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# Tree Diversity and Ecosystem Carbon Stock Patterns Along Selected Land Use, Land Cover Systems in Tripura, Northeastern India

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## ABSTRACT

Natural Forests (NF), Managed Plantations (MP) and Jhum Fallow (JF), including their soils are important stocks and sequester of Carbon . Plant diversity, biomass and total ecosystem carbon in these three lands use systems of Tripura, northeast India, were estimated during 2013 using 100×10 m transects where trees were assessed in ten 10×10 m contiguous quadrats, shrubs in 5×5m quadrats, and herbs and litter in 1×1m nested quadrats. Soil was sampled and the understorey biomass was estimated in each transect. Soil Organic Carbon (SOC) stocks were estimated at five depths in each plot. Tree species diversity was significantly high ($p < 0.0001$) in NF (83.1), followed by JF (3.8) and MP (1.8). Tree biomass (Mg $ha^{-1}$) ranged from 127.22 (NF) to 5.78 (JF) and varied ($p< 0.0001$) among the three land uses. Higher C stock was estimated in NF (213.16) than in JF (159.28) and MP (131.76). Conversion of NF into JF and MP results in enormous loss of ecosystem organic C stock by 33.82- 61.77%. The C storage potential in these land uses may increase over time, if managed properly.

Key Words: Land Use; Diversity; Biomass; Soc; Ecosystem Carbon Pool; Edaphic Properties.

## INTRODUCTION

Land use is the observed physical or biological cover over the earth's surface (Brady 2016). Demand for food, fiber and timber of the growing population has led to conversion of land use pattern of tropical forests (Lambin et al. 2001). The distribution of biodiversity, biomass and carbon in a land use is influenced by a range of environmental factors such as climate, soil and disturbance (Talbot 2010). Land use conversion has serious implications, on carbon dynamics, e.g. emission of 1.7±0.8 giga tons carbon per year (Pg C $yr^{-1}$) and 1.6 Pg C $yr^{-1}$ during 1980s and 1990s has been attributed to the effects of land use changes (Houghton et al. 2000). About two-thirds of terrestrial carbon are stored in different terrestrial pools like rocks and sediments and are sequestered in the standing forests, forest understorey plants, leaf and forest debris, and in forest soils (Sedjo et al. 1998). Carbon content and its distribution on forest ecosystems are important components of the global carbon budget, and are thus part of the basis for predicting future climate change (Dixon et al. 1994). In the soil under tropical rainforest, the Soil Organic Carbon (SOC) pool is almost equal to that of aboveground biomass (Sombroeck et al. 1993) and SOC pool and soil properties are heavily influenced by land use (Ussiri et al. 2006). Although SOC and the biomass carbon share is only 6.06% and 1.68% of total terrestrial carbon pool (Bouwmann 1990), it is highly dynamic in nature, i.e. biomass on the earth's surface can fluctuate from 0-400 Mg $ha^{-1}$ (Houghton 2005). Out of the total carbon stored in an ecosystem, 89 % loses are due to the loss of living biomass, which is an indicator of eco-system services (Houghton 2005). Biomass restoration is being looked as one of the options for carbon sequestration (IPCC 2000). Shrinking natural forest necessitates us to look for potential of the man made plantation for sequestering carbon both in soil and biomass. Growing forests and tree plantations and their soils are major sinks of atmospheric carbon (Schimel et al. 2001). To restore carbon in biomass as of 2005, roughly 140 million ha were afforested with plantations, with additional 2.8 million ha afforested per year (FAO 2006b).

The effects of land use change on biodiversity and SOC are of concern in the context of international policy agreements on greenhouse gas emissions mitigation. Carbon dynamics in terrestrial ecosystems, and particularly in forest ecosystems, have emerged as an important field of research since global warming became a recognized problem in recent years (IPCC 1996). In India, numerous experiments have quantified either diversity variables or biomass structure; and very few studies have explained both diversity and biomass or carbon stock along different forest ecosystems. However, it is widely recognized that, Northeast India represents several virgin, natural, semi-natural and modified ecosystems due to greater variation in physiographic, climatic, edaphic and anthropogenic factors. Forest inventories in Northeast India are perceived as quantitative and qualitative vegetation assessments. Relatively very little information has been gleaned on the forest biomass and carbon allocation estimation, especially keeping mind various land use land cover types. Hence, there is a need to calculate species diversity, forest structure, plant biomass accumulation and carbon storage for better understanding of different forest ecosystems in this region. The biomass estimation with the help of space-borne image is rapid and cost effective, but less reliable in close canopy and high biomass forests (Waring et al. 1995). In Tripura, NF (Natural Forest), MP (Managed Plantation) and Jhum cultivation/fallows are the prominent land use and are having an area of 62.84 M ha, 4.92 M ha and 2.42 M ha respectively (NRSC 2011). Forest area and vegetation cover of the state have shrunk by about 22.9% and 12.4% respectively in the last 50 years (SFR 2011). Hence, we tried (1) to estimate the plant diversity and biomass of different land use systems, (2) to quantify the SOC stock and some selected edaphic parameters and (3) to establish a relationship between tree diversity, plant biomass and SOC in three important land use systems. We assumed that, conversion of NF into MP and JF has led to significant change in tree diversity and ecosystem organic carbon stocks.

## MATERIALS AND METHODS

### Study Area

Tripura is the India's third smallest hilly state, located in the northeast part of the country. The State lies approximately between the latitudes 22° 56' and 24°32' N and between longitudes 91° 0' and 92° 22' E in the north east extension ranges of the Himalaya. It is bounded on the North West, south and southeast of Bangladesh, whereas in the east it has a common boundary with Assam and Mizoram. The pre-independence princely state of Tripura was once an abode of rich tropical forests inhabited by a wide variety of wildlife. It is the land of high hills, hillocks and patches of plains interspersed with rivers and valleys having moderately warm and humid climate. The present study was conducted in North, Unakoti and Dhalai Districts of Tripura. Three most abundant lands uses viz. Natural Forest (NF), 25-yr-old *Shorea robusta* managed plantation (MP) and one year old Jhum Fallow (JF) were selected for the study. The location of the study areas is given in Figure 1.

### Climate

The climate of the region may be divided into four seasons. December to February is the cold season, which is followed by summer season (March-May). June to September is the monsoon season and October to November is the post monsoon period. The cold weather has a daily maximum temperature of 26 $^0$C and minimum of 8-4 ºC. During summer season (March-May), maximum temperature is 38 ºC. Humidity is high throughout the year; during summer season the relative humidity ranges 50 to75%, while in monsoon period it is over 85%. The state receives an average of 2479 mm rain

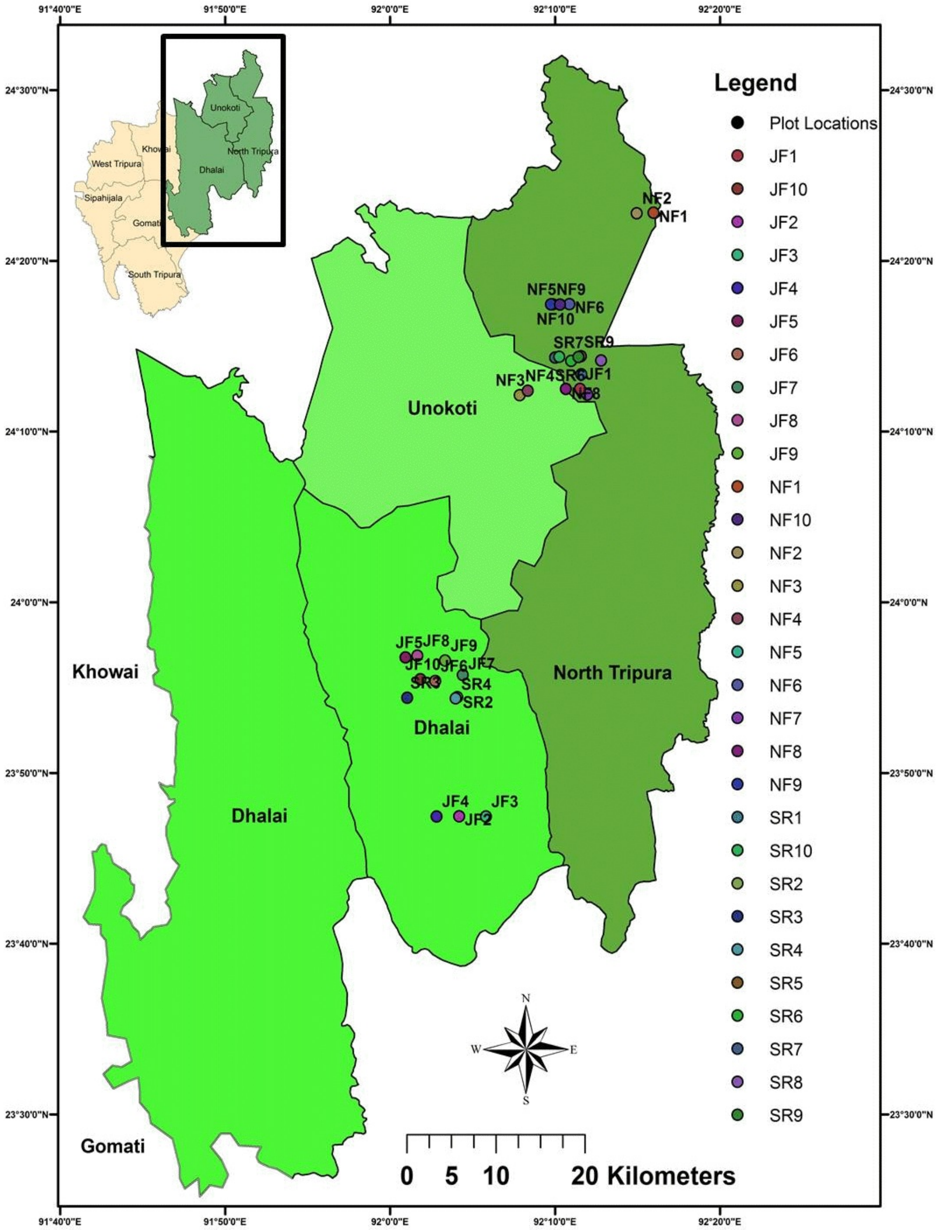


Figure 1. Study area in Tripura, Northeast India, showing location of sampling plots representing three land use-land cover

every year. About 63% of the annual rainfall occurs during the south-west monsoon period. The mean wind speed is 7.1 km $hr^{-1}$, with a maximum of 13.1 km $h^{-1}$ in May and a minimum of 3 km $h^{-1}$ in December. The monthly, annual average temperature; relative humidity and precipitation recorded at the Indian meteorological station, Agartala is given in (Figure 2).

Due to high precipitation and high humidity Tripura is floristically very rich and largely covered with evergreen and moist deciduous forests. The geology of Tripura comprises of sedimentary rocks which are grouped into the Suma group (further Dupitilla group). The Sedimentary group ranges in age from mid-Tertiary (15M years to recent (<1 M years old). The soil of the state is lateritic in the hills and hillocks and alluvial in plains and foothills and very rich in iron oxides. According to the 2011 census, the total population of the state was 3.671 million. The indigenous tribal populations living in the hills have traditionally derived their livelihood from floral and faunal resources of the state.

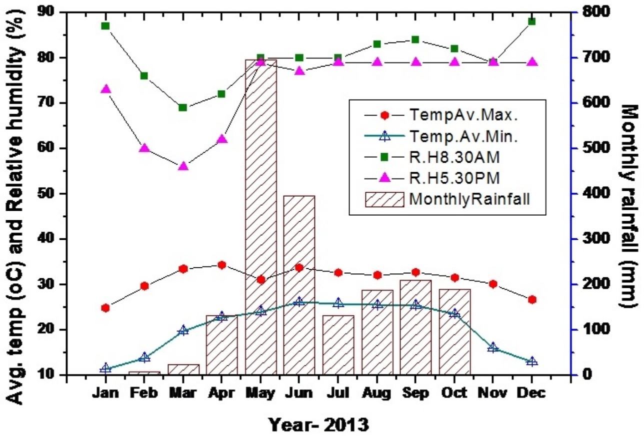


Figure 2. Meteorological parameters at the station nearest to the study area

## Land Use and Land Cover (LULC)

NF is the most important land use-land cover of the state. The forests in the state are mainly tropical evergreen, semi evergreen and moist deciduous and cover 77.18% of total geographical area. The state has 4686 km$^2$ area under moderately dense forests and 3,182 km$^2$ area under open forest (FSI 2011). However, the actual forest area is about 60.02% of its geographical area, including Reserve Forests (66.33%), Protected Forests (0.03%) and Unclassed Forests (33.64%). MP have different choices of commercial timber yielding species like *Shorea robusta* C.F. Gaertn, *Tectona grandis* L.f., *Gmelina arborea* Roxb., *Syzygium cumini* (L.) Skeels., *Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg., *Cassia fistula* L., *Lagerstroemia parviflora* Roxb., *Dipterocarpus turbinatus* C.F.Gaertn., *Litchi chinensis* Sonn. and *Anacardium occidentale* L. According to State of Forests Report (2013), total area under plantation forest was 30,915 ha, 55,485 ha, 2, 25 078 ha and 2, 98,851 ha in the years 1972, 1978, 1998 and 2013, respectively. Jhum cultivation is the major form of agroforestry practiced in the region. The entire socioeconomic structure is woven around this system and farmers maintains high species diversity. According to one estimate shifting cultivation, accounts for around 60% of the tropical deforestation. It is carried out by between 300 to 500 million small farmers in the tropics, to undertake subsistence agriculture. However, with reduced shifting cultivation cycle, the system has become ecologically unsound and has resulted in forest degradation. Under the rehabilitation scheme, the government has given land on lease (*patta*) to Jhumia (more than 6000 families given about 3000 ha of forest land). Until 2013, a total of 1,20,418 families had 1,69,292 ha of land on lease. Due to shortening the period, lack of labour force and changing source of livelihood by tribal people, JF lands are scattered all over the hills of the state (Gupta 2000).

## Field Sampling

After a reconnaissance survey and selection of each land use, we adopted a stratified random sampling method for the study. Ten 100x10 m transects were laid in each of the three LULC (NF, MP and JF)". Each transect were sub-divided into ten 10x10 m, 5x5 and 1x1 m quadrats for sampling tree diversity and shrubs, herbs and litter and deadwood biomass. Thus, each transect represented an area of 0.1 ha and encompassed 10 contiguous subplots (MacDicken 1997, FSI 2002). Due to the distribution of these land uses over a large area, we laid transects in each land use in diverse locations to increase their representation. All woody individuals at ≥10 cm girth over bark at 1.3 m height were measured. Plant specimens were identified with the help of The Flora of Tripura State (Deb 1981 and 1983) and the Flora of Assam (Kanjilal et al. 1934–1940). The reference herbarium was deposited in the herbarium of Botany Department, Tripura University. For the study of SOC content and other properties of soil, 5 random soil samples were taken at the upper, middle and lower levels of each LULC with the cylindrical soil corer of known volume during February-March 2013. The soil cores were divided into 0-10cm, 10-30cm, 30-50cm and 50-100cm depth classes. Composite samples were prepared, air-dried, ground and passed through a 2 mm sieve and for each LULC five replicates of each composite were analyzed.

## Diversity Indices

Field data were quantitatively analyzed for density and basal area (Curtis and McIntosh 1950, Mueller–Dombois and Ellenberg 1974). Species diversity for each forest patch was determined by Shannon and Weiner (1963) index and Index of Dominance of the community was calculated as per Simpson (1949). The index of species richness (Menhinick 1964) and evenness of the community (Pielou 1966) were also calculated.

### Tree and Understory Biomass Estimation

Tree data collected for the analysis of community structure were also used for estimation of aboveground tree biomass (AGTB), using regression equation for the moist region (rainfall 150-400 cm per year):

$$Y = 42.69-12.800(D) +1.242(D^2);$$

where, Y= biomass per tree in kg, D = dbh in cm; and $r^2$= 0.84. (Brown 1989). The dbh ranged from 5 to148cm, and the number of trees was170.

The belowground tree biomass (BGTB) was assumed to be 15% of AGTB (MacDicken 1997). Understorey biomass included shrubs, herbs, and small trees with a DBH <10 cm. For shrubs, herbs and grasses and litter, the complete harvest method was used. The material was separated, dried at 80ºC to determine its dry weight (Rai 1984). The aboveground tree carbon (AGTC) and understorey C were estimated by converting biomass value into carbon equivalent by multiplying by 0.5 because the carbon content in plant tissues is about half of the dry weight of the aboveground live biomass (Higuchi et al. 1998, Malhi and Grace 2000).

### Soil Sampling and Analysis

The SOC was estimated by the wet oxidation method (Walkley and Black 1934). Dry soil bulk density (BD) at 105°C was estimated by the core method (Guo and Gifford 2002). The carbon stock as Mg ha$^{-1}$ was calculated by following standard method (Guo and Gifford 2002). Soil pH was measured in 1M KCl suspension of 1:5 (soil: liquid) using a pen type digital pH meter. Soil texture was analysed by the Bouyocucos hydrometer method (Okalebo and Gathua 1993). Textural class was determined using the Triangular diagram provided in the TSBF manual (Guo and Gifford 2002). Soil moisture was calculated on dry weight basis (Anderson and Ingram 1994). The ANOVA was used to compare the means of structural variables, carbon pools and other edaphic properties in different LULC. All statistical analysis was performed by PAST version 1.89 (Hammer et al. 2001).

## RESULTS

### Tree Diversity Under Different Land Uses

Data on plant species composition for all LULC are given in Appendix I. A total of 1494 individuals were counted which represented NF 692 stems ha$^{-1}$, MP 748 ha$^{-1}$ and JF 54 stems ha$^{-1}$. Total 92 species belonging to 69 genera and 39 families were recorded in the 3 ha sampling area. *Shorea robusta* C.F. Gaertn and *Syzygium cumini* (L.) Skeels. were observed in Manage plantations (MP). The number of observed species (F=163.7, df =2, 27; p<0.0001) and genera (F=221.8, df =2, 27; p<0.001) significantly varied within each LULC group. Tree diversity (species ha$^{-1}$) was highest in NF (83.10± 19.74), followed by JF (3.80±0.57) and MP (1.80 ± 0.32) (Table 2). The Shannon diversity index was significantly (F=254.6, df= 2, 27; p<0.001) higher in NF than other LULC. Simpson dominance was highest in MP (1±0.1), followed by JF (0.5±0.28) and NF (0.072±0.02). Species were more evenly distributed in MP (0.95±0.14), followed by NF (0.604±0.04) and JF (0.45±0.27). Similarly, tree density (individual ha$^{-1}$) also ranged from 748 ha$^{-1}$ (MP) to 54 ha$^{-1}$ (JF). The basal area ranged from 41.97 m$^2$ ha$^{-1}$ (MP) to 37.08 m$^2$ ha$^{-1}$ in NF. The tree density (F=65.19, df= 2, 27; p<0.0001) and basal area (F=17.11, df= 2, 27; p<0.0001) differed significantly between three LULC. The contribution of LULC in the overall tree density was 43.95% (NF), 52.91% (MP) and 3.77% (JF) (Table 1).

### Aboveground Biomass and Carbon Stocks

The total aboveground carbon (TAGC) storage in NF was 84.16 Mg ha$^{-1}$, followed by MP 64.41 Mg ha$^{-1}$ and JF 9.45 Mg ha$^{-1}$; which differ significantly (F=37.69, df =2, 27; p<0.0001) along the land uses (Figure 3). AGTC values ranged from 63.61 Mg ha$^{-1}$ (NF) to 58.44 Mg ha$^{-1}$ (MP) and only 2.89 Mg ha$^{-1}$ in JF. Carbon stock in tree pool was significantly different among the land uses (F=36.35, df =2, 27; p<0.0001). Trees contributed 98.96% of C to the total aboveground C pool in MP compared to 91.97% in NF and 32% in JF.

Understorey vegetation in of study area mainly comprised of *Cynodon dactylon* (L.) Pers., *Panicum maximum* Jacq., *Eupatorium odoratum* L., *Euphorbia hirta* L., *Crotalaria pallida* Aiton R.Br., *Nelsonia campestris* R.Br., *Desmodium triflorum* (L.) DC., *Blumea lacera* (Roxb.) DC., *Hyptis suaveolens* (L.) Poit., *Mimosa pudica* L., *Vernonia cinerea* (L.) Less., *Sida cordifolia* L., *Sida acuta* Burm.f., *Ageratum conyzoides* L., *Spilanthes paniculata* Wall. ex DC., *Urena lobata* L., *Melastoma malabathricum* L., *Saccharum sponta-neum* L., *Borreria hispida* (L.) K.Schum., *Eleusine indica* (L.) Gaertn., *Panicum maximum* Jacq. and *Ichnocarpus frutescens* (L.) R.Br.

Table 1. Tree diversity and stand structural variables and carbon pool (mean ±standard error) along different land use land cover (NF-Natural Forest, MP-Manage Plantation and JF-Jhum Fallows), Tripura, Northeast India. Variations are analyzed by ANOVA (degree of freedom 2, 27).

| Diversity variables | Forest types | | | | |
|---|---|---|---|---|---|
| | NF | MP | JF | F-value | *p*-value |
| No. of Plots (N) | 10 | 10 | 10 | | |
| No. of Species (S) | 83.1 ±19.73 | 1.8 ±1.03 | 3.8 ±1.81 | 163.7 | <0.0001 |
| No. of Genus (G) | 30 ±5.65 | 1.5 ±0.53 | 3.2 ±1.22 | | |
| Shannon diversity (H') | 3.047 ±0.24 | 0.01 ±0.003 | 0.82 ±0.48 | 254.6 | <0.0001 |
| Simpson dominance (D) | 0.072 ±0.02 | 1 ±0.1 | 0.5 ±0.28 | 81.75 | <0.0001 |
| Peilou evenness (E) | 0.604 ±0.04 | 0.95 ±0.14 | 0.45 ±0.27 | 61.2 | <0.0001 |
| **Structural Variables** | | | | | |
| Density ($ha^{-1}$) | 692 ±154.95 | 748 ±56.80 | 54 ±8.59 | 65.19 | <0.0001 |
| Basal Area ($m^2$ $ha^{-1}$) | 37.08 ± 8.21 | 41.97 ±12.1 | 2.25 ±0.50 | 17.11 | <0.0001 |
| **Carbon Pools** | | | | | |
| Shrub C ($Mgha^{-1}$) | 3.81 ±0.34 | 0.08 ±0.002 | 2.68 ±0.81 | 83.23 | <0.0001 |
| Herb and grasses C (Mg $ha^{-1}$) | 1.22 ±0.25 | 0.37 ±0.09 | 0.17 ±0.05 | 19.62 | <0.0001 |
| Litter & Dead wood ( Mg $ha^{-1}$) | 0.53 ±0.07 | 0.17 ±0.05 | 2.04 ±0.33 | 26.05 | <0.0001 |
| Total Understorey C (Mg $ha^{-1}$) | 11.11 ±2.39 | 1.23 ±0.84 | 12.30 ±3.25 | 65.16 | <0.0001 |
| Aboveground Tree Carbon (Mg $ha^{-1}$) | 63.61 ±8.37 | 58.44 ±4.80 | 2.89 ±2.04 | 36.35 | <0.0001 |
| Total Aboveground C (Mg $ha^{-1}$) | 84.16 ±11.72 | 64.41 ±6.89 | 9.45 ±1.27 | 37.69 | <0.0001 |
| Belowground Tree C (Mg $ha^{-1}$) | 9.54 ±1.36 | 8.77 ±2.28 | 0.43 ±0.10 | 36.35 | <0.0001 |
| SOC (Mg $ha^{-1}$) | 117.2 ±8.0 | 85.34 ±4.41 | 121.87 ±3.51 | 6.41 | 0.007 |
| Ecosystem C pool (Mg $ha^{-1}$) | 213.16 ±31.5 | 159.28 ±14.35 | 131.76 ±6.32 | 20.77 | <0.0001 |

Table 2. Showing different edaphic properties (mean ±standard error) along different land use land cover (NF-Natural Forest, MP-Manage Plantation and JF-Jhum Fallows), Tripura, Northeast India. Variations are analyzed by ANOVA (degree of freedom 2, 13).

| Soil Parameter | NF | MP | JF | F-value | *p*-value |
|---|---|---|---|---|---|
| Soil pH (KCl) | 4.39 ±0.18 | 4.40 ±0.14 | 4.40 ±0.17 | 0.012 | 0.98 |
| Moisture content (%) | 18.20 ±0.78 | 15.79 ±0.91 | 18.82 ±1.61 | 3.22 | 0.09 |
| Soil Temp ($^{O}C$) | 23.29 ±0.39 | 23.59 ±0.63 | 26.68 ±1.01 | 27.63 | 0.0001** |
| Bulk density (g $cm^{-3}$) | 1.37 ±0.081 | 1.47 ±0.053 | 1.41 ±0.085 | 5.27 | 0.05* |
| % SOC | 0.85 ±0.18 | 0.62 ±0.1 | 0.87 ± 0.2 | 3.28 | 0.091 |
| SOC stock (total) | 117.12 ±7.99 | 85.34 ±4.41 | 121.87 ±3.51 | 60.33 | 1.495 |
| SOC stock (mean) | 11.70 ±0.79 | 8.50 ±0.44 | 12.20 ±0.35 | 60.33 | 1.495 |
| Clay (%) | 29.57 ±2.22 | 31.38 ±0.91 | 26.81 ±1.25 | 1.27 | 0.37 |
| Silt (%) | 27.51 ±1.01 | 28.43 ±29.82 | 27.11 ±1.16 | 3.68 | 0.0904 |
| Sand (%) | 42.93 ±0.11 | 40.19 ±0.66 | 46.88 ±0.04 | 342.2 | 3.37 |

(*)- Significant difference between LULC types at <0.05 level.(**)-Significant difference between LULC types at <0.001 level.

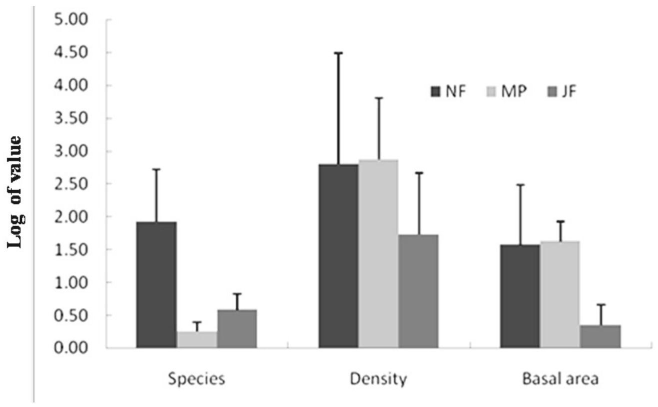


Figure 3. Plant diversity and structural differences of three land use-land cover systems in Tripura (NF-Natural Forest, MP-Managed Plantation and JF-Jhum Fallows), Northeast India .

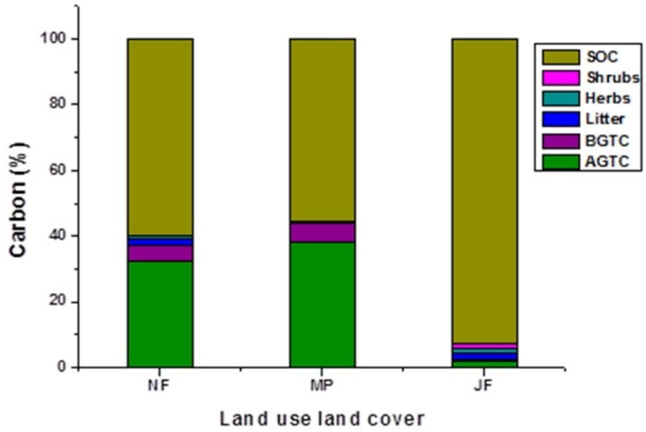


Figure 5. Showing percent contribution of various pools to total Carbon stock under different land use land cover systems in Tripura (NF-Natural Forest, MP-Managed Plantation and JF-Jhum Fallows), Northeast India .

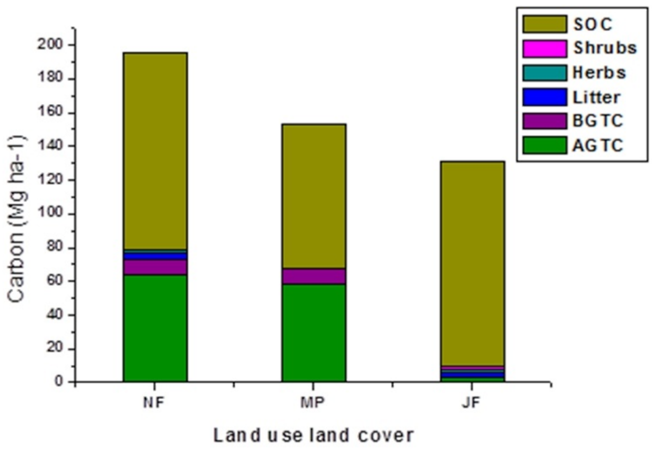


Figure 4. Distribution of Carbon stock under different pools of three land use land cover systems in Tripura (NF-Natural Forest, MP-Managed Plantation and JF-Jhum Fallows).

Understorey shared 68.02% of the total above-ground C pool in JF, 8.03% in NF and 1.03% in MP. The understorey C pool also varied significantly (F=65.61, df =2, 27; p<0.0001) among the land uses and was highest for JF (12.30 ±3.25 Mg ha$^{-1}$; Figure 4).

The BGTC ranges from 19.08 MG C ha$^{-1}$ in NF to 0.87 MG C ha$^{-1}$ in JF and it also significantly differed among the land uses (F=36.65, df =2, 27; p<0.0001). Density of trees and basal area was change significant along the land uses and showed negative correlations with litter C ($r$ = -0.99, $P$ < 0.05) (Table 1).

## Soil Organic Carbon stock

Maximum SOC stock was high in JF (121.87 Mg C ha$^{-1}$), followed by NF (117.12 Mg C ha$^{-1}$) and MP (85.34 Mg C ha$^{-1}$) (Table 2, Figure 5). In the top soil (0-10 cm depth), maximum SOC stock was recorded in NF (20± 2.73), followed by JF (17.81 ± 2.22) and MP (12.20 ± 0.85) (Figure 5). In all land uses, SOC stock decreases with increasing depth; it decreased by 60.5% (NF), 68.03 % (MP) and 65.07% (JF) at 10-30 cm depth. But at 10-30 cm soil depth, the % SOC was low in MP (26.31), NF (36.11) and JF (37.57) as compared with that in the top layer (Figure 6). In the total soil profile, SOC ranged from 0.88% (JF) to 0.61% (MP). Data on soil properties are tabulated in Appendix II and Figure 7.

## Edaphic Properties

The soil of the study area was loam to sandy loam (Table 2). The BD ranged from 1.47 (MP) to 1.37 (NF) and found significantly high in NF (F=5.27, df =2, 12; p<0.05). All soil samples were strongly acidic. The maximum pH of the 1 m column of soil was nearly similar in three land uses (4.40). The MC ranged between 18.82 in JF and 15.79 in MP. Soil moisture content (MC) showed highly significant and positive correlation with SOC ($r$ = 0.99, $P$ < 0.05). The soil temperature ranged from 26.68 ±1.01 ºC (JF) to 23.29 ± 0.39 ºC (NF) and overall it differed significantly (F=27.63, df =2, 12; p<0.001). AGTC was highly significantly and negatively correlated with soil temperature ($r$ = -0.99, $P$ < 0.05) (Table 3).

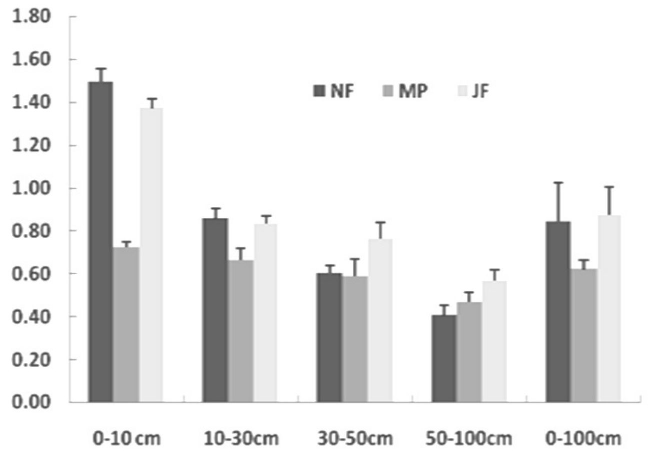


Figure. 6. Value (Mean ± SE) of soil organic carbon (%) under different land use land cover systems in Tripura (NF-Natural Forest, MP-Managed Plantation and JF-Jhum Fallows).

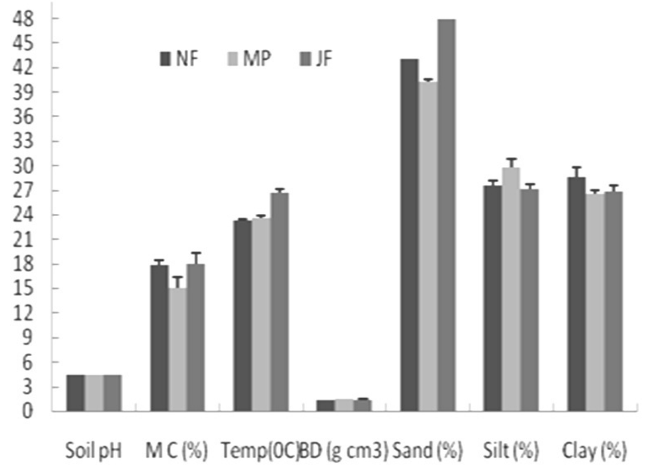


Figure 7. Value (Mean ± SE) of different edaphic properties of different land use land cover in Tripura (NF-Natural Forest, MP-Managed Plantation and JF-Jhum Fallows).

Table 3. Correlations between soil characteristics, tree diversity (number of species and density) and stand structural variables (basal area) and carbon pool in herbs, shrubs, litter and total aboveground (AGTC) and belowground (BGTC) along different land use land cover (NF-Natural Forest, MP-Manage Plantation and JF-Jhum Fallows), Tripura, Northeast India. (*) Significant difference at confidence level <0.05 and (**) Significant difference at confidence level <0.001.

| | Soil pH | Soil Moisture | Bulk Density | Soil Temp | Soil Org. Carbon | BGTC | Litter Carbon | Herb Carbon | Shrub Carbon | AGTC | Number of species | Density | Basal Area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Soil pH | | -0.46 | 0.80 | 0.57 | -0.39 | -0.56 | 0.33 | -0.33 | -0.73 | -0.57 | -0.99* | -0.35 | -0.40 |
| Soil Moisture | | | -0.90 | 0.46 | 0.99* | -0.47 | 0.68 | 0.99 | 0.94 | -0.47 | 0.48 | -0.66 | -0.63 |
| Bulk Density | | | | -0.03 | -0.86 | 0.04 | -0.29 | -0.83 | -0.99 | 0.04 | -0.82 | 0.27 | 0.23 |
| Soil Temperature. | | | | | 0.53 | -0.99* | 0.97 | 0.59 | 0.14 | -0.99* | -0.55 | -0.97 | -0.98 |
| Soil Org. C | | | | | | -0.54 | 0.74 | 0.99* | 0.91 | -0.54 | 0.41 | -0.72 | -0.69 |
| BGTC | | | | | | | -0.97 | -0.59 | -0.15 | 0.99** | 0.55 | 0.97 | 0.9 |
| Litter Carbon | | | | | | | | 0.78 | 0.40 | -0.97 | -0.31 | -0.99* | -0.99* |
| Herb Carbon | | | | | | | | | 0.88 | -0.59 | 0.35 | -0.77 | -0.73 |
| Shrub Carbon | | | | | | | | | | -0.15 | 0.75 | -0.38 | -0.33 |
| AGTC | | | | | | | | | | | 0.55 | 0.97 | 0.98 |
| No. of Species | | | | | | | | | | | | 0.33 | 0.38* |
| Density Trees | | | | | | | | | | | | | 1.00 |
| Basal Area | | | | | | | | | | | | | |

## DISCUSSION

Our studies showed significant variation in terms of species richness, forest structure and carbon stock's potential along the land use systems. However, we do not know the actual value of biomass and carbon stock deposited within the primary forests of Tripura, but we assumed that the present value showed for NF was highest and was taken as baseline biomass and carbon stock value to compare the changing other LULC in the state. The occurrence of high species richness in the NF rather than MP and JF is a typical phenomenon, as we also expected high diversity and stand complexity within the NF than other land LULC. Lower plant diversity could potentially decline the ability of long lived carbon pools of terrestrial ecosystems to continue to act as carbon sinks of atmospheric carbon dioxide ($CO_2$) (Pacala et al. 2001). Result from other mixed species plantations suggested that the identity of the dominant species plays an important role in determining carbon gained by the trees (Redondo Brenes, 2007). It has been observed that at the stand level mixed species performed better in terms of wood volume, basal area, biomass, and carbon sequestrations in comparison to pure monoculture stands (Alice et al. 2004). Our efforts were also to observe the relationships between vegetation biomass and species diversity potentiality, which was also performed in other studies (Loreau et al. 2003; Liang et al. 2007). Forest ecosystems required longest response time to adopt through migration and regrowth (Leemans and Eickhout 2004). A long gestation period is required to develop and implementing adaptation strategies in the forest (Ravindranath and Sathaye 2002). Hence, the rate of recovering carbon is slow. Most of the MP in Tripura is kept in Reserve Forest and managed by Forest Department. However, being a monoculture plot and strict protection people rarely visit these MP. While, in most cases, NF are rich in diversity and for that these areas are frequently visited by firewood and Non Timber Forest Products (NTFP) collectors. The lower density in NF may be explained by the fact that human influences on NF which may reduce tree density and thereby basal area compared to MP. We found the differential use of natural lands which has an adverse impact on biodiversity and total carbon stock. The NF was having the highest value of diversity indices, evenness and TAGC (Table 1).

Aboveground biodiversity can also affect soil C stocks by increasing reliability of inputs to the soil (Eglin et al. 2011). The value of the AGTC of the total carbon pool was increased from 2.2 % (JF) to 38% in MP and NF showed the intermediate value (32%). Our result is comparable with other studies as carbon stocked in the tree layer varies widely from 23% to 82 % of the total ecosystem carbon pool (Usoltsev and Vanclay 1995). It means that if we convert NF into JF, the loss of carbon from aboveground biomass will be greater than other pools and opposite of that if we allow JF to regenerate into NF to regain the biomass carbon stock. Similarly, carbon %, stored in understorey layer was maximum for JF (4.68), followed by NF (2.83%) and MP (0.40) (Figure 5). In spite of low tree density and basal area in NF than MP, NF showed high potential of storing biomass carbon. But, NF is more vulnerable to continuous conversion and degradation, especially when large areas of forest have been converted to settlements. Although, the effects of afforestation on soil carbon pool vary. Our study shows that MP has the lowest value of SOC. This result is similar to other studies where the decline in SOC has been reported after afforestation (Richards et al. 2007). Conversion of forested areas into JF is adversely affected total AGC pool, our result agreed with the previous study as the present trend led to 95% loss of biomass carbon from NF to JF. About 223 $km^2$ of forest land (3.76%) of total geographical area of the state is cleared annually, higher than the national average of 2.26% (Gupta, 2000). Jhuming is characterized by a short fallow cycle of 3-5 years, and it is predicted that the short duration of the fallows did not allow enough to restore JF with dense woody communities. Our study also showed that NF had maximum potential for AGC storage in understorey biomass than MP (only 1.23 Mg C $ha^{-1}$ or 9.05% of total AGC). Negi (1984) also reported 2.3% understory biomass contribution to the total stand biomass in sal forest. This may due to the plantation management practices at regular interval by means of annual fire, grazing and weeding. These factors may reduce the process of biomass accumulation through sufficient germination, seedling regeneration, sapling and adult tree growth. However expand of grass mask, litter and dead wood deposited on the floor may increase ground fire vulnerability and influences the flow of carbon in the MP. A high proportion of understorey carbon accumulation in JF than NF is estimated in the present study may due to continuous growth of lower story vegetation in absence of shade providing canopy spreading trees. Since, some dominant canopy forming trees oppose the growth of understorey, biomass i.e. shrubs, herbs and grasses (Lugo & Brown, 1992). The % SOC value (upto 1 m depth) of three LULC in the present study is less than 1% and in top profile the value is less than 1.5%. Present value compare quite low to Greenland et al. (1975), who considered the value is 2% of SOC as the minimum requirement for maintenance of satisfactory soil aggregates stability. In northeast India, Tripura has the highest area (>89%) of the total geographical area with relatively low SOC content (1.0-1.5%) and SOC content of <1% was recorded in a small area (7.55%) and ≥1.5% was only about 3.42% (Choudhury et al. 2013). In terms of carbon stock, it recorded higher percentage of area (81.8) under relatively low SOC density (10-20 Mg $ha^{-1}$) (Choudhury et al. 2013). Our study showed similar results, since our LULC mean value of complete profiles ranged from 8.5 ± 0.44 in MP to 12.2± 0.35 in JF Mg C $ha^{-1}$. Similarly, our estimated value of SOC is similar to the other studies of the surrounding area with similar climatic condition. Singh et al. (1991) in Mizoram have reported 82.1-134.1 SOC Mg $ha^{-1}$ and 115.9-268.7 Mg $ha^{-1}$ in Assam (Singh et al. 1995). Comparatively, the high value of SOC in NF can be explained by the fact that it was having more diverse structure (Table 2 and Appendix I). Mixed population of tree may increase the plant productivity and litter inputs (Hook et al. 1991). In the present study, NF represented high SOC and this may be due to its habitat, nature with profuse growths of trees and shrubs compared to MP and JF. Dense canopy and thick undercover results in increased amount of forest floor organic matter. Thick layer of litter (about 2.5 cm) was observed, which might recycle continuously SOC content in the sub-soil horizon. A recent study in tropical forests estimated that increased litter fall would actually increase soil carbon release through a process called priming effect (Sayer et al. 2011). Variation in soil carbon accumulation was also reported to be proportional to the biomass input into the soil, which in turn was largely dependent on biodiversity (Lambers et al. 2004). The contribution of below ground roots for SOC accumulation was considered to be more compared to aboveground biomass (Puget and Drinkwater 2001). Low value of SOC in MP can also explain by the fact that restriction in priming effects, since a considerable amount of litter (annual turnover in sal plantation is 11.27 Mg $ha^{-1}$ $yr^{-1}$; Raizada et al. 2003) is being not recycled. The high value of SOC in JF may be due to fact that it had a thick cover of understorey vegetation, which might help in retaining moisture level, protected the soil aggregates and hence reduce the oxidation of carbon. The values for SOC and BD were also high in JF and considered as an important variable for estimation of overall SOC stock. Our present study shows comparatively lower value for SOC than the value in 6 years old Jhum fallow in similar climatic condition (Uma Shankar et al. 1995). This may due to the high fallowing duration than in the present study (1 year), which permitted enough time for successional development of plant communities to sequester more C and stock sufficient biomass. Lower value of the SOC stock in MP (85.34 Mg ha-1), may due to its monoculture of sal plantation (25 years old). As the tree matures, they sequester less carbon due to some physical limitations. Stands which are more productive also have higher mean C stock of trees and higher SOC stock than less productive, pure stands (Shanin et al. 2011). Some environmental perspectives are also associated with monoculture plantation viz. clearing or undergrowth vegetation, soil erosion by fire treatment, litter raking and effect on water cycling. BD is the measurement of compactness of soil and its measurement is important for SOC stock estimation. Result suggested that the value of SOC was found minimum when BD was highest and vice versa. A similar trend was observed in other studies; e.g., SOC content increases with a decline in BD (Pando-Moreno et al. 2004). Another important factor may be clearing of MP ground with the help of fire by the forest department is the regular practice. We found a significant correlation between SOC and MC ($r=0.99$; $p<0.05$). Annual weeding and firing altered soil moisture content and temperature, which accelerate the decomposition of organic matter (Jackson et al. 2000). Lack of sufficient ground cover may aggravate the heating of the soil and hence, induce the C oxidation process. High temperature also influences SOC content, mostly due to secondary effects of oxidation, decomposition and mineralization or accumulation rates (Follett and Schimel 1989). Comparatively high value of pH in JF may be explained by the fact that a few years back it received a considerable amount of ash while preparing the land Jhum cultivation and burning of aboveground vegetation is considered to increase the soil pH (Ram and Ramakrishnan 1988). MC (%) influences the other parameters of soil like pH, Soil temperature and % carbon. High amount of MC in JF may relate to thick ground vegetation cover (Table 2). At the regional scale, some results showed that soil texture had little influence on SOC. For example, silt and clay contents were not significantly related to SOC in forests of western Oregon (Homann et al. 1995) and Spain (Hontoria et al. 1999). Furthermore, clay content can hardly explain the variability of SOC (Percival et al. 2000). In our study, silt and clay contents did not vary among different LULC types.

## CONCLUSION

The study shows that plant diversity and community structure changed significantly from NF to other land uses. Biomass and potential stock of carbon decrease significantly in JF. In spite of diverse population in NF and MP, both have similar value of stocked tree carbon. But, the understorey and SOC accumulation, are poor in MP. In spite of higher economic value, MP do not provide carbon accumulation in soil. Normally, soil carbon is in steady-state in NF, but as soon as deforestation (or afforestation) occurs, the equilibrium is affected. Carbon level in soil influences the belowground diversity and nutrient cycling. It is a strong indicator of soil health and productivity. On an average, 3869 $km^2$ area in the country is placed under shifting cultivation each year. Our study shows that land clearing practice like jhum cultivation has significant impact on AGC accumulation, but a change in SOC is a comparatively long term process. In this study, carbon stock in soil is about 59.8% (NF), 55.72 (MP) and 92.78% (JF) of the aboveground pool. This result is comparable to the report that about two-thirds of the carbon in terrestrial ecosystems come from soil organic carbon (Eswaran et al. 1993). This result also reveals that JF has enough potential to sequester AGC in the near future. Other studies have also reported that lands with degraded vegetation cover have the potential to stock more carbon (Iverson et al. 1993). Nevertheless, it is essential to understand the potential of carbon stocked in land, different pools' contribution and how it changes with differential use of land. The actual dynamics of carbon pool can only be understood only by knowing the emission pattern. So, further study is required to estimate sequestration, storage and emission potential of these land uses.

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**Conflict of Interest**: We declare that there is no conflict of interest

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## Annexure –I

IVI value of different tree species found in three land use land cover systems.
NF- Natural Forest; SR- *Shorea robusta* plantation and JF- Jhum Fallow.

| Sl No | Name of species | Family | Land Use Land Cover (LULC) types | | |
|---|---|---|---|---|---|
| | | | NF | SR | JF |
| 1 | *Acacia auriculiformis* A. Cunn. ex Benth. | Leguminosae | 0.57 | - | - |
| 2 | *Alangium chinensis* (Lour.) Harms. | Alangiaceae | 1.43 | - | - |
| 3 | *Alangium salvifolium* Linn. | Alangiaceae | 1.66 | - | - |
| 4 | *Albizia chinensis* (Osbeck) Merr. | Leguminosae | 1.40 | - | - |
| 5 | *Albizia procera* (Roxb.) Benth. | Leguminosae | 2.47 | - | 18.22 |
| 6 | *Alstonia scholaris* (L.) R.Br. | Apocynaceae | 0.57 | - | - |
| 7 | *Amoora wallichii* King. | Meliaceae | 6.36 | - | - |
| 8 | *Aegle marmelos* (L.) Correa | Rutaceae | 3.52 | - | - |
| 9 | *Anogeissus acuminata* (Roxb. ex DC.) | Combretaceae | 6.01 | - | - |
| 10 | *Anthocephalus chinensis* (Lam.) A. Rich ex Walp. | Rubiaceae | 3.56 | - | - |
| 11 | *Artocarpus heterophyllus* Lam. | Moraceae | 1.08 | - | 9.44 |
| 12 | *Artocarpus chama* Buch.-Ham. ex Wall. | Moraceae | 7.68 | - | 9.77 |
| 13 | *Azadirachta indica* A. Juss | Meliaceae | 2.34 | - | - |
| 14 | *Bauhinia malabarica* Roxb | Caesalpiniaceae | 2.35 | - | - |
| 15 | *Bischofia javanica* Bl. | Euphorbiaceae | 1.28 | - | - |
| 16 | *Bombax ceiba* L. | Malvaceae | 1.07 | - | - |
| 17 | *Bridelia retusa* (L.) A. Juss | Euphorbiaceae | 0.60 | - | - |
| 18 | *Butea monosperma* Lam. Kuntze | Papilionaceae | 6.91 | - | - |
| 19 | *Callicarpa arborea* Roxb. | Lamiaceae | 0.67 | - | - |
| 20 | *Calophyllum polyanthum* Wall. | Clusiaceae | 2.64 | - | - |
| 21 | *Canthium glabrum* Blume | Rubiaceae | 0.54 | - | - |
| 22 | *Careya arborea* Roxb. | Lecythidaceae | 25.73 | - | - |
| 23 | *Cassia fistula* L. | Leguminosae | 2.71 | - | - |
| 24 | *Cassia siamea* (Lam.) Irwin et Barneby | Leguminosae | 1.16 | - | - |
| 25 | *Castanopsis armata* (Roxb.) Spach. | Fagaceae | 0.77 | - | - |
| 26 | *Ceiba pentandra* Gaertn. | Bombacaceae | 2.76 | - | 3.3 |
| 27 | *Chaetocarpus castanicarpus* (Roxb.) Thwaites. | Peraceae | 0.54 | - | - |
| 28 | *Cinnamomum glanduliferum* (Wallich) Nees. | Lauraceae | 1.10 | - | - |
| 29 | *Cordia dichotoma* G. Forst. | Boraginaceae | 2.49 | - | - |
| 30 | *Cordia grandis* Roxb. | Boraginaceae | 0.54 | - | - |
| 31 | *Crypteronia glabra* (Wall.) Blume. | Crypteronuaceae | 0.70 | - | - |
| 32 | *Dillenia indica* L | Dilleniaceae | 0.58 | - | - |
| 33 | *Dillenia pentagyna* Roxb. | Dilleniaceae | 1.86 | - | - |
| 34 | *Dipterocarpus turbinatus* C.F.Gaertn. | Dipterocarpaceae | 0.53 | - | - |
| 35 | *Duabanga grandiflora* Walp. | Lythraceae | 0.67 | - | - |
| 36 | *Dysoxylum binectariferum* Hook.f. ex Bedd. | Meliaceae | 1.31 | - | - |
| 37 | *Emblica officinalis* Gaertn. | Euphorbiaceae | 0.84 | - | 4.12 |
| 38 | *Ficus auriculata* Lour. | Moraceae | 1.74 | - | - |
| 39 | *Ficus lepidosa* Wall. | Moraceae | 1.64 | - | - |
| 40 | *Ficus nervosa* Roth | Moraceae | 0.56 | - | - |
| 41 | *Ficus racemosa* Wild. | Moraceae | 3.94 | - | - |
| 42 | *Ficus religiosa* L. | Moraceae | 0.58 | - | - |
| 43 | *Ficus semicordata* Buch.-Ham. ex Sm. | Moraceae | 2.54 | - | - |
| 44 | *Ficus virens* Aiton | Moraceae | 0.58 | - | - |
| 45 | *Firmiana colorata* (Roxb.) R.Br. | Sterculiaceae | 1.74 | - | - |
| 46 | *Flacourtia jangomas* Raeusch. | Flacourtiaceae | 1.12 | - | - |
| 47 | *Garuga pinnata* Roxb. | Burseraceae | 0.59 | - | - |

| Sl No | Name of species | Family | Land uuse land cover (LULC)types | | |
|---|---|---|---|---|---|
| | | | NF | SR | JF |
| 48 | *Glochidion assamicum* Hook.f. | Phyllanthaceae | 0.56 | - | - |
| 49 | *Gmelina arborea* Roxb. | Lamiaceae | 3.68 | - | 1.23 |
| 50 | *Grewia hirsuta* Roxb. | Malvaceae | 1.82 | - | - |
| 51 | *Grewia viminea* Wall. | Malvaceae | 2.60 | - | - |
| 52 | *Gynocardia odorata* Roxb | Flacourtiaceae | 1.34 | - | - |
| 53 | *Heteropanax fragrans* Seem. | Araliaceae | 0.53 | - | - |
| 54 | *Holarrhena antidysenterica* Wall. | Apocynaceae | 1.28 | - | - |
| 55 | *Hydnocarpus kurzii* (King) Warb. | Flacourtiaceae | 3.33 | - | - |
| 56 | *Hymenodictyon excelsum* Wall. | Rubiaceae | 5.54 | - | - |
| 57 | *Indigofera atropurpurea* Buch.-Ham. ex Roxb. | Papilionaceae | 1.85 | - | - |
| 58 | *Lagerstroemia parviflora* Roxb. | Lythraceae | 3.89 | - | 7.55 |
| 59 | *Leea indica* (Burm. f.) Merr. | Vitaceae | 3.62 | - | - |
| 60 | *Litsea cubeba* (Lour.) Pers | Lauraceae | 3.98 | - | - |
| 61 | *Litsea glutinosa* (Lour.) C.B.Rob. | Lauraceae | 2.90 | - | - |
| 62 | *Macaranga denticulata* Müll.Arg. | Euphorbiaceae | 6.49 | - | - |
| 63 | *Macaranga peltata* Müll.Arg. | Euphorbiaceae | 2.72 | - | - |
| 64 | *Mallotus philippensis* (Lam.) Müll.Arg. | Euphorbiaceae | 7.05 | - | - |
| 65 | *Mallotus tetracoccus* (Roxb.) Kurz | Euphorbiaceae | 1.37 | - | - |
| 66 | *Mangifera indica* Wall. | Anacardiaceae | 1.35 | - | 11.42 |
| 67 | *Mangifera syvatica* Roxb. | Anacardiaceae | 5.92 | - | - |
| 68 | *Markhamia stipulata* Seem. | Bignoniaceae | 1.27 | - | - |
| 69 | *Mesua ferrea* L. | Clusiaceae | 5.69 | - | - |
| 70 | *Michelia champaca* L. | Magnoliaceae | 1.74 | - | - |
| 71 | *Microcos paniculata* L. | Tiliaceae | 4.37 | - | - |
| 72 | *Mitragyna rotundifolia* Kuntze | Rubiaceae | 1.56 | - | - |
| 73 | *Palaquium polyanthum* Merr. | Sapotaceae | 1.87 | - | - |
| 74 | *Schima wallichii* Choisy. | Theaceae | 4.39 | - | - |
| 75 | *Shorea robusta* C.F. Gaertn. | Dipterocarpaceae | 0.61 | 289.77 | - |
| 76 | *Suregada multiflora* Baill. | Euphorbiaceae | 4.69 | - | - |
| 77 | *Swintonia floribunda* Griff. | Anacardiaceae | 2.79 | - | - |
| 78 | *Symplocos ferruginea* Roxb. | Symplocaceae | 6.16 | - | - |
| 79 | *Syzygium cerasoides* Raizada. | Myrtaceae | 2.41 | - | - |
| 80 | *Syzygium cumini* (L.) Skeels. | Myrtaceae | 8.77 | 10.11 | 3.15 |
| 81 | *Syzygium grande* Wall. | Myrtaceae | 8.37 | - | - |
| 82 | *Tamarindus indica* L. | Leguminoceae | 2.26 | - | 5.33 |
| 83 | *Tectona grandis* L.f. | Lamiaceae | 11.10 | - | 14.22 |
| 84 | *Terminalia bellerica* Roxb. | Combretaceae | 7.53 | - | 1.01 |
| 85 | *Terminalia chebula* Retz. | Combretaceae | 2.27 | - | - |
| 86 | *Toona ciliata* M.Roem. | Meliaceae | 8.40 | - | 9.11 |
| 87 | *Trewia nudiflora* L. | Euphorbiaceae | 11.97 | - | - |
| 88 | *Trema orientalis* Blume. | Cannabacaceae | 4.02 | - | - |
| 89 | *Vitex peduncularis* Wall. | Lamiaceae | 7.56 | - | - |
| 90 | *Zanthoxylum limonella* (Dennst.) Alston | Rutaceae | 1.97 | - | - |
| 91 | *Ziziphus rugosa* Lam. | Rhamnaceae | 7.01 | - | - |
| 92 | *Ziziphus xylopyrus* Hochst. ex A.Rich. | Rhamnaceae | 5.40 | - | 2.17 |
| Total | | | 300 | **300** | **300** |

**Annexure-II**

**Edaphic properties (depth wise) of different land use land cover system.**
NF- Natural Forest; SR- Shorea robusta plantation and JF- Jhum Fallow.

| Soil property | Soil depth (cm) | NF | SR | JF |
|---|---|---|---|---|
| pH (KCl) | 0-10 | 4.61 ± 0.06 | 4.35± 0.08 | 4.62± 0.28 |
| | 10-30 | 4.49 ± 0.02 | 4.35± 0.04 | 4.25± 0.19 |
| | 30-50 | 4.22 ± 0.06 | 4.24± 0.07 | 4.35± 0.38 |
| | 50-100 | 4.15 ± 0.03 | 4.29± 0.06 | 4.32± 0.16 |
| | 0-100 | 4.43 ± 0.10 | 4.29± 0.08 | 4.46± 0.13 |
| Moisture Content (%) | 0-10 | 16.35 ± 0.32 | 12.34± 0.37 | 13.81± 0.52 |
| | 10-30 | 17.26 ± 0.59 | 13.75± 0.83 | 18.43± 0.87 |
| | 30-50 | 17.36 ± 0.70 | 15.49± 0.39 | 19.01± 1.45 |
| | 50-100 | 18.26 ± 0.75 | 12.95± 0.49 | 21.31± 1.45 |
| | 0-100 | 17.86 ± 0.25 | 13.08± 0.81 | 17.94± 1.45 |
| Soil Temperature (° C) | 0-10 | 21.40 ± 1.75 | 20.28± 0.37 | 20.50± 2.1 |
| | 10-30 | 21.38 ± 1.14 | 21.08± 0.35 | 20.28± 0.76 |
| | 30-50 | 21.16 ± 0.85 | 19.26± 0.6 | 21.08± 1.11 |
| | 50-100 | 20.16 ± 0.79 | 20.8± 0.7 | 19.26± 2.21 |
| | 0-100 | 19.32 ± 0.76 | 20.20± 0.05 | 20.80± 2.12 |
| SOC (%) | 0-10 | 1.33 ± 0.04 | 0.85± 0.06 | 1.37± 0.13 |
| | 10-30 | 1.42 ± 0.02 | 0.69± 0.02 | 0.83± 0.21 |
| | 30-50 | 1.45 ± 0.04 | 0.60± 0.03 | 0.80± 0.11 |
| | 50-100 | 1.39 ± 0.05 | 0.56± 0.02 | 0.58± 0.21 |
| | 0-100 | 1.36 ± 0.03 | 0.77± 0.02 | 0.88± 0.13 |
| Bulk Density (g $cm^{-3}$) | 0-10 | 1.54 ± 0.06 | 1.45± 0.01 | 1.30± 0.11 |
| | 10-30 | 1.02 ± 0.08 | 1.45± 0.05 | 1.39± 0.3 |
| | 30-50 | 0.94 ± 0.06 | 1.42± 0.08 | 1.40± 0.27 |
| | 50-100 | 0.76 ± 0.06 | 1.43± 0.01 | 1.49± 0.11 |
| | 0-100 | 1.08 ± 0.02 | 1.41± 0.02 | 1.38± 0.3 |
| SOC Stock(mean) | 0-10 | 16.84 ± 1.01 | 12.29± 0.82 | 17.81± 1.11 |
| | 10-30 | 15.24 ± 1.21 | 9.86± 0.27 | 11.59± 2.09 |
| | 30-50 | 13.46 ± 1.20 | 8.18± 0.35 | 11.19± 1.13 |
| | 50-100 | 10.08 ± 0.73 | 8.69± 0.42 | 8.60± 2.1 |
| | 0-100 | 14.89 ± 0.34 | 11.01± 2.7 | 12.19± 2.13 |
| Total C Stock (Mg $ha^{-1}$) | 0-10 | 22.73 ± 1.01 | 12.29± 0.82 | 17.81± 1.11 |
| | 10-30 | 37.29 ± 2.42 | 16.7± 1.96 | 23.2± 0.94 |
| | 30-50 | 26.26 ± 2.40 | 15.2± 1.24 | 22.4± 1.73 |
| | 50-100 | 43.70 ± 3.64 | 34.5± 3.49 | 43.0± 4.44 |
| | 0-100 | 141.07 ± 3.37 | 85.3± 1.97 | 121.9± 1.56 |