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Effect of Land Use Changes on Carbon Stock Dynamics in Major Land Use Sectors of Mizoram, Northeast India

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Abstract

Land use change activities have greatly affected the total ecosystem carbon stock (TECS) and also contribute to global change through emission of greenhouse gases. The present study assessed the change in vegetation biomass carbon stock (VBCS) and soil organic carbon stock (SOCS) following conversion in major land use sectors (agriculture, agroforestry, forest and plantation) in Mizoram, Northeast India. SOCS was the highest in agroforestry (50.85 Mg C ha^{-1}) and the lowest in agriculture (33.99 Mg C ha^{-1}). VBCS was the highest in plantation (131.66 Mg C ha^{-1}) and the lowest in agriculture (7.44 Mg C ha^{-1}). The highest positive TECS change rate was observed when agriculture was converted to plantation (6.61 Mg C $ha^{-1}\cdot yr^{-1}$), while negative rate of change in carbon stock was observed following the establishment of agriculture from other land use. A positive rate of change was observed in both VBCS and SOCS with TECS rate of 3.58 Mg C $ha^{-1}\cdot yr^{-1}$ when agriculture got converted to agroforestry. The absolute carbon stock change rates were higher in VBCS than SOCS signifying the importance to maintain tree based vegetation cover.

Keywords

Land Use Change, Soil Organic Carbon Stock, Vegetation Biomass Carbon Stock

1. Introduction

Greenhouse gas (GHG) emissions from land-use, land-use change and forestry (LULUCF) activities substantially increased [1] [2] [3] and these land use changes, mainly deforestation accounts for 12% - 20%, to be the second largest source of anthropogenic GHG emissions [4]. The alarming rate of GHG increase held responsible for ongoing climate change has consequently drawn research attention associated with land use changes [5] [6] [7]. Carbon storage in different pools (live biomass, litter, deadwood and soil) were directly affected by land use change [8] and its rate of change varies in accordance to climatic responses, vegetative cover, choice of species, management practices and anthropogenic interventions [9] [10]. Hence, past and current land use practices stand out as an indicator either to be carbon sinks or source [11]. Carbon stock in both vegetation and soil have been reported to loss following conversion of primary forest to secondary forest [12] [13], and several other studies also reported variations either a gain or loss of carbon stock associated with land use change in diverse ecosystems [14] [15] [16] [17]. Several initiatives have been reported to reduce anthropogenic carbon emission form land use change with adoption of scientific land use management practices such as tree buffer plantations around farmlands, mulching and soil enrichment fertilizer applications, forest slash and crop residue retention, elongation of fallow periods in shifting cultivation, crop rotation and tree plantation in degraded areas [18]. However, studies on carbon stock changes associated with the wide range of prevailing land use types following conversions in Mizoram, Northeast India have been lacking behind and no importance was given to the carbon implications of various land uses before making land use change decisions. This necessitates the present study to assess ecosystem carbon stock in different land use types and stock change rate following conversions in major land use sectors. The study further aims to monitor carbon pool dynamics following land use changes and provide scientific knowledge to support policy decision making for land use change planning and enhance the regional carbon stocks overall as an option for climate change mitigation.

2. Materials and Methods

2.1. Study Sites

The study was undertaken in Mizoram, Northeast India which lies between 21˚58' to 24˚35'N and 91˚15' to 93˚29'E with a geographical area of 21,081 km^2. The elevations ranges 40 to 2157 m above sea level from the western (Bairabi valley) to eastern side (Phawngpui). Annual rainfall averages 2500 mm occurring between May to October while December and January are the driest months. Temperature varies from about 11˚C in winter to 30˚C in summer or spring. Based on interpretation of satellite data, the forest cover of Mizoram is 18186 km^2 with 131 km^2 under very dense forest, 5861 km^2 under moderately dense forest and 12194 km^2 under open forest in terms of forest canopy density classes [19]. The state witnessed different predominant land use/land cover types such as Shifting cultivation (locally known as "jhum")—Current Jhum (1091.11 km^2) and Jhum fallow (2869.30 km^2); Bamboo Forest (6708.37 km^2); Forest plantation (85.64 km^2); and Oil palm plantation (233.58 km^2) responsible for forest cover reduction of 1054 km^2 from 2009 to 2017 [20]. Shifting cultivation and plantation crops (oil palm, arecanut, teak, orange etc.) have widely replaced many of the native and bamboo forests. The government of Mizoram also promoted cultivation of these horticultural cash crops through various sponsored schemes at the cost of forest destruction and degradation. To estimate the difference in carbon stock among different land uses, we identified four major land use sectors in Mizoram, *viz.* 1) Agriculture, 2) Agroforestry, 3) Forest and 4) Plantation. Agriculture comprised of Current Jhum, Jhum Fallow and Wet Rice Cultivation; Agroforestry comprised of Old Homegarden and Young Homegarden; Forest comprised of Dense Forest, Open Forest, Bamboo Forest and Grassland; and Plantation comprised of Arecanut, Coffee, Mango, Oil Palm, Orange, Pine and Teak. A total of 38 sites distributed over 16 land use types were selected for the present study (**Figure 1**). The age of the different land use types were recorded from the landholders and villagers.

2.2. Biomass Carbon Estimation

Permanent plots (250 × 250 m^2) were set up in each of the selected land use types following ISRO-GBP/NCP-VCP protocol [21], and four nested sampling quadrats were laid in the corners. The permanent plot sizes were reduced to 100 × 100 m^2 in land use types where land holding size was less than 2 ha. Nested quadrats size were of 0.1 ha (31.62 × 31.62 m^2) for estimating tree and deadwood; two quadrats of size 5 × 5 m^2 to estimate saplings/shrub/bamboo; and four quadrats of size 1 × 1 m^2 for herbs and standing litter (**Figure 2**). All trees

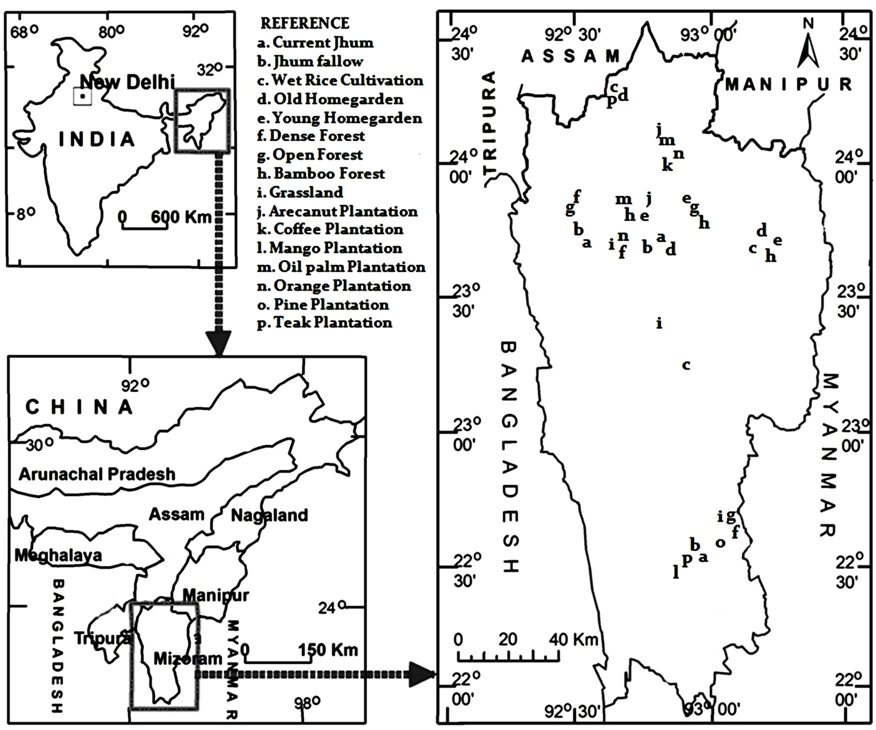

Figure 1. Location of the selected different land use types in Mizoram, Northeast India.

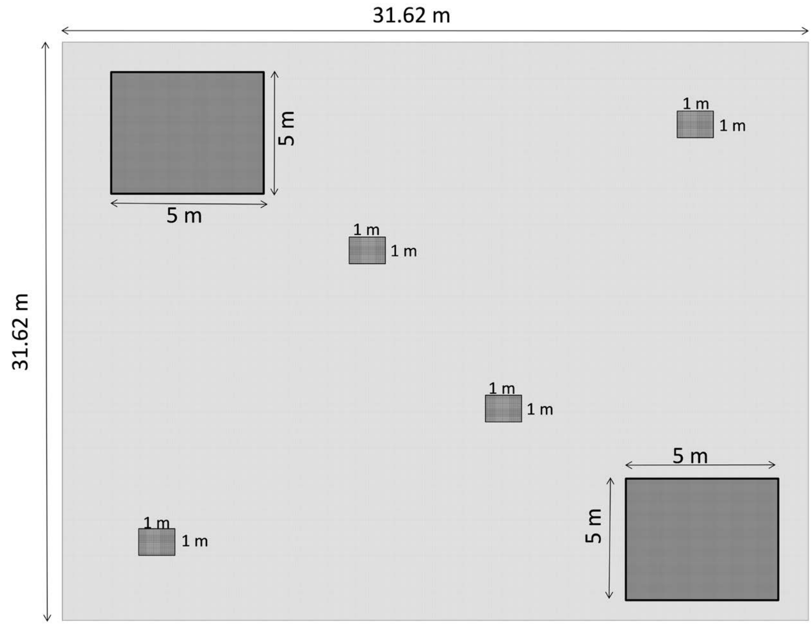

Figure 2. Nested quadrats scheme for sampling: Trees & Deadwood (31.62 × 31.62 m); Saplings/Shrubs/Bamboo (5 × 5 m, 2 nos.); and Herbs & Litter (1 × 1 m, 4 nos.).

greater than 30 cm girth over bark at breast height (GBH, 1.37 m above ground level) were identified and tagged, and were measured for GBH using a metal tape and height by use of Haga altimeter and measuring tape. All coarse deadwood biomass (>10 cm diameter) were recorded following fixed-area sampling (FAS) [22]. Collar diameter (5 cm above ground level) and height of all saplings and shrubs encountered were measured with digital vernier caliper and measuring tape respectively. Plant density (ha^{-1}) and basal area ($m^2 \cdot ha^{-1}$) was calculated from the expanded values of each nested plots and averaged for each land use type. Above ground biomass (AGB) and below ground biomass (BGB) were estimated using appropriate allometric models for the trees/deadwood and saplings/shrubs (**Table 1**). The specific wood density values of trees were adopted from the Global Wood Density Database [23]. Volume of deadwood was multiplied with determined values of its corresponding decay classes, *viz*. sound, partial and full decomposed considered as 0.45, 0.35 and 0.25 $g \cdot cm^{-3}$ respectively [24]. Bamboo biomass (*Melocanna baccifera*) was estimated by harvesting bamboo culms samples from different diameter classes and total bamboo biomass was estimated as the sum after multiplying dry biomass with the corresponding densities of its diameter class. The aboveground biomass of herbs and litter was estimated by harvest method [25]. All biomass measurements were converted to a per hectare basis (Mg ha^{-1}).

2.3. Soil Organic Carbon (SOC) Stock Estimation

Physico-chemical characteristics of soil were analyzed with soil samples collected from the permanent plots for every land use type and each nested plot being laid. Sampling points (5 nos.) were randomly selected from which soils were collected

Table 1. Summary of allometric equations used in the study.

Biomass type	Equation	Reference
Trees	$AGB = 0.0673 \times (\rho D^2 H)^{0.976}$	[26]
Banana	$AGB = 0.0303 \times D^{2.1345}$	[27]
Arecanut/Palm	$AGB = 4.5 \times 7.7 \times H$	[28]
Oil palm	$AGB = 71.797 \times H - 7.0872$	[29]
Saplings/Shrubs	$AGB = exp(-3.5 + 1.65 \times \ln(CD) + 0.842 \times ln(H)$	[30]
Root estimate	$BGB = exp(-1.085 + 0.9256 \times ln(AGB))$	[31]
$DW_{log/stump}$	$V = (L \times \pi \times D_m^2)/4$	[32]
$DW_{oil\ palm\ frond}$	$CWD = (220.08 + 0.16 \times W_{fb} \times L_f)/1000$	[33]

AGB = dry above ground biomass (kg); ρ = wood density (g·cm^{-3}); D = diameter at breast height (cm); CD = collar diameter (cm); H = total height (m); BGB = below ground biomass (kg); DW = Deadwood; V = volume (cm^3); D_m= mid-diameter of the log/stump (cm); L = Length or height of log/stump (cm); CWD = Coarse Woody Debris (kg); W_{fb} = Width of frond base (cm); L_f = Length of frond (cm).

at three depth classes: 0 - 15, 15 - 30 and 30 - 45 cm. The five sub samples from each nested plot and depth class were mixed respectively to obtain one composite sample for each depth class with a total of 456 samples (38 land use × 4 plots × 3 depths × 1 composite sample), which were air dried, lightly grounded and sieved through 2 mm mesh for SOC estimation by rapid titration method [34] [35]. A total of 456 samples (38 land use × 4 plots × 3 depths) for soil bulk density (BD) measurements were obtained by inserting the soil core horizontally at the middle of each soil depth class [36]. Soil Organic Carbon Stock (Mg C ha^{-1}) for each land use type and depth up to 45 cm were computed as follows [37]:

$$\begin{aligned} SOC &= \sum_{horizon=1}^{horizon=n} SOC_{horizon} \\ &= \sum_{horizon=1}^{horizon=n} \left([SOC] \times \text{Bulk density} \times \text{Depth} \times (1 - \text{frag.}) \times 10 \right)_{horizon} \end{aligned} \quad (1)$$

where, SOC = representative soil organic carbon stock, Mg C ha^{-1}; $SOC_{horizon}$ = SOC stock for a constituent soil horizon, Mg C ha^{-1}; [SOC] = concentration of soil organic carbon, g C (kg soil)$^{-1}$; Bulk Density = soil mass per sample volume, Mg m^{-3}; Depth = horizon depth or thickness of soil layer, m; frag =% volume of coarse fragments/100, dimensionless.

2.4. Total Carbon Stock Change Estimation

Biomass carbon stock density (Mg C ha^{-1}) for each of the land use was estimated by using the default carbon content of 47% [37]. Above ground biomass (AGB) carbon stock comprised the sum of above ground estimates of trees, saplings/shrubs/bamboos, herbs, litter and deadwood; while below ground biomass (BGB) carbon stock comprised the below ground estimates of trees, saplings/shrubs/bamboos and herbs. Total carbon stock of each land use types was estimated as the sum of stock in the different carbon pools: vegetation biomass (AGB and BGB) and SOC stock (0 - 45 cm). Carbon stock change (Mg C ha^{-1}) after land use change is estimated depending on the changes in carbon stocks between prior (C_{LU0}) and immediate (C_{LUn}) land use type [38]. The carbon stock of prior land use type was set as the baseline for calculating the rate of carbon stock change (Mg C $ha^{-1}\cdot yr^{-1}$) in the conversion process, and thus the rate of change (R_{stock}) is calculated as follows:

$$R_{stock} = \frac{C_{LU0} - C_{LUn}}{\text{Age of } C_{LUn}} \quad (2)$$

2.5. Data Analysis

Analysis of variance (ANOVA) was tested at 95% confidence interval to study the effect of major land use sectors and land use types on plant density, basal area cover, soil BD, SOC concentration and carbon stock in various pools with general linear model (GLM) test. Tukey HSD (honestly significant difference) post hoc test was performed to indicate significant differences ($p < 0.05$) in carbon stock between the major land use sectors. All statistical calculations and figures were prepared using MS-Excel 2007 and IBM SPSS, ver.17.0.

3. Results and Discussion

3.1. Land Use Characteristics

Density and basal area of the trees and saplings/shrubs/bamboo showed significant variation ($p < 0.05$) in different land use types (**Table 2**). The highest tree density was encountered in arecanut plantation (1520 ha^{-1}) and the lowest in grassland (110 ha^{-1}). Saplings/shrubs/bamboo density was highest in bamboo forest (26,833 ha^{-1}) followed by dense forest (7817 ha^{-1}) and the lowest in oil palm plantation (1150 ha^{-1}). No trees and woody species were encountered in the Wet Rice Cultivation land use system. Plant density (individual ha^{-1}) variation in different land use types was greatly influenced by the intensity of anthropogenic interventions and management practices [39]. The presence of more number of trees in jhum fallow as compared to current jhum in the present study indicated a rapid recovery and high resilience of regenerating secondary forest, however tree growth was reportedly inhibited by shrub dominance [40]. Tree densities in old and young homegarden (513 and 408 ha^{-1} respectively) from the present study are higher in range with 239 - 319 ha^{-1} in Kerala [41] and 220 - 409 ha^{-1} in Philippines [42] which might be due to the maximum number of trees in lower girth classes (<90 cm dbh) and multi-strata canopy structure as reported from homegardens in Mizoram [43]. Low tree density (408 ha^{-1}) observed in open forest is attributed to deforestation prevalent due to land use change conversions [44]. Low density of bamboo (*Melocanna baccifera*) in the present study with 26833 culms ha^{-1} might be due to overexploitation of mature culms more than 4 years old leaving mostly the immature culms [45]. Amongst the forest, dense forest followed by open forest had showed significantly ($p < 0.05$) higher tree densities than bamboo forest and grassland. The basal area of trees was highest in oil palm plantation (117.4 $m^2\cdot ha^{-1}$) and the lowest in bamboo forest (1.8 $m^2\cdot ha^{-1}$). Dense forest observed the highest understorey woody

Table 2. Density (individual ha^{-1}) and Basal Area ($m^2 \cdot ha^{-1}$) of trees and saplings/shrubs/bamboo in different land uses in Mizoram, Northeast India.

Major Land Use Sectors	Land use Sub-types	Mean Age (years)	Trees		Saplings/Shrubs/Bamboo	
			Density	Basal Area	Density	Basal Area
Agriculture	Current Jhum (3)	1.7 ± 0.11	148 ± 18	3.9 ± 0.5	3700 ± 406	2.4 ± 0.6
	Jhum Fallow (3)	7.7 ± 0.4	219 ± 18	5.3 ± 0.6	3183 ± 219	0.8 ± 0.1
	Wet Rice Cultivation (3)	30.0 ± 0.0	0 ± 0	0.0 ± 0.0	0 ± 0	0.0 ± 0.0
Agroforestry	Old Homegarden (3)	17.3 ± 0.4	513 ± 21	14.9 ± 1.1	3700 ± 268	4.8 ± 1.0
	Young Homegarden (3)	10.8 ± 0.4	408 ± 13	10.0 ± 0.6	3517 ± 140	3.2 ± 0.2
Forest	Dense Forest (3)	41.7 ± 1.9	982 ± 37	36.2 ± 0.6	7817 ± 377	16.0 ± 0.9
	Open Forest (3)	41.7 ± 1.9	408 ± 13	19.8 ± 2.7	3433 ± 282	5.6 ± 0.7
	Bamboo Forest (3)	14.7 ± 0.4	194 ± 16	1.8 ± 0.2	26833 ± 662	14.3 ± 0.3
	Grassland (3)	23.7 ± 1.3	110 ± 10	3.1 ± 0.4	1883 ± 131	0.5 ± 0.1
Plantation	Arecanut Plantation (2)	16.5 ± 0.6	1520 ± 56	17.6 ± 1.0	1700 ± 217	0.4 ± 0.1
	Coffee Plantation (1)	50.0 ± 0.0	236 ± 8	62.0 ± 3.7	3600 ± 183	9.2 ± 0.6
	Mango Plantation (1)	15.0 ± 0.0	684 ± 12	24.7 ± 0.9	1450 ± 126	0.8 ± 0.1
	Oil palm Plantation (2)	7.0 ± 0.4	154 ± 4	117.4 ± 16.2	1150 ± 295	0.4 ± 0.1
	Orange Plantation (2)	10.5 ± 1.7	855 ± 34	7.7 ± 1.7	2750 ± 330	1.5 ± 0.6
	Pine Plantation (1)	12.0 ± 0.0	331 ± 41	22.8 ± 3.5	1600 ± 318	1.7 ± 0.2
	Teak Plantation (2)	14.0 ± 0.8	942 ± 78	40.1 ± 6.4	1875 ± 426	0.6 ± 0.1
	F-value	165.44	207.38	41.21	387.34	94.44
	p-value	0.000	0.000	0.000	0.000	0.000

Note: Values are mean followed by standard errors with ±. Results of one way ANOVA at 95% confidence level has been given in lower portion of the table. Figures within parenthesis are the number of permanent plots for each land use selected.

vegetation basal area with 16.0 $m^2 \cdot ha^{-1}$ followed by bamboo forest (14.3 $m^2 \cdot ha^{-1}$) and the lowest in arecanut and oil palm plantations (0.4 $m^2 \cdot ha^{-1}$).Basal area cover in different land use is dependent on species composition, tree size and growth pattern [46]. Despite low tree density, oil palm had the highest basal area (117.4 $m^2 \cdot ha^{-1}$) followed by coffee plantation comprising of matured trees (62.0 $m^2 \cdot ha^{-1}$) as a result of maximum number of trees in large circumference class. Whereas, the basal area in orange (7.7 $m^2 \cdot ha^{-1}$) and arecanut (17.6 $m^2 \cdot ha^{-1}$) plantations were low due to maximum distribution of stems in small size circumference class. Overall, average tree density and basal area was the highest in plantations with 745 ha^{-1} and 43.21 $m^2 \cdot ha^{-1}$ respectively showing significant differences with the other land uses. However, the Tukey HSD test indicate no significant differences in tree basal area cover among agriculture, agroforestry and forest ($p > 0.05$). Higher overall density and basal area in plantation compared to forest, agroforestry and agriculture indicate the efficiency of land use pattern where farmers follow intensive monoculture practices. However, land use conversion to plantation accompanies loss of biodiversity, vegetation structural changes, lower ground water table, etc. which further affects the ecosystem's carbon dynamics [47].

Soil bulk density (≤2 mm) and soil organic carbon (SOC) content also varied significantly ($p < 0.05$) amongst different land use types at various soil depths (**Table 3**). Agroforestry based land uses showed higher bulk density in all depths amongst the major land use sectors, however significantly ($p < 0.05$) different only in 0 - 15 and 15 - 30 cm. Soil bulk density was highest under old home garden (0 - 15 and 15 - 30 cm) and wet rice cultivation (30 - 45 cm) and lowest at all depth classes in the pine plantations. The higher soil bulk density found in all soil layers in agroforestry and plantation compared to forest can be attributed to more soil compaction as a result of frequent cultivation activities; however, similar bulk density values in agriculture with forest might be due to constant tillage practices adopted [48]. SOC concentration (%) decreased significantly ($p < 0.05$) with increasing soil depth in all land uses. The decreasing trend of SOC content with increasing soil depth, common in all mineral soils, is in agreement with earlier studies [36] [49]. This might be due to higher organic matter input and

Table 3. Soil Bulk Density of fine soil (<2 mm) and Soil organic Carbon (SOC) concentration at various depth classes (cm) in different land use systems in Mizoram, Northeast India.

Land use Sub-types	Bulk Density ($g \cdot cm^{-3}$)			SOC (%)		
	0 - 15	15 - 30	30 - 45	0 - 15	15 - 30	30 - 45
Current Jhum	0.43 ± 0.03	0.41 ± 0.03	0.38 ± 0.03	2.51 ± 0.35	2.01 ± 0.30	1.35 ± 0.13
Jhum Fallow	0.44 ± 0.05	0.42 ± 0.05	0.41 ± 0.05	2.12 ± 0.34	1.26 ± 0.10	0.83 ± 0.15
Wet Rice Cultivation	0.60 ± 0.01	0.66 ± 0.01	0.71 ± 0.03	2.90 ± 0.05	1.28 ± 0.06	0.69 ± 0.05
Old Homegarden	0.67 ± 0.04	0.68 ± 0.03	0.70 ± 0.03	2.44 ± 0.12	1.85 ± 0.15	1.66 ± 0.06
Young Homegarden	0.65 ± 0.01	0.67 ± 0.01	0.67 ± 0.02	1.65 ± 0.04	1.68 ± 0.07	0.94 ± 0.03
Dense Forest	0.40 ± 0.03	0.37 ± 0.02	0.38 ± 0.03	4.82 ± 0.45	3.72 ± 0.43	2.13 ± 0.21
Open Forest	0.50 ± 0.04	0.48 ± 0.04	0.50 ± 0.04	2.67 ± 0.10	1.67 ± 0.07	1.45 ± 0.06
Bamboo Forest	0.62 ± 0.01	0.60 ± 0.01	0.60 ± 0.01	1.28 ± 0.04	1.10 ± 0.04	0.90 ± 0.03
Grassland	0.47 ± 0.04	0.44 ± 0.05	0.43 ± 0.05	2.20 ± 0.36	1.19 ± 0.12	0.56 ± 0.03
Arecanut Plantation	0.56 ± 0.06	0.58 ± 0.07	0.58 ± 0.07	2.10 ± 0.11	1.68 ± 0.09	1.35 ± 0.07
Coffee Plantation	0.50 ± 0.00	0.51 ± 0.00	0.51 ± 0.00	2.01 ± 0.05	1.43 ± 0.04	0.97 ± 0.03
Mango Plantation	0.52 ± 0.00	0.54 ± 0.00	0.56 ± 0.00	1.08 ± 0.06	0.53 ± 0.14	0.38 ± 0.04
Oil palm Plantation	0.60 ± 0.02	0.56 ± 0.01	0.64 ± 0.05	1.87 ± 0.25	1.15 ± 0.04	0.96 ± 0.13
Orange Plantation	0.63 ± 0.03	0.66 ± 0.04	0.66 ± 0.05	1.76 ± 0.07	1.30 ± 0.09	0.95 ± 0.07
Pine Plantation	0.26 ± 0.00	0.26 ± 0.00	0.26 ± 0.00	3.40 ± 0.02	1.95 ± 0.06	1.41 ± 0.09
Teak Plantation	0.63 ± 0.07	0.65 ± 0.08	0.65 ± 0.08	2.11 ± 0.12	1.41 ± 0.19	0.90 ± 0.03
F-value	8.13	9.92	10.01	12.37	13.88	18.59
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Note: Values are mean followed by standard errors with ±. Results of one way ANOVA at 95% confidence level has been given in lower portion of the table.

more microbial activities in the upper soil layers by plant roots [50]. SOC content was highest in dense forest and lowest in mango plantation for all soil depth.SOC content was observed highest in forest with 2.74% and 1.92% for 0 - 15 and 15 - 30 cm soil depth respectively, showing significant ($p < 0.05$) differences only with plantations.SOC content showed significant ($p < 0.05$) differences only between agriculture and forest at 15 - 30 cm amongst the major land uses, highest being in agroforestry (1.30%). Plantations had the lowest SOC content of 2.0% and 1.36% in 0 - 15 and 15 - 30 cm soil depth respectively, while agriculture land use had the lowest SOC content (0.95%) at 30 - 45 cm soil depth. Average SOC content was found highest in forest significantly ($p < 0.05$) different from plantations only (**Figure 3**). Lower SOC content in plantation and agriculture as compared to forest and agroforestry could be due to less organic matter input and more soil disturbance resulting in high carbon mineralization rate as a result of cultivation [51] [52] [53]. Removal of biomass during harvesting and periodic tillage breaking up soil macro aggregates further reduces SOC content in agriculture and plantations [54].

The highest biomass (aboveground + belowground) was observed in coffee plantation (1065.44 Mg ha^{-1}) followed by teak plantation (487.03 Mg ha^{-1}), dense forest (341.38 Mg ha^{-1}) and the lowest in wet rice cultivation (7.63 Mg ha^{-1}). Amongst the forest, dense forest recorded the highest biomass with significant ($p < 0.05$) differences followed by open forest (178.54 Mg ha^{-1}), bamboo forest (14.60 Mg ha^{-1}) and grassland (39.22 Mg ha^{-1}). The allometric models and sampling approach used could have substantial influences on the results of ground based biomass estimates, and thus locally developed and calibrated models have the potential to minimize this uncertainty in biomass carbon accounting [28] [55] [56]. However, in our present study, we used the most recent model keeping into account of similarities in climatic and ecological parameters.

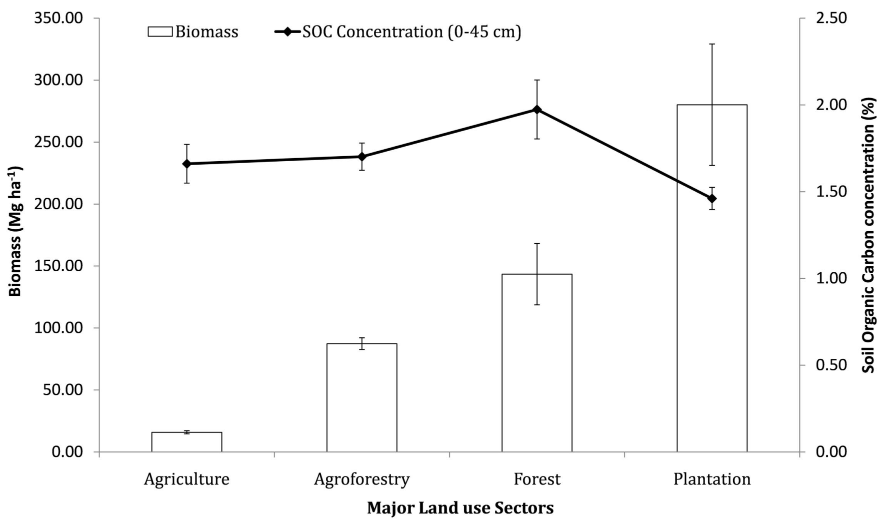

Figure 3. Biomass and Soil Organic Carbon concentration of major land use sectors in Mizoram, Northeast India. Different letters a, b, c, d indicate significant difference between the different major land use sectors.

Amongst the plantations, orange and oil palm plantations recorded the lowest biomass (34.85 and 47.19 Mg ha^{-1} respectively). On an average, highest biomass was found in plantation (280.13 Mg ha^{-1}) and lowest in agriculture (15.84 Mg ha^{-1}). Higher biomass in plantation, forest and agroforestry is mainly attributed by the presence of more woody vegetation in the form of trees and shrubs as compared to agriculture. Role of these tree-based systems in atmospheric carbon sequestration is well understood, especially in the tropics, however it depends on the structure and functions of the different components within the system affected by environmental and socio-economic factors [57] [58] [59].

3.2. Vegetation Biomass Carbon, SOC and Total Ecosystem Carbon Stock

Vegetation biomass carbon (VBC) stock comprising of all aboveground and belowground components of trees, saplings/shrubs/bamboos, herbs, standing litter and deadwood showed a significant ($p < 0.05$) variation amongst the different land use types (**Table 4**). VBC stock was highest in coffee plantation (500.76 Mg C ha^{-1}) and lowest in wet rice cultivation (3.59 Mg C ha^{-1}). Highest VBCS in

Table 4. Carbon stock (Mg C ha^{-1}) distribution in different pools of various land use types in Mizoram, Northeast India.

Land use Sub-types	VBC Stock	SOC Stock	TEC Stock	SOC: TEC (%)
Current Jhum	10.32^{abehij}	32.83^{abceghijklmno}	43.15^{abcdhijk}	75.47^{abgm}
Jhum Fallow	8.43^{abehij}	22.92^{abhiklmn}	31.35^{abdhijk}	73.33^{abglm}
Wet Rice Cultivation	3.59^{abehij}	46.21^{acdefghijkmno}	49.80^{abcdhijk}	92.75^{cg}
Old Homegarden	46.49^{abdehij}	59.07^{cdefgjkno}	105.56^{accdfhijk}	56.58^{dehlm}
Young Homegarden	35.62^{abdehij}	42.63^{acdeghijklmno}	78.25^{abdfhijk}	54.54^{dehl}
Dense Forest	160.45^{cfhk}	62.58^{cdfjo}	223.03^{eghl}	30.45^{fino}
Open Forest	83.92^{bdhij}	42.90^{acdeghijklmno}	126.82^{cdfghijk}	35.67^{fin}
Bamboo Forest	6.86^{abehij}	29.83^{abceghijklmno}	36.69^{abdhijk}	81.18^{abcgm}
Grassland	18.43^{abehij}	27.68^{abceghijklmno}	46.11^{abcdhijk}	56.30^{dehlm}
Arecanut Plantation	138.62^{cdfhj}	44.52^{acdefghijklmno}	183.14^{efghik}	23.65^{fijkno}
Coffee Plantation	500.76^{g}	33.38^{abcdeghijklmno}	534.14^{h}	6.33^{ijko}
Mango Plantation	81.45^{abdefhij}	16.00^{abeghijklmn}	97.45^{abcdfghik}	16.57^{fijko}
Oil palm Plantation	22.18^{abdehij}	36.73^{abceghijklmno}	58.90^{abcdfhijk}	60.51^{dhlm}
Orange Plantation	16.38^{abdehij}	39.49^{abcdeghijklmn}	55.87^{abcdfhijk}	69.92^{bdeghlm}
Pine Plantation	62.39^{abdefhij}	26.05^{abceghijklmno}	88.44^{abcdfghijk}	30.53^{fikno}
Teak Plantation	224.68^{ck}	44.66^{acdefghijkmno}	269.33^{cehl}	17.18^{ijkno}
F-value	50.28	8.18	47.69	75.47
p-value	0.000	0.000	0.000	0.000

Note: Values are mean and results of one way ANOVA at 95% confidence level has been given in lower portion of the table. Superscripted different letters indicate significant difference between the different land use types. VBC—Vegetation Biomass Carbon; SOC—Soil Organic Carbon; TEC—Total Ecosystem Carbon.

coffee plantation (500.76 Mg C ha^{-1}) was mainly contributed by the mature big trees (50 years old) present there as shade trees. Teak plantation, dense forest and arecanut plantations had a fairly higher biomass carbon storage than other land uses. The higher value of VBCS in current jhum in comparison to jhum fallows was attributed by the presence of more deadwood biomass in the former following its conversions from forest. Orange and oil palm plantations had lesser VBCS amongst plantations owing to its age and species composition, in accordance to low values 76.3 Mg C ha^{-1} for a 25 year old orange plantation and 45.3 Mg C ha^{-1} for a 23 years old oil palm plantation reported from Ghana [60]. VBC stock was the highest in plantations (131.66 Mg C ha^{-1}) and follows the trend: plantation > forest > agroforestry > agriculture (**Table 5**). SOC stock was highest in agroforestry (50.85 Mg C ha^{-1}) and followed the trend: agroforestry > forest > plantation > agriculture (**Table 5**). Highest VBCS in plantations from other land uses signifies the great potential for biomass carbon sequestration through effective and proper management planning.

The SOC stock up to 45 cm depth ranges from 16.00 (mango plantation) to 62.58 Mg C ha^{-1} (dense forest) and the total ecosystem carbon (TEC) stock which is the sum of VBC and SOC stocks ranged from 31.35 (jhum fallow) to 534.14 Mg C ha^{-1} (coffee plantation) (**Table 4**). Differences in total ecosystem carbon (TEC) stock amongst land uses have been attributed to differences in VBCS and SOCS. The distributions of SOC proportion at different depths varied significantly in the different land use types (**Figure 4**). Overall, an average of 46.58%, 31.33% and 22.09% of SOC stock were distributed within 0 - 15, 15 - 30 and 30 - 45 cm soil depths respectively in all the land use systems. Location, soil type, tree species and plantation management system influencing soil bulk density and SOC content might be responsible for SOC stock differences between

Table 5. Vegetation Biomass Carbon (VBC), Soil Organic Carbon (SOC) and Total Ecosystem Carbon (TEC) stock expressed in Mg C ha^{-1} of major land use sectors in Mizoram, Northeast India.

Major Land Use Sectors	VBC stock			SOC stock	TEC stock	SOC: TEC (%)
	AGB	BGB	Total			
Agriculture	5.87^{ab} (0.50)	1.57^{ab} (0.15)	7.44^{ab} (0.62)	33.99^{acd} (1.85)	41.43^{ab} (1.55)	80.52^{a} (1.76)
Agroforestry	31.24^{abc} (1.69)	9.82^{abc} (0.59)	41.06^{abc} (2.22)	50.85^{bc} (2.05)	91.91^{abc} (3.70)	55.56^{bc} (1.21)
Forest	50.94^{bc} (8.79)	16.47^{bc} (2.85)	67.41^{bc} (11.63)	40.75^{abcd} (3.29)	108.16^{bc} (13.03)	50.90^{bc} (3.35)
Plantation	98.45^{d} (17.26)	33.21^{d} (5.32)	131.66^{d} (0.46)	36.93^{abcd} (22.56)	168.59^{d} (23.25)	36.00^{d} (3.70)
F-value	12.12	14.63	14.63	5.37	11.40	35.33
p-value	0.000	0.000	0.000	0.000	0.000	0.000

Note: Values are mean followed by standard errors within parenthesis. Results of one way ANOVA at 95% confidence level has been given in lower portion of the table. Superscripted different letters indicate significant difference between the different major land use sectors.

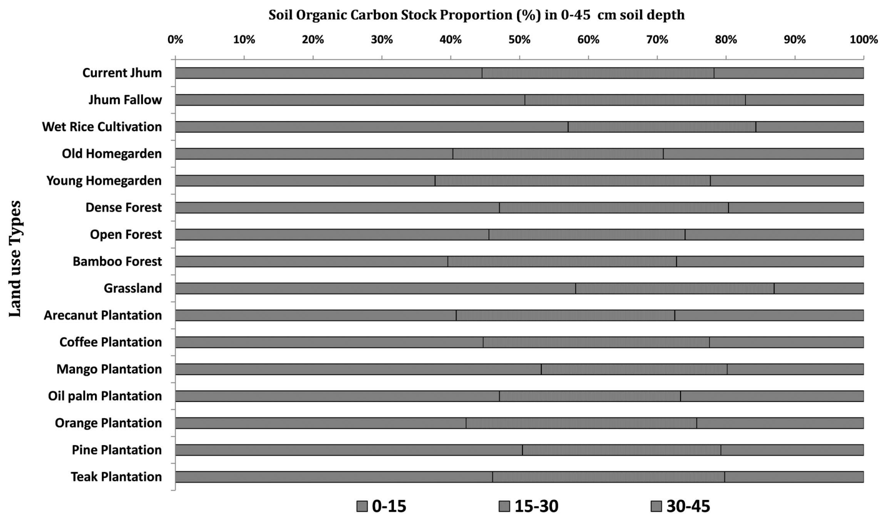

Figure 4. Soil organic carbon stock proportion at different depths across various land use types in Mizoram, Northeast India.

land uses and all the three soil depths [61] [62]. SOC stocks in grassland are low in comparison to other forest land use types, as reported from other parts of India [63]. In the present study, on an average more than one-third (46.58%) of SOC was stored in the top 15 cm depth relative to the total depth studied (0 - 45 cm), being the highest in grassland (58.14%) followed by wet rice cultivation (57.05%) in accordance to SOC vertical distribution pattern reported from other studies across the world [64] [65]. SOC stocks distribution at various soil depths except 0 - 15 cm across land use sectors indicated a significant decrease with increasing depth (**Figure 5**). Understanding the SOC vertical pattern of different land uses will enhance our knowledge of carbon dynamics along a profile and its potential response to climate change [66]. SOC stock in agroforestry was significantly ($p < 0.05$) different only with agriculture and plantation. Agroforestry stored the highest SOC (50.85 Mg C ha^{-1}) stock compared to forest and plantations and the lowest in agriculture for a soil depth of 0 - 45 cm, which is comparable to findings from other studies where traditionally managed agroforestry systems have higher SOC storage than agricultural systems [17] [67] which may be due to differences in species diversity, composition and intensity of management practices leading to soil disruptions [68].

The SOC: TEC stock ratio was highest for wet rice cultivation (92.75%) and the lowest was for mango plantation (16.57%) across the land use types (**Table 4**). SOC: TEC was the highest for agriculture (80.52%) followed by agroforestry (55.56%), and lowest in plantation (36.00%) being significantly ($p < 0.05$) different from other major land uses (**Table 5**) which indicates the direction of change in carbon storage in different pools. In the present study, the higher proportion of SOC with corresponding low floor biomass and vegetative cover makes the land use more prone to SOC losses through accelerated soil erosion [69]. Low proportion of SOC in plantations may be due to constant removal of litter biomass through weeding, cleaning and harvesting. The ratio of SOC: TEC

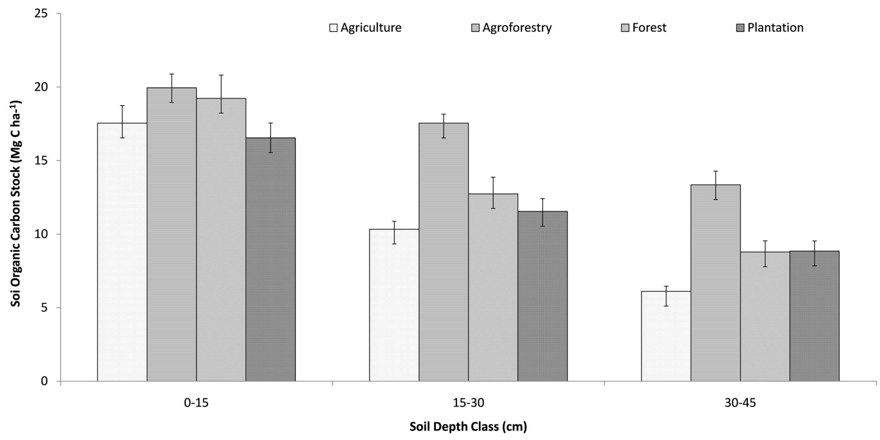

Figure 5. Variation of Soil Organic Carbon stock (Mg C ha^{-1}) across major land use sectors in various soil depths of Mizoram, Northeast India. Different letters indicate significant differences with respect to land use and depth at $p \leq 0.05$. Letters a, b, c indicate the variation within land uses in different depth, while letters x, y, z indicate variation among the land uses in each depth.

implies the need for management practices to maintain the balance between plant biomass productivity and microbial decomposition for SOC stock following land use changes in the wake of impending climate change [70]. It is important to evaluate SOC storage potential and improve the biological cycle of ecosystems to maintain an equilibrium fixation and storage [71].

3.3. Carbon Stock Change Estimation

Land use changes showed positive and negative carbon stock change rates depending on land use type (**Table 6**). Positive rate of carbon stock change was observed in all the pools when current jhum was converted to teak, arecanut, young home garden and oil palm plantations. However, the conversion of current jhum to grassland witnessed a loss of SOC stocks (−0.22 Mg C $ha^{-1} \cdot yr^{-1}$) although the vegetation biomass carbon stock gained (0.34 Mg C $ha^{-1} \cdot yr^{-1}$). Land use conversions may result either a decrease [72] or an increase in rate of SOCS change [73]. The negative rate of change following conversions of dense and open forest to current jhum and grasslands observed in the present study is similar to reports from China [74]. The establishment of arecanut and oil palm plantations from jhum fallows and grassland had also indicated a gain in carbon stock change rate of all pools. Establishment of oil palm plantations from old home garden and open forest also observed negative TECS change rate at −6.67 and −9.70 Mg C $ha^{-1} \cdot yr^{-1}$ respectively. The conversion of open forest and old homegarden to oil palm plantations also contributed carbon stock losses in all pools with TECS change rate of -6.67 and −9.70 Mg C $ha^{-1} \cdot yr^{-1}$ respectively. The rate of carbon stock change after conversion of different land use types to one or the other showed a wide range of variation (**Figure 6**). The highest positive TECS change rate was observed in teak plantations (10.86 Mg C $ha^{-1} \cdot yr^{-1}$) and the least negative TECS change rate in current jhum (−53.50 Mg C $ha^{-1} \cdot yr^{-1}$).

Table 6. Changes in Soil Organic Carbon (SOCS), Vegetation Biomass Carbon (VBCS) and Total Ecosystem Carbon (TECS) stock expressed in Mg C $ha^{-1} \cdot yr^{-1}$ after conversion of some important land use types in Mizoram, Northeast India.

Land Use Changes Type	SOCS Changes				VBCS Changes			TECS Changes
	0 - 15 (cm)	15 - 30 (cm)	30 - 45 (cm)	0 - 45 (cm)	Above ground	Below ground	Total	
CJ to Teak	0.42	0.29	0.13	0.84	11.32	3.99	15.31	16.16
JF to Arecanut	0.40	0.41	0.50	1.31	5.67	2.22	7.89	9.20
CJ to Arecanut	0.21	0.19	0.31	0.71	5.57	2.21	7.78	8.48
GL to Arecanut	0.13	0.37	0.52	1.02	5.19	2.09	7.28	8.30
OF to Coffee	−0.09	−0.03	−0.07	−0.19	6.45	1.89	8.34	8.15
OHG to Arecanut	−0.34	−0.24	−0.30	−0.88	3.91	1.67	5.58	4.70
JF to DF	0.43	0.32	0.20	0.95	2.74	0.91	3.65	4.60
BF to DF	0.42	0.26	0.10	0.79	2.77	0.92	3.69	4.47
JF to YHG	0.42	0.91	0.52	1.85	1.93	0.62	2.55	4.40
CJ to DF	0.36	0.23	0.12	0.71	2.70	0.90	3.60	4.32
JF to Oil Palm	0.81	0.33	0.83	1.97	1.47	0.50	1.96	3.94
CJ to YHG	0.14	0.56	0.22	0.92	1.76	0.61	2.37	3.29
CJ to Oil Palm	0.38	−0.20	0.38	0.56	1.22	0.47	1.69	2.25
GL to Oil Palm	0.17	0.24	0.88	1.29	0.33	0.21	0.54	1.83
YHG to OHG	0.45	0.06	0.44	0.95	0.49	0.14	0.63	1.58
CJ to GL	0.06	−0.13	−0.15	−0.22	0.26	0.08	0.34	0.13
DF to OF	−0.24	−0.21	−0.03	−0.47	−1.37	−0.47	−1.84	−2.31
OF to Pine	−0.53	−0.39	−0.48	−1.4	−1.35	−0.44	−1.79	−3.20
OF to GL	−0.15	−0.18	−0.32	−0.64	−2.07	−0.69	−2.77	−3.41
OHG to Orange	−0.68	−0.46	−0.73	−1.87	−2.26	−0.61	−2.87	−4.73
DF to WRC	−0.10	−0.27	−0.17	−0.55	−5.23	−3.92	−1.31	−5.77
OHG to Oil Palm	−0.93	−1.20	−1.06	−3.19	−2.68	−0.79	−3.47	−6.67
DF to GL	−0.56	−0.54	−0.37	−1.47	−4.49	−1.51	−6.00	−7.48
OF to Oil Palm	−0.32	−0.37	−0.19	−0.88	−6.68	−2.14	−8.82	−9.70
OF to CJ	−2.95	−0.70	−2.39	−6.04	−33.17	−10.99	−44.16	−50.20
DF to CJ	−8.90	−5.86	−3.09	−17.85	−90.08	−67.46	−22.62	−107.93

CJ—Current Jhum; JF—Jhum Fallow; WRC—Wet Rice cultivation; YHG—Young Homegarden; OHG—Old Homegarden; DF—Dense Forest; OF—Open Forest; BF—Bamboo Forest; GL—Grassland

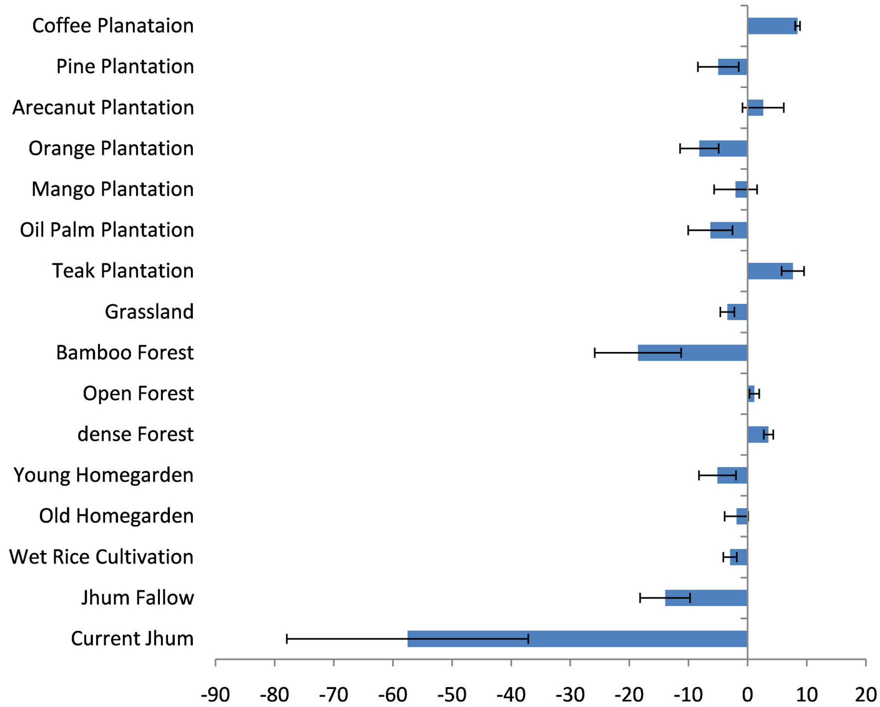

Figure 6. Average Total Ecosystem Carbon Stock change (Mg C $ha^{-1} \cdot yr^{-1}$) after conversion in different land use types of Mizoram, Northeast India. Different letters indicate significant difference between the different land use types.

The highest TECS rate was computed at 6.61 Mg C $ha^{-1} \cdot yr^{-1}$ when agriculture was converted to plantation, and the least was observed when plantation converted to agriculture with −36.27 Mg C $ha^{-1} \cdot yr^{-1}$. Conversion of jhum fallow and bamboo forest to dense forest also showed positive carbon stock change rates. Conversion of land uses to agriculture showed a negative TECS change rate of −22.04 Mg C $ha^{-1} \cdot yr^{-1}$, while land use conversion to plantation attracts a positive TECS change rate of 3.59 Mg C $ha^{-1} \cdot yr^{-1}$ (**Figure 7**). Highest positive TECS change rate was observed when agriculture was converted to plantations (6.61 Mg C $ha^{-1} \cdot yr^{-1}$) followed by agroforestry (3.58 Mg C $ha^{-1} \cdot yr^{-1}$) and forest (1.57 Mg C $ha^{-1} \cdot yr^{-1}$), while negative values were observed following conversion of land uses to agriculture. The conversions of current jhum, jhum fallow and grassland to arecanut and oil palm plantation crops had observed a positive SOCS change rate as reported from other similar studies [75] [76]. SOCS change rate showed a negative value with major land use conversions to agriculture; agroforestry and forest to plantation; and agroforestry to forest (**Table 7**). Whereas, SOCS change rate were positive in conversion of land uses to agroforestry; agriculture and plantation to forest; and agriculture to plantation. A positive SOCS change rate of 0.33 Mg C $ha^{-1} \cdot yr^{-1}$ in the top 20 cm soil was reported following conversion of cropland to forest in China which is similar to the findings from the present study [77]. The establishment of current jhum and grassland from dense and open had resulted manifold losses in SOCS, however the rate of change was comparatively lower in grassland similar with findings reported

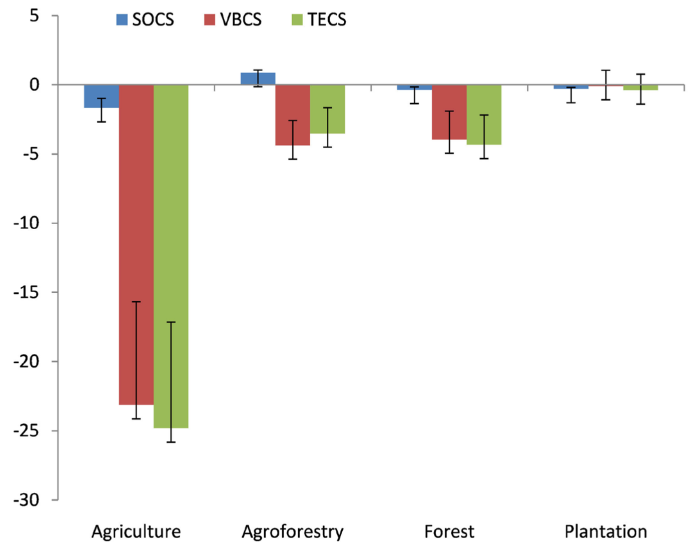

Figure 7. Average carbon stock change rate (Mg C $ha^{-1}\cdot yr^{-1}$) after conversion in different major land use sectors of Mizoram, Northeast India. Different letters indicate significant difference between carbon pools among the land use. SOCS—Soil organic carbon stock; VBCS—Vegetation biomass carbon stock; TECS—total ecosystem carbon stock.

Table 7. Averaged changes in Soil Organic Carbon (SOCS), Vegetation Biomass Carbon (VBCS) and Total Ecosystem Carbon (TECS) stock expressed in Mg C $ha^{-1}\cdot yr^{-1}$ after conversion of major land use sectors in Mizoram, Northeast India.

Major Land Use Sector Changes	SOCS Changes	VBCS Changes	TECS Changes
Agriculture to Plantation	0.06 ± 0.24^{abdef}	6.54 ± 1.04^{ab}	6.61 ± 1.10^{ab}
Agroforestry to Plantation	-1.24 ± 0.30^{abcdef}	3.95 ± 1.51^{ab}	2.71 ± 1.70^{ab}
Agriculture to Forest	0.09 ± 0.17^{abdef}	1.48 ± 0.44^{ab}	1.57 ± 0.56^{ab}
Forest to Plantation	-0.46 ± 0.26^{abdef}	1.92 ± 1.54^{ab}	1.46 ± 1.74^{ab}
Agriculture to Agroforestry	1.13 ± 0.36^{abdef}	2.45 ± 0.13^{abc}	3.58 ± 0.27^{abc}
Agroforestry to Forest	-0.58 ± 0.29^{abdef}	0.15 ± 0.75^{ab}	-0.43 ± 1.02^{abc}
Forest to Agroforestry	0.62 ± 0.44^{abdef}	-2.09 ± 1.83^{abc}	-1.48 ± 2.26^{abc}
Plantation to Forest	0.07 ± 0.11^{abdef}	-4.14 ± 1.52^{ab}	-4.07 ± 1.57^{ab}
Plantation to Agroforestry	1.10 ± 0.23^{abdef}	-8.31 ± 3.48^{abc}	-7.21 ± 3.53^{abc}
Agroforestry to Agriculture	-4.87 ± 2.37^{acd}	-7.98 ± 3.46^{abc}	-12.85 ± 5.75^{abc}
Forest to Agriculture	-2.30 ± 1.61^{abdf}	-14.69 ± 7.80^{abc}	-16.99 ± 9.35^{abc}
Plantation to Agriculture	-0.68 ± 0.78^{abef}	-35.59 ± 14.72^{bc}	-36.27 ± 14.86^{bc}
F-value	4.05	3.89	3.83
p-value	0.000	0.000	0.000

Note: Values are mean followed by standard errors with ±. Results of one way ANOVA at 95% confidence level has been given in lower portion of the table. Superscripted different letters indicate significant difference between the different major land use sectors.

from tropical forest soils [78]. This implies the degradation impacts of slash and burn practices involved with shifting cultivation (jhum) in the tropics where land become scarce and leads to reduced fallow periods [79], thereby the natural nutrients recovery for crop production is not complete and the intensification of shifting cultivation on the same land makes it become unsustainable. In the present study, establishment of plantations following conversions from forest and homegardens observed a negative SOCS change rate similar to findings reported by other studies [80]. SOCS changes due to land use change are caused by changes in soil carbon inputs (litter quality and quantity) and outputs (alterations in decomposition processes) when one vegetation is replaced by the other [81]. VBCS change rate showed positive gain following conversion of land uses to plantation; agriculture and agroforestry to forest; and agriculture to agroforestry. Conversion of land uses to agriculture; forest and plantations to agroforestry; and forest to agroforestry had exhibited a negative VBCS change rate. This suggests that the tree-based systems have substantially enhanced the ecosystem carbon storage and aid to climate change mitigation/adaptation. In the present study, the absolute carbon stock change rates following land use change were higher in VBCS than SOCS, except for land use conversion from agroforestry to forest. This signifies the importance and vulnerability of vegetation biomass pool whose sequestration is greatly affected by land use management implications subject to changing climate and soil conditions. Therefore, land uses which are degraded physically, chemically and biologically following conversions need to be restored through tree-based systems. The study results indicate ecosystem carbon sequestration rates to be significantly high in plantations, however they have been often associated with environmental issues of biodiversity losses and disruption of ecological cycle [82]. Thus, the land use change management needs to focus and identify potential systems such as agroforestry systems which would preserve species, accumulate soil carbon and tree biomass in the longer run.

4. Conclusion

Diversified land use patterns in different sectors: agriculture, agroforestry, forest and plantations have been prevalent in Mizoram, Northeast India which is influenced by a combination of different reasons such as resource scarcity, market opportunities, policy interventions, increased vulnerability to resource access and change in attitudes. These land use changes in various forms affect the total ecosystem carbon storage whereby management practices involved induced great differences amongst carbon pools. The highest carbon stock was observed in plantations and the lowest in agriculture. Both biomass and soil carbon stocks were observed higher in tree-based land use systems compared to agriculture. The SOC stock proportionately contributed more in agriculture systems and less in plantations. Among all the managed plantations, coffee plantations have a dense canopy with large diameter shade trees and exhibited the highest carbon storage indicating the best management practices adopted. Absolute carbon stock change rate following conversions were maximum in agriculture with losses in all carbon pools. Conversions to agroforestry attract a positive change soil carbon pool; whereas conversions to plantations exhibited negative change in soil and a positive rate of change in biomass carbon with an overall gain in total ecosystem carbon stock. However, considering environmental management and conservation issues, the rampant conversion of land uses to plantation should not be encouraged. In all the land use changes, the rate of change is comparatively higher in biomass than soil carbon pools, which signifies that maximum gain/loss in total ecosystem carbon stock, can be achieved through the management perspectives to maintain vegetation type and cover in the system. Increase in vegetation and floor biomass will also eventually lead to soil carbon enrichment. Open forest and jhum fallows should be kept undisturbed and allowed to recover fully through natural and assisted regeneration to dense forest. Selective land use and adoption of scientific cultivation practices should be the efforts of policy makers in tune with climate and carbon mitigation challenges. Thus, agroforestry systems and plantations equipped with sustainable management practices could be adopted in large scale for restoration of degraded lands in Mizoram.

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Conflicts of Interest

No potential interest of conflict was reported by the authors.

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