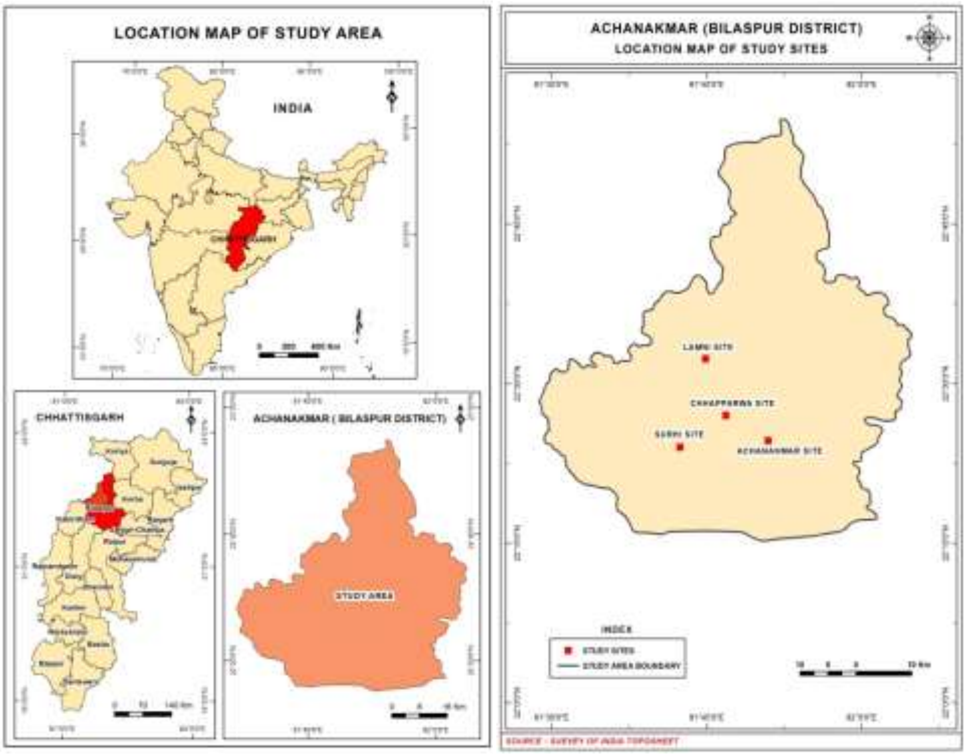

Fig. 1. Location map of study area and study sites.

Procedure for soil sampling design and collection

The present study for knowing the soil carbon sequestration potential of forest land, agriculture land, grassland and wasteland in Achanakmar was carried out at 4 selected sites: Achanakmar, Chhapparwa, Lamni and Surhi shown in Fig. 1.

At each sampling site, the soil samples were randomly collected at three different soil depths: 0-20, 20-50 and 50-100 cm by using a soil core sampler. A total of 120 (4x10x3) soil samples were collected for SOC estimation.

A randomly selected soil samples among different land covers viz, sal, teak, bamboo, mixed, open and scrub was also collected for estimating the SOC storage potential. A total of 75 (5x5x3) soil samples were collected among different land covers. It was ensured that sampling sites typically represent the whole study area.

The soil samples collected were packed in zip locked polythene bags and were tagged with the geo-morphological information (location of site, elevation, latitude, longitude) using GPS (Garmin etrex-30) and were taken to the laboratory for SOC analysis.

Separate soil samples were also collected for soil bulk density estimation of soil. A total of 36 (3x4x3) soil samples were collected from four different land uses and 30 (2x5x3) soil samples from different five vegetation covers at three different soil depths. The collected soil samples from the field were brought to the laboratory and oven dried at 60°C till constant weight. The weight of oven dried soil samples was taken and recorded. The weight of oven dried soil samples was divided by its volume to estimate the value of soil bulk density. Bulk density measurements were estimated by using standard core method (Wilde *et al.,* 1964). Sieving of soil samples was done using the 2 mm sized sieve and the fraction smaller than 2 mm size was used for the estimation of SOC.

Calculation of SOC

Standard Walkley and Black method (1934) was used to determine organic carbon content in soil.

The SOC content was calculated as:

Percentage (%) of SOC in soil = (B-S) x 0.003x 1.33x 100/W

Where,

B: Volume of ferrous sulphate solution for blank titration (ml)

S: Volume of ferrous sulphate solution for sample titration (ml)

W: Weight of soil sample (g)

0.003: Milli equivalent wt. of carbon

1.33: Correction factor (100/77)

The total organic carbon stock (ton/ha) was calculated by following formula;

SOC stock (t ha^{-1}) = soil depth (cm) x bulk density (g cm^{-3}) x C conc. (%) x CFst (1-% stone + % gravel/100).

Total SOC estimation

For determining the total SOC pool under different land use system, the total SOC pool was calculated by multiplying the mean SOC stock in each unit area (ton/ha) by the total area covered by them. Summation of SOC stock in each depth gave the total SOC pool (tons) in each land use system. Mitigation Potential was calculated by dividing the total individual pool of carbon in each land use and land cover by the lowest pool of carbon occupied under land use and land cover.

The difference in the carbon stock obtained at the interval of one year was used to estimate the annual carbon sequestration rate of carbon under different land use and land cover.

Results

The present study was set up to estimate and compare the SOC pools under different land uses viz. forest land, agriculture land, grassland and wasteland in Achanakmar, Chhattisgarh. Among different land use in AABR, the dominant land use was found under dense forest land (71%), followed by agricultural land (21%), grassland (1%), wasteland (1%) and others (6%). The mean soil bulk density values of dense forest land (0.98, 1.12 and 1.24g cm^{-3}), agricultural land (1.11, 1.19, 1.28g cm^{-3}), grassland (1.15, 1.24, and 1.30g cm^{-3}) and waste land (1.21, 1.28, 1.37g cm^{-3}) were observed in 0-20, 20-50, 50-100 cm soil depths respectively (Table 1). It shows that bulk density values increased with the increasing depths among all land uses. It was observed that wasteland had higher values of bulk density followed by grass land, agricultural land and least bulk density values were found in forest land use systems. This is because the percentage of sand and silt is higher in the soils of wasteland and grassland, compared to the forest and agricultural lands and lack of organic matter (litter) in the wasteland compared to the forest land.

A negative trend of SOC was observed with increasing soil depths among all four land uses. The maximum SOC percentage was found in top surface layer of 0-20 cm under soils of dense forest land (2.52%) followed by grassland (1.72%), agricultural land (1.43%) and least in wasteland (0.98%). In the middle layer of 20-50 cm it was observed that higher carbon content was exhibited by dense forest land (1.18%) followed by grassland (0.89%), agricultural land (0.73%) and wasteland (0.51%). In the lower, 50-100 cm soil horizon, higher carbon content was exhibited by dense forest land (0.51%) followed by grassland (0.39%), agricultural land (0.31%) and least under wasteland (0.22%). The highest mean SOC stock was found under forest land (49.18, 39.24, and 29.72 t ha^{-1}) followed by grassland (38.90, 32.66, and 23.98 t ha^{-1}), agricultural land (31.19, 25.66 and 18.85 t ha^{-1}) and least under wasteland (23.43, 19.12, and 14.50 t ha^{-1}) across three different soil depths. It shows that higher carbon stock was found at the top surface layer i.e. (0-20 cm depth) followed by decreasing trend at middle depth (20-50cm) and least SOC stock was found at lower depth (50-100 cm) among all land uses. The total SOC pool in the 100 cm soil depth of forest land was highest (118.14 t ha^{-1}), followed by grassland (95.54 t ha^{-1}), agricultural land (75.70 t ha^{-1}) and least was found in wasteland (57.05 t ha^{-1}). Data revealed that highest SOC stock was found in upper 0-20 cm soil depth, followed by 20-50 cm soil depth and least in 50-100 cm among all land uses. This shows a general trend of decreasing SOC stock from upper to lower soil depths. Similarly, the total SOC pool in tons observed under land use systems were: forest land, both dense and open forests (1,90,76,556.3 tons), agricultural land (38,97,157.08), grassland (1,88,872.7 tons) and wasteland (2,07,796.73 tons). The overall percentage share of SOC pool sequestration exhibited under different land use systems found in AABR were: forestland, both dense and open (81%), agricultural land (17%), grassland (1%) and wasteland (1%). The annual C sequestration rate found in different land use was highest in forest land (8.59 t ha^{-1}/yr) followed by grassland (3.85 t ha^{-1}/yr) and wasteland (0.66 t ha^{-1}/yr) and the reverse trend was observed in agricultural land (-12.5 t ha^{-1}/yr) which may be due to the anthropogenic practices adopted in the agricultural lands (Table 1).

Table 1. Soil organic carbon storage potential under different land uses.

Land Use	Area (ha)	Soil Depth (cm)	SOC (%)	B. D (g cm^{-3})	SOC (ton/ha)	SOC Pool (tons)	SOC Sequestration Potential (ton C ha^{-1}/yr)
		0-20	2.52	0.98	49.18	74,31,540.62	
Forest land	151109	20-50	1.18	1.12	39.24	59,29,517.15	
		50-100	0.51	1.24	29.72	44,90,203.94	8.59
Total		0-100			118.14	1,78,51,261.71	
		0-20	1.43	1.11	31.19	16,05,817.15	
Agricultural land	51485	20-50	0.73	1.19	25.66	13,21,105.1	-12.5
		50-100	0.31	1.28	18.85	9,70,234.83	
Total		0-100			75.70	38,97,157.08	
		0-20	1.72	1.15	38.90	76,905.3	
Grassland	1977	20-50	0.89	1.24	32.66	64,568.82	3.85
		50-100	0.39	1.30	23.98	47,398.58	
Total		0-100			95.54	1,88,872.7	
		0-20	0.98	1.21	23.43	85,355.49	
Wasteland	3643	20-50	0.51	1.28	19.12	69,635.95	
		50-100	0.22	1.37	14.50	52,805.29	0.66
Total		0-100			57.05	2,07,796.73	
Others	14381	-	-		-	-	-
Overall	2,47,678	-	-	-	-	-	-

The mean values of soil bulk density under different land covers viz. sal (0.88, 0.97, 1.12g cm^{-3}), teak (0.94, 1.06, 1.20g cm^{-3}), bamboo (0.96, 1.08, 1.22 g cm^{-3}), mixed (0.98, 1.12, 1.24g cm^{-3}), open and scrub (1.01, 1.15, 1.25g cm^{-3}) were observed in 0-20, 20-50, 50-100 cm soil depths respectively. Soil bulk density was higher under open and scrub compared to the other land covers. Soil bulk density increased with increase in soil depth among land covers (Table 2).

At the top 0-20 cm soil depth, mixed vegetation cover had the greatest SOC concentration (2.52%), followed by teak (1.63%), bamboo (1.45%), sal (1.36%), open and scrub (0.86%). At the middle, 20-50 cm depth mixed forest cover still had the greatest SOC concentration (1.18%) followed by teak (0.91%), sal (0.77 %), bamboo (0.76 %), open and scrub (0.53%). The SOC concentration in the lower, 50-100 cm depth was found higher under mixed vegetation cover (0.51%) followed by sal (0.35%), teak (0.31%), bamboo (0.28%) and least under open and scrub (0.25%). Soil organic carbon concentration decreased with increasing soil depths (Table 2).

Table 2. Mean soil bulk density and soil organic carbon in soils under different land covers. Different letters indicate significant differences between land covers ($p < 0.05$).

Land Cover	Depth (cm)	Bulk density ($g\ cm^{-3}$)	Soil organic carbon (%)	Soil organic carbon ($ton\ ha^{-1}$)	SOC pool ($t\ ha^{-1}$)	SOC Sequestration Potential ($t\ ha^{-1}/yr$)
Sal	0-20	0.88^{c}	1.36^{b}	23.69^{c}		
	20-50	0.97^{b}	0.77^{c}	21.70^{d}		
	50-100	1.12^{a}	0.35^{e}	18.90^{d}	64.28^{a}	6.45
Teak	0-20	0.94^{b}	1.63^{b}	31.42^{c}		
	20-50	1.06^{b}	0.91^{c}	28.74^{c}		
	50-100	1.20^{a}	0.31^{e}	17.75^{d}	76.64^{b}	8.53
Bamboo	0-20	0.96^{b}	1.45^{b}	27.52^{c}		
	20-50	1.08^{b}	0.76^{c}	24.43^{c}		
	50-100	1.22^{a}	0.28^{e}	16.95^{d}	67.21^{a}	1.61
Mixed	0-20	0.98^{b}	2.52^{a}	49.18^{a}		
	20-50	1.12^{a}	1.18^{b}	39.24^{b}		
	50-100	1.24^{a}	0.51^{d}	29.71^{c}	118.18^{c}	8.59
Open and Scrub	0-20	1.01^{b}	0.86^{c}	18.14^{d}		
	20-50	1.15^{a}	0.53^{d}	16.78^{d}		
	50-100	1.25^{a}	0.25^{e}	13.82^{e}	48.72^{d}	0.58

Same alphabets represent statistically at par group.

Regarding the soil organic carbon stock among different land covers at the 0-20 cm soil depth, mixed vegetation had the highest soil carbon stock (49.18 C ton ha^{-1}) followed by teak (31.42 C ton ha^{-1}), bamboo (27.52 C ton ha^{-1}), sal (23.69 C ton ha^{-1}), open and scrub(18.14 C ton ha^{-1}). At the middle, 20-50 cm depth, mixed land cover still had the highest soil carbon stock (39.24 C ton ha^{-1}) followed by teak (28.74 C ton ha^{-1}), bamboo (24.43 C ton ha^{-1}), sal (21.70 C ton ha^{-1}), open and scrub (16.78 C ton ha^{-1}). At the lower, 50-100 cm depth mixed land cover had the highest soil carbon stock (29.71 C ton ha^{-1}) followed by sal (18.90 C ton ha^{-1}), teak (17.75 C ton ha^{-1}), bamboo (16.95 C ton ha^{-1}), open and scrub (13.82 C ton ha^{-1}). Soil carbon stock also decreased with increasing soil depths (Table 2).

The total soil carbon sequestration potential under different natural vegetation covers was estimated and data has been presented in Table 3. Maximum SOC pool (118.18 t ha^{-1}) was found in the soils under mixed vegetation cover, followed by soils under teak vegetation (76.64 t ha-1), bamboo vegetation (67.21 t ha^{-1}), sal vegetation (64.28 t ha^{-1}) and minimum under soils of open and scrub vegetation cover (48.72 t ha^{-1}). Subset for alpha = 0.05 indicates that the SOC pool under open and scrub vegetation placed in subset'd' was not statistically at par with the sal, teak, bamboo and mixed forests, except sal and bamboo forests represents statistically at par group stands alone in subset 'a' whereas teak and mixed vegetation can be placed separately in subset 'b' and 'c' respectively (Table 2).

The percentage of SOC pool was highest under mixed vegetation (31.51%), followed by teak (20.43%), bamboo (17.92%), sal (17.14%) and least SOC pool under open and scrub vegetation cover (12.99%). Results of one-way ANOVA indicate that SOC pool between the different forest vegetation covers was significantly different among a, b, c, and d subsets at 0.05 level (Variance ratio, $F = 11.356$; $P < 0.05$). SOC sequestration under soils of mixed forests and open and scrub forests was significantly different from the SOC sequestration under sal, teak and bamboo vegetation covers. However, the SOC sequestration under sal, teak and bamboo were not significantly different from each other. Mitigation potential was also worked out for soils under different vegetation covers. Maximum mitigation potential was found in mixed vegetation (2.43) followed by teak (1.58), bamboo (1.38), sal (1.32) and least under open and scrub vegetation cover (1.0) (Table 2).

The annual C sequestration rate found in different vegetation cover was highest in mixed vegetation (8.59 t ha^{-1}/yr) followed by teak vegetation (8.53 t ha^{-1}/yr), sal vegetation (6.45 t ha^{-1}/yr), bamboo (1.61 t ha^{-1}/yr), open and scrub (0.58 t ha^{-1}/yr) (Table 2).

Discussions

The soil organic carbon stocks at three different depths under forest land use was much higher as compared to the other land uses, this is because of the highest litter fall and plant residues associated with microbial activities was observed in the forests which shows the inter-linkage of forest ecosystems in sequestration of soil organic carbon compared to other land uses. Moreover, the differences in the SOC storage of land uses can be associated with varying levels of clay and sand contents which affect the storage of SOC stocks (Rojas *et al.,* 2012; Yao *et al.,* 2010). Since no such past study was found in this area, present study is in correspondence with the study of Venkanna *et al.* (2014) who studied soil C sequestration pool in semi-arid tropical region of southern India and the results of his study reveals that forest land use system were having highest C sequestration potential followed by grassland, agricultural land and wasteland. Choudhury *et al.* (2013) estimated soil C sequestration pool in soils of North East India and found that forest land contains highest SOC pool followed by grassland, agricultural crop land and wasteland. Thus, results of our study are similar and almost in the same trend under different land uses as estimated by these researchers.

Among different land covers the soil C sequestration potential was found higher under mixed land cover. The lower soil C sequestration was found under open and scrub. This may be due to low litter production and input in these vegetation covers. Differences in soil carbon stocks between different land uses and land covers in this study could be attributed to differences in presence of litter, quality of litter, composition of vegetation and rate of litter decomposition. Indeed, differences in the amount of litter produced and resulting biochemical properties among different land-use and vegetation covers effect litter decomposition rates, and eventually influence soil carbon stocks (Sariyildiz and Anderson, 2003). In general, litter of mixed vegetation contains a mixture of components that have the varying decomposing rate than single or mono-cropping type of vegetation cover. The slower decay rates of monocropping vegetation compared to the mixed vegetation could have contributed to the larger accumulation storage of soil carbon under the mixed land cover compared to the other vegetation covers. Thus, higher litter production and higher decomposition rate of soil organic matter in soils of mixed vegetation have a greater role in storage of the soil carbon.

Conclusion

A better understanding of the impact of the different land use and land cover on soil carbon storage is necessary as it will help us in identifying and knowing the influence of different land use and land cover on soil C storage and how different land use and land cover management practices influence the soil C storage in soils. The results have shown that SOC stock distribution in upper soil profile are sensitive to SOC loss due to land use and land cover conversion in Achanakmar and could be proposed as one of the most appropriate biological indicator for studying the long term effects of LULC on soil properties. Understanding the carbon storage potential of different land-use and land cover will help to understand the potential role of soils in carbon storage and may provide opportunities for its long term storage. The study concludes that forest land-use with mixed land cover has a greater role in carbon storage compared to the mono-cropping system.

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