Original Research

Journal website : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Journal of Environmental Biology

JEB™ p-ISSN: 0254-8704
e-ISSN: 2394-0379
CODEN: JEBIDP

DOI : http://doi.org/10.22438/jeb/42/2(SI)/SI-288

# Above and below ground carbon stock of forest and agricultural land under different agro-ecosystems of Jorhat district

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*Received*: 13.06.2020 *Revised*: 15.11.2020 *Accepted*: 15.12.2020

## Abstract

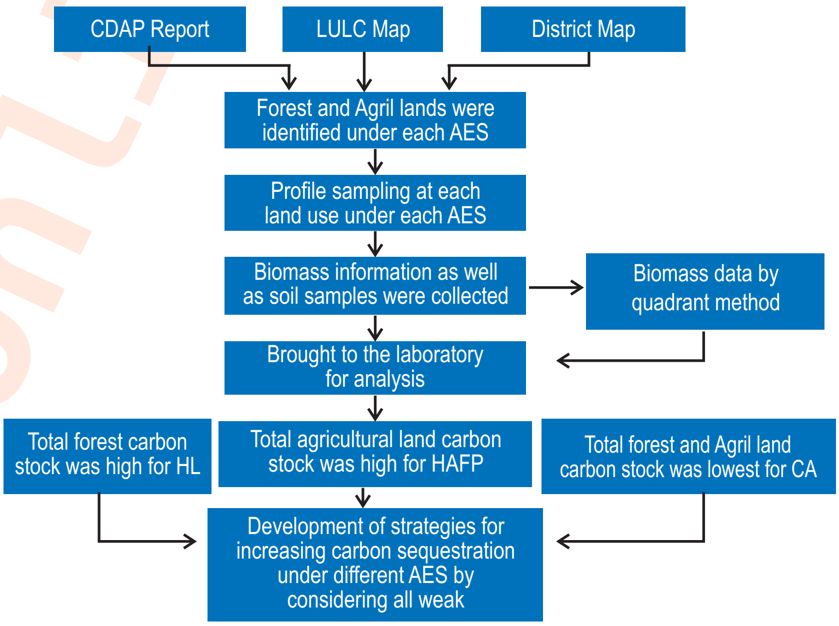
**Aim:** To develop detail data base for carbon stock in different agro-ecosystem (AESs) for forest and agricultural lands of Jorhat district.

**Methodology:** Soil samples from 12 different profiles along with biomass data at each site from 10x10 m, 5x5 m and 1x1 m quadrant for tree, shrub and herb and litter layer were collected from forest as well as agricultural lands covering the entire district.

**Results:** Study revealed that among different agro-ecosystems (AESs), above ground biomass (AGB) carbon was found to be highest for *Humid Alluvial* Flood Free (HAFF) (7.92 Tg) followed by High Land (HL) (3.20 Tg) and lowest was recorded for Char Area (CA) where as total biomass carbon stock was high under Humid Alluvial Flood Free (HAFF) situation followed by Humid Alluvial Flood Prone (HAFP) and then High Land (HL). Bulk density (BD) was higher for agricultural land compare to forest soil, but cation exchange capacity and organic carbon were opposite. Profiles under forest land use system exhibited relatively higher SOCD than paddy irrespective of AESs with an exception in one location of *HAFF* where SOCD under paddy showed higher value than forest land use system.

**Interpretation:** It is important to develop some strategies or methodologies to improve soil carbon reserve in this region to reduce $CO_2$ emission. Moreover, monitoring of change in carbon stock over years in different agro-ecosystems is also important to evaluate efficiency of different methodologies and proper implementation.

**Key words**: Agro-ecosystems, Biomass carbon, Carbon stock, Quadrat sampling, Soil organic carbon




**How to cite :** Baruah, R., B.K. Medhi, D. Bhattacharya and D.K. Patgiri: Above and below ground carbon stock of forest and agricultural land under different agro-ecosystems of Jorhat district. *J. Environ. Biol.*, **42**, 563-571 (2021).

## Introduction

There has been growing concern over the effects of increasing carbon dioxide ($CO_2$) in the earth's atmosphere. Human interventions causing decline of vegetation cover is one of the most significant reason which leads to increase of $CO_2$ concentration in the atmosphere. As per the records of Forest Survey of India (FSI 2003), the area under forest was 102.68 m ha in 1880, which has been reduced to 67.83 m ha in 2003. Since 2003, carbon stocks in Indian forests are continuously decreasing under excessive anthropogenic pressures (Rai and Chakrabarti, 2001; Sheikh *et al.,* 2011). On the contrary, according to recent IFS (2017) report there is an increase of 39 million tonnes of carbon stock in overall Indian forest as compared to previous assessment even though Assam has suffered loss of about 30% of forest cover during 2015-2017.

Carbon sequestration is a net removal of $CO_2$ from atmosphere and all the pools of carbon stock involves sequestration of carbon in different forms to maintain critical $CO_2$ level in the atmosphere. Various terrestrial ecosystems such as forests, grasslands and agricultural systems have different potential of carbon storage (DOE 1999). Among these, the forest ecosystem usually contains more carbon per unit area than other systems and within forest ecosystems, soil organic carbon stock appears to be very efficient parameter as compared to above ground and below biomass for restoration of soil health (Bhattacharyya *et al.,* 2007) as well as mitigation of climate change. It is a fact that rate of carbon sequestration varies with the species composition, region, climate, topography and management practices etc. (Lal, 1999). Therefore, it is important to assess the role of each pool within every ecosystem to understand the carbon sequestration potential of the ecosystem.

A report indicated that most of the Indian soils have the potential to sequester up to 82 Pg per unit area of SOC (Velayutham *et al*., 1999) but North East Region of the country is rich in SOC content as compared to other states of the country (Choudhury *et al.,* 2013).

Among all the states of NER, Arunachal Pradesh has been reported to the have highest carbon stock (1051 million ton) followed by Mizoram (Sharma *et al.,* 2018) but compared to these states, Assam reported to have only 172.6 million-ton carbon stock (Choudhury *et al.,* 2013) within 1 m depth, which indicates need of immediate attention towards improvement of carbon stock. Moreover, regional level data on carbon stock of Assam state is very negligible. In-order-to improve overall carbon sequestration in Assam, it is very important to act locally. As importance of regional study of carbon stock is increasing in the present condition, this study was designed to determine total carbon stock of two major land use under different agro-ecosystems of Jorhat district through non-destructive measures.

## Materials and Methods

**Study area:** The present study was performed in Jorhat district of Assam. It is located between 26° 37' N and 27° 20' N and 94°50'E and 93° 57'E. The district is bounded by Lakhimpur district on north, Sivasagar in East, Golaghat district on West and by Nagaland in South (Fig. 1). It is situated under Upper Brahmaputra valley zone of Assam. It has flat topography with some undulating foot hill areas. It has total geographical area of about 2,851 sq km and experiences 138.04 mm of mean annual rainfall. The average temperature varies from 13.2ºC to 32.15ºC with January being the coldest month having minimum average temperature of 11.6 ºC and August the hottest month with average maximum temperature of 31.78 ºC. The relative humidity ranges from 52.34 per cent during February to 96.5 per cent during June-July. The elevation of the district varies from 80 to 120 m above mean sea level (MSL). The altitude of the hills in the southern and eastern parts of the district is 312 m above msl. Out of the total geographical area of 2.8 lakh ha, 1.19 lakh ha (42.5%) is the net cropped area while, forest occupies significant area of 0.22 lakh ha (7.86%) in the district (ACPD, 2012).

Based on physiographic climate, soil, flood proneness, socio-economic condition and cropping pattern whole district is divided into four agro-ecological systems (AESs) and the proposed study is confined to these four AESs that cover the entire district for detail information and interpretation (Table 1).

**Sampling method:** Reconnaissance survey was made throughout the study areas prior to data and sample collection. Land use land cover map was used to demarcate and extract the forest and agricultural lands and suitable sampling areas were identified for unbiased representation of the whole district. As there was no map demarcating the four (4) agro-ecosystems,

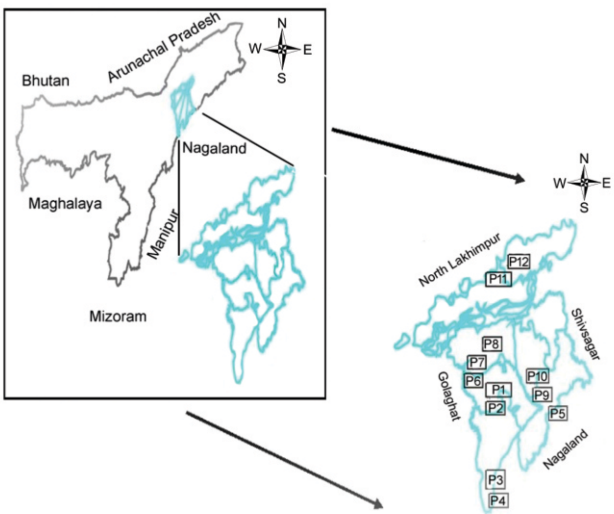



**Fig. 1 :** Location map of Jorhat district along with sampling locations.

**Table 1 :** Different agro-ecosystems of the district and number of samples collected

| Agro-climatic zone | Agro-ecosystems | Forest | | Agriculture | |
|---|---|---|---|---|---|
| | | Area (sq km) | No of samples | Area (sq km) | No of samples |
| Upper Brahmaputra Valley Zone | Humid Alluvial Flood Free (HAFF) | 2.64 | 2 | 1194.29 | 2 |
| | Humid Alluvial Flood Prone (HAFP) | 0.026 | 1 | 800.42 | 2 |
| | High Land (HL) | 143.62 | 2 | 70.30 | 1 |
| | Char Area (CA) | NA | NA | 161.82 | 2 |

**Table 2 :** Volume equations and wood density used in the present study (FSI 2003)

| Scientific name | Allometric equations | Wood density |
|---|---|---|
| **A. HAFF** | | |
| *Stephegyne parvifolia* | $V=0.0697/D^2-1.4597/D+11.79933-2.35397D$ | 0.619 |
| *Dalbergia sissoo* | $V=0.00331/D^2+0.000636$ | 0.669 |
| *Castanopsis indica* | $V = 52.28 (D^2 H)0.89$ | 0.480 |
| *Ficus bengalensis* | $SQRT(V)=0.03629+3.95389D-0.84421^{SQRT}D$ | 0.619 |
| *Tectona grandis* | $V=0.04346-0.26352^{SQRT}D+8.79334D^2$ | 0.577 |
| *Schima wallichii* | $V=-0.01637+6.08487D^2$ | |
| **B. HAFP** | | |
| *Dalbergia sissoo* | $V=0.00331/D^2+0.000636$ | 0.669 |
| *Zizyphus jujube* | $V=0.0697/D^2-1.4597/D+11.79933-2.35397D$ | 0.597 |
| *Madhuca latifolia* | $V=-0.00092-0.55547D+7.34460D^2$ | 0.619 |
| *Syzygium cummini* | $V=0.08481-1.81774D+12.63047D^2-6.69555D^3$ | 0.647 |
| **C. HL** | | |
| *Bombax ceiba* | $V=0.18573/D^2-2.85418/D+15.03576$ | 0.329 |
| *Butea monosperma* | $V=0.0697/D^2-1.4597/D+11.79933-2.35397D$ | 0.465 |
| *Cassia fistula* | $V=0.066+0.287D^2H$ | 0.746 |
| *Dalbergia latifolia* | $V=0.04422+2.328465D^2+0.309150D^2H$ | 0.754 |
| *Diospyros melanoxylon* | $V=0.10426/D^2-1.69816/D+12.29196$ | 0.678 |
| *Terminalia arjuna* | $V=0.0697/D^2-1.4597/D+11.79933-2.35397D$ | 0.686 |
| *Dipterocarpus retusus* | $V= \exp(-1.232+2.178 \times \log D)$ | 0.657 |
| *Phyllanthus emblica* | $V=-0.406+3.540D-3.231D^2$ | 0.619 |

therefore, we have selected the sites based on our preliminary survey, elevation and land use. In this study, soil samples from 12 different profiles representing agricultural land and forest area along with allometric data, such as, tree height, Diameter at breast height (DBH), height of the crown (Hc) including crown length and breadth were collected through quadratic method from same spot. Along with profile data, surface soil samples were also collected for the spatial distribution of carbon throughout the district.

**Allometric data collection and calculation :** Allometric data for biomass carbon estimation were collected through non-destructive method. Data were collected in three different sized quadrants, *i.e.*, 10x10 m, 5x5 m and 1x1 m (Fig. 3) at each sampling site. Within 10 × 10 m quadrate (tree layer), data of all trees within the quadrant were studied and diameter at breast height (DBH), length, breath, height and crown height were recorded against each species of tree. Again for 5 × 5 m quadrate (shrub layer), all shrubs were studied and similar to trees all data were recorded. But for shrubs, species specific models were not available, therefore, a generalized model (as mention below) published by FAO (2004) was used to estimate the biomass carbon for shrub layer at each sampling site. Similarly, the undergrowth layer, including seedlings, shrubs, climbers, grasses, litter (twigs and leaves) and paddy rice in paddy field, was collected from four 1 × 1 m quadrates at each sampling points for each profile.

Tree biomass carbon (10x10m quadrant) of each tree was estimated through volume equations and wood density of each tree species (Table 2) which were collected from Indian Forest Survey website (FSI, 2003). Species volume equation and wood density of recorded tree species are summarized in Table 2. The DBH and height for each tree species were used for regression analysis to get an estimate of biomass (Roy and Ravan, 1996).

The AGB of trees >2.5 cm in DBH estimated using the allometric models, the equations are as follows:

Basal area ($A_b$) = $A_b=\pi r^2$ (Eq. 1)

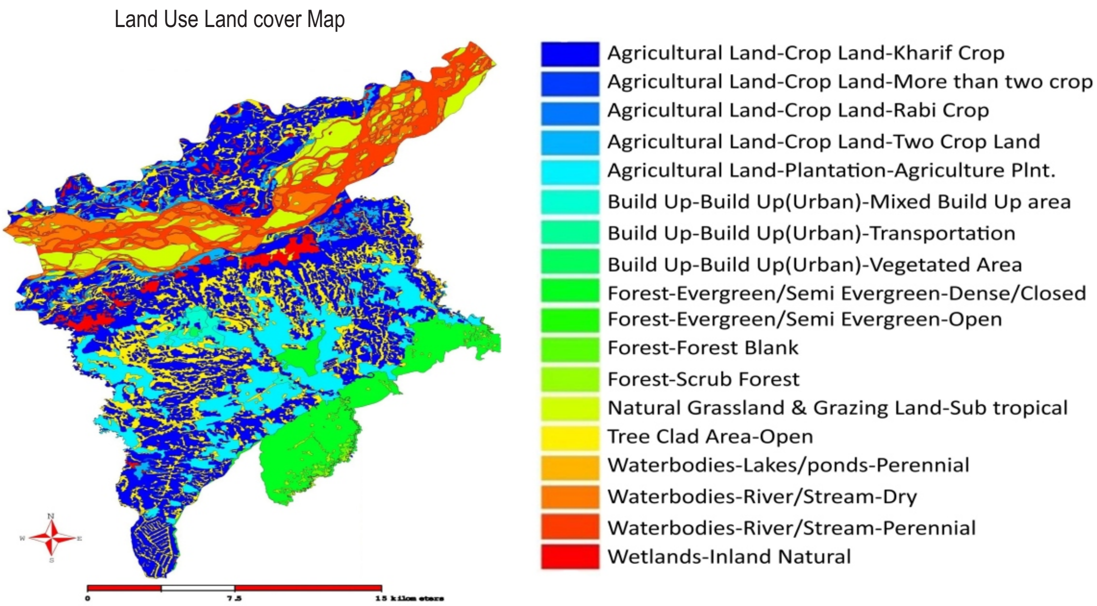



**Fig. 2 :** Land use land cover map

Where, π=3.14 and r= radius (=DBH/2)

The volume of wood for trees was estimated using species specific equation and for shrub layer (5x5m quadrant) the following equation was used;

$$\text{Volume of wood (V)} = A_b \times H \times Kc \qquad \text{(Eq. 2)}$$

Where, H is the height of the tree and Kc is the site-dependent constant (Kc= 0.5463)

Then, for both tree and shrub layer following equations were used;

$$\text{Wood Biomass (WB)} = V \times WD \times 1000 \qquad \text{(Eq. 3)}$$

Where, WD is the wood density [WD for shrub layer was considered as 0.35; FAO (2004)]

$$\text{Crown Biomass } [V' (m^3)] = \pi \times Db \times Hc/12 \qquad \text{(Eq. 4)}$$

Where, Hc is the height of the crown, Db is the crown length+ crown width

The final formula was Above Ground Biomass (AGB) as follows:

$$AGB = WB + V' \qquad \text{(Eq. 5)}$$

For each agro-ecosystem, the total AGB was estimated by summarizing biomass of each tree species and extrapolated to the areal extent of each agro-ecosystem.

**Below ground biomass:** To measure BGB, the root-to-shoot ratio methodology was used, where root biomass was measured from the shoot biomass. The equation developed by MacDicken was used (1997) to estimate Belowground biomass:

$$BGB = AGB \times 0.2 \qquad \text{(Eq. 6)}$$

**Carbon stocks in herb and litter layer:** Oven-dry weights of herb and litter sub samples were determined to compute for the total dry weights using the formula (Hairiah *et al.,* 2001):

$$\text{Total dry weight (kg m}^{-2}) = \text{Total fresh weight (kg)} \times \frac{\text{(Subsample dry weight (g)}}{\text{(Subsample fresh weight (g)}} \times \text{Sample area (m}^2) \qquad \text{Eq. (7)}$$

Carbon storage in herb and litter layer was computed by the following formula (Lasco *et al.,* 2006):

$$\text{C stored (ton ha}^{-1}) = \text{Total dry weight} \times \text{C content} \qquad \text{(Eq. 8)}$$

The carbon stock (carbon content) for dry biomass of herbs and litters was 47% of the total dry biomass of the quadrate (IPCC, 2007).

**Soil carbon stock :** Collected composite soil samples were examined for SOC estimation using the Walkely-Black methods (Black *et al.,* 1965). SOC per quadrate and then per hectare in tons calculated as follows:

$$SOC = (\rho b \text{ (g cm}^3) \times D \text{ (cm)} \times \%C) \qquad \text{(Eq. 9)}$$

Where, SOC is the soil organic carbon (t/ha), % OC is the organic carbon concentration of the quadrate (%) expressed in decimal, ρb = bulk density of the quadrate (g cm$^{-3}$), D is the depth of the soil sample (cm).

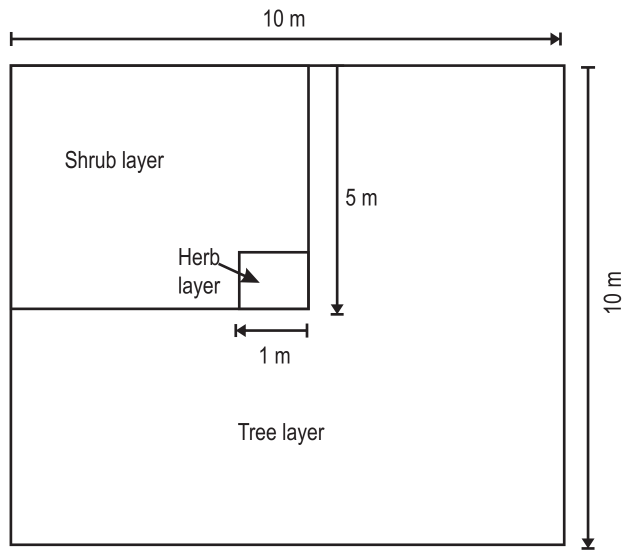



**Fig. 3 :** Quadrate sampling for biomass in both forest and agricultural land

**Total carbon stock:** The total carbon stock from various carbon pools was calculated by aggregating the carbon stock densities of individual carbon pools using the equation given by Subedi *et al.,* (2010).

$$TC= AGC + BGC + SOC \qquad \text{(Eq. 10)}$$

Where, TC is total carbon, AGC is aboveground carbon, BGC is belowground carbon and SOC is soil organic carbon.

Data were tested for normality and homogeneity of variance usingtheLevene's Test. They were then subjected to parametric statistical analysis. Means were compared by the Tukey's test at the 5% probability level.

## Results and Discussion

**Biomass carbon of tree, shrub and herb:** Above ground and below ground biomass of (142.65 mg ha$^{-1}$ AGBC and 28.53 mg ha$^{-1}$ BGBC) was higher by about 200% compared to HAFF (66.22 Mg ha$^{-1}$ AGBC and 14.24 mg ha$^{-1}$ BGBC) and by more than 800% as compared to HAFP (16.50 mg ha$^{-1}$ AGBC and 3.30 mg ha$^{-1}$ BGBC) agro-ecosystem (Table 3) which indicated abundance of carbon sink in biomass under HL agro-ecosystem. Similarly for shrub layer the AGB and BGB was higher for HL (0.211 mg ha$^{-1}$ AGBC and 0.042 mg ha$^{-1}$ BGBC) by about 130% as compared to HAFP (0.160 mg ha$^{-1}$ AGBC and 0.032 mg ha$^{-1}$ BGBC) and by more than 270% as compared to HAFF (0.079 mg ha$^{-1}$ AGBC and 0.016 mg ha$^{-1}$ BGBC) agro-ecosystem. According to the findings of Ullah and Amin (2012) under more matured forest, the amount of biomass in undergrowth shrubs as well as herbs reduced to 3% or less of total biomass of the forest, but this condition is not satisfactory under current study. Moreover, herbaceous population which is mostly affected by flooding was also abundant under HL agro-ecosystem which might be due to higher elevation of this ecosystem which results in less frequency of flood. The herbaceous biomass carbon of HL (0.314 mg ha$^{-1}$) was almost at per with HAFF (0.304 mg ha$^{-1}$) followed by HAFP and lowest for CA, which is most flood affected area of the district.

**Estimation of above and belowground carbon stocks:** It was found that forest land use had more biomass carbon as compared to adjacent agricultural land under all agro-ecosystems (Table 4). Above ground biomass and below ground biomass carbon (AGBC) for the district was found to be highest for HAFF (7.92 Tg and 1.70 Tg) system (Table 4) and clearly forest ecosystem contributed more compared to agricultural land, which was followed by HL, where, total AGBC was found to be 3.20 Tg and BGBC was 0.64 Tg. Similarly, for HAFP region, AGBC was 1.92 Tg and BGBC was 0.41 Tg and agricultural land had lower (0.294 Mg ha$^{-1}$) biomass (Table 4) compared to forest ecosystem. HL system had more forest area, therefore, it showed (Table 3) maximum biomass carbon (171.18 Mg) per unit area compared to other agro-ecosystems. Raju (2012) reported that aerial extent of each system is an important parameter which determines the carbon stock. The more aerial extent indicates more biomass (Solomon *et al.* 2017) resulted in more carbon storage.

**Soil characteristics under different agro-ecosystems under both land use :** Soils of forest under HAFF agro-ecosystem had BD ranging from 1.13 to 1.48 g cc$^{-1}$ (Table 5) which was higher than agricultural land (1.0- 1.40 g cc$^{-1}$) which might be attributed to the presence of more sand than clay (Houston *et al.* 2010). But in case of other agro-ecosystems (viz; HAFP, HL and CA), agricultural land had higher BD compared to forest (Kodiwo *et al.,* 2014) which might be due to compaction because of different agricultural activities. Soils were found to be acidic (4.19 – 6.58) to near neutral under all agro-ecosystem in all land use. Higher values of pH were observed for agricultural land (Meetei *et al.*, 2017) under CA agro-ecosystem (Table 5) which might be due to alluvial soil which gets washed and redeposited during monsoon period. Organic carbon (OC) of forest under all agro-ecosystems was higher compared to agricultural land (Amanuel *et al.,* 2018) which was due to higher biomass deposit under forest compared to agricultural land or due to repeated cultivation or disturbance of soil over the year (Majumdar *et al.,* 2008) or complete removal of crop from the field due to various reasons. Agricultural land of HAFF showed higher mean OC (Table 5) compared to agricultural lands of other agro-ecosystems (Borah 2012). Higher OC in soil of agricultural land near to forest might be due to erosion of topsoil from nearby forest and deposit at agricultural land or higher clay content (Meetei *et al.,* 2017) or higher value of CEC. Similarly, cation exchange capacity (CEC) of agricultural land was lower compared to forest, except soils under HAFF. The higher CEC values of agricultural land compare to forest might be due to higher clay content (Chen *et al.,* 2016).

**Soil organic carbon density (SOCD) and Soil Carbon Stock (SCS) :** SOC density of HAFF was recorded to be 230.83 mg ha$^{-1}$ for

**Table 3 :** Biomass carbon stock of all layers under different agro-ecosystems

| Agroecosystems | AGB (mg ha$^{-1}$) | BGB (mg ha$^{-1}$) | AGBC (mg ha$^{-1}$) | BGBC (mg ha$^{-1}$) | TBC (mg ha$^{-1}$) |
|---|---|---|---|---|---|
| **Tree** | | | | | |
| HAFF | 66.22 | 13.24 | 66.22 | 14.24 | 80.46b |
| HAFP | 16.50 | 3.30 | 16.50 | 3.30 | 19.80a |
| HL | 156.95 | 31.39 | 142.65 | 28.53 | 171.18c |
| CA | —— | —— | ——— | ——- | ——— |
| Shrub | | | | | |
| HAFF | 0.203 | 0.101 | 0.079 | 0.016 | 0.095a |
| HAFP | 0.060 | 0.012 | 0.160 | 0.032 | 0.192b |
| HL | 0.130 | 0.026 | 0.211 | 0.0422 | 0.253c |
| CA | ——- | —— | ——- | —- | —- |
| Herb | | | | | |
| HAFF | —- | —- | —— | —— | 0.304c |
| HAFP | —- | —- | —— | —— | 0.294b |
| HL | —- | —- | —— | —— | 0.314c |
| CA | —- | —- | —— | —— | 0.158a |

a, b, c = Means across rows among agro-ecosystems that do not share a letter are significantly different

**Table 4:** Above and below ground and herbal biomass carbon under both land use for different agroecological system

| Agro-ecological system | Area | Total AGBC | Total BGBC | Total BC |
|---|---|---|---|---|
| | (sq m) | | ————Tg——- | |
| HAFF | 1198.68 | $7.92^{b}$ | $1.70^{a}$ | $9.66^{c}$ |
| HAFP | 1194.29 | $1.92^{b}$ | $0.41^{a}$ | $2.43^{c}$ |
| HL | 224.02 | $3.20^{b}$ | $0.64^{a}$ | $3.85^{c}$ |
| CA | 164.03 | NA | NA | 0.0026 |

a,b,c= Means across rows among agro-ecosystems in each biomass pool that do not share a letter are significantly different.

**Table 5 :** Soil characteristics at different depth under different agro-ecosystems for both land use

| Land use | Soil | BD | | pH | | OC | | CEC | |
|---|---|---|---|---|---|---|---|---|---|
| | profiles | Range | Mean± SD | Range | Mean± SD | Range | Mean± SD | Range | Mean± SD |
| **HAFF** | | | | | | | | | |
| Forest | P1 | 1.13-1.48 | 1.26±0.14 | 4.47-5.60 | 4.97±0.41 | 5.10-20.40 | 10.08±6.26 | 4.40-9.60 | 7.24±2.30 |
| | P2 | 1.16-1.43 | 1.33±0.11 | 4.73-6.39 | 5.86±0.54 | 2.10-9.30 | 4.46±2.46 | 4.67-9.73 | 6.89±2.17 |
| Agricultural land | P3 | 1.00-1.38 | 1.24±0.13 | 4.19-5.56 | 5.12±0.53 | 0.90-10.50 | 6.21±3.33 | 5.80-9.80 | 7.11±1.65 |
| | P4 | 1.11-1.40 | 1.28±0.11 | 4.61-6.21 | 5.37±0.47 | 6.90-18.30 | 12.30±3.80 | 1.80-7.20 | 4.46±1.83 |
| **HAFP** | | | | | | | | | |
| Forest | P5 | 1.24-1.34 | 1.28±0.03 | 5.55-6.21 | 5.78±0.23 | 2.40-14.70 | 7.90±5.26 | 4.80-10.20 | 8.09±2.29 |
| Agricultural land | P6 | 1.19-1.47 | 1.34±0.12 | 5.26-6.50 | 5.73±0.42 | 3.90-7.20 | 5.80±1.16 | 1.40-2.40 | 1.93±0.35 |
| | P7 | 1.31-1.58 | 1.54±0.10 | 6.11-7.22 | 6.81±0.47 | 1.50-6.30 | 3.21±1.66 | 1.03-1.17 | 1.08±0.30 |
| **HL** | | | | | | | | | |
| Forest | P8 | 1.15-1.33 | 1.23±0.09 | 5.11-6.14 | 5.41±0.31 | 6.60-17.40 | 13.09±3.15 | 5.60-10.13 | 6.85±1.50 |
| | P9 | 1.24-1.26 | 1.25±0.11 | 5.06-5.85 | 5.44±0.33 | 5.40-15.90 | 9.60±4.26 | 5.07-9.60 | 6.73±1.79 |
| Agricultural land | P10 | 1.30-1.36 | 1.33±0.04 | 5.48-6.02 | 5.80±0.18 | 1.20-12.60 | 4.50±4.22 | 5.00-10.40 | 8.07±1.84 |
| **CA** | | | | | | | | | |
| Agricultural land | P11 | 1.21-1.51 | 1.38±0.12 | 5.66-6.88 | 6.38±0.39 | 0.30-16.50 | 6.68±7.1 | 0.60-6.40 | 3.75±2.12 |
| | P12 | 1.15-1.46 | 1.37±0.14 | 5.35-6.16 | 5.41±0.18 | 3.10-12.30 | 6.44±3.32 | 2.10-13.00 | 5.61±3.74 |

forest and 240.05 Mg ha$^{-1}$ for agricultural soil (Table 6). Similarly, for HAFP, forest SOCD (133.59 mg ha$^{-1}$) was lower compared to agricultural land (163.45 Mg ha$^{-1}$). Lower SOCD in case of paddy soil compared to forest might be attributed to forest degradation and erosion problem (Lal, 2004) owing to human interventions (Baruah *et al.,* 2017) which resulted in deposition of fertile forest surface soil

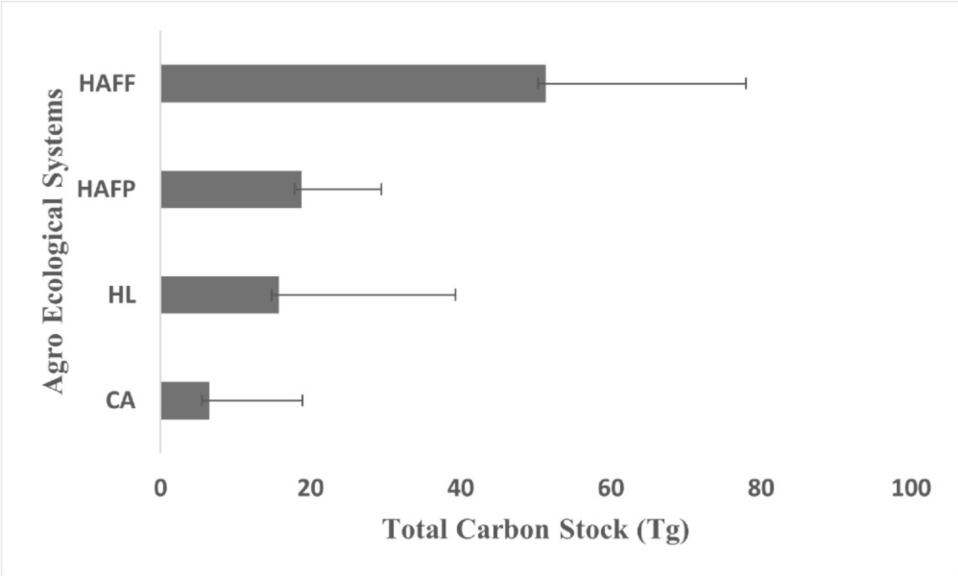



**Fig. 4 :** Total carbon stock of different agro-ecosystems of Jorhat district (with bar of standard deviation)

**Table 6 :** Soil organic carbon density (SOCD) and SCS for differentagro-eco systems

| Land use | Basal area (sq km) | Soil organic carbon density (Mg $ha^{-1}$) | Total soil carbon stock (Tg) |
|---|---|---|---|
| **HAFF** | | | |
| Forest | 2.64 | $230.83^a$ | $0.061^a$ |
| Agricultural land | 1194.29 | $240.05^a$ | $41.79^b$ |
| Total | | 470.88 | 41.85 |
| **HAFP** | | | |
| Forest | 0.026 | $133.59^a$ | $3.2x10^{-4a}$ |
| Agricultural land | 800.42 | $163.45^b$ | $13.08^b$ |
| Total | | 297.04 | 13.08 |
| **HL** | | | |
| Forest | 143.62 | $499.21^a$ | $7.17^b$ |
| Agricultural land | 70.30 | $49.48^b$ | $0.35^a$ |
| Total | | 548.69 | 7.52 |
| **CA** | | | |
| Forest | NL | ------ | ------ |
| Agricultural land | 161.82 | 265.58 | 3.65 |
| Total | | 265.58 | 3.65 |

a,b,c= means across column under each agro-ecosystem in both soil carbon pool that do not share a letter are significantly different

on nearby paddy field. Due to more aerial extent of agricultural field in HAFF and HAFP compared to forest cover (Solomon *et al.,* 2017), SCS was recorded high in paddy fields (41.79 Tg and 13.08 Tg respectively). On the other hand, HL had SOCD of 499.21 Mg $ha^{-1}$ for forest and only 49.48 Mg $ha^{-1}$ for agricultural land which may be attributed to more area under forest as people of HL mostly engaged in tea garden activities (Baruah *et al*., 2017). Moreover, higher residue additions in forest (Meetei *et al.*, 2017) due to higher land cover compared to agricultural land also can stand for higher carbon density. SCS of HL for forest was 7.17 Tg and that for agricultural land was 0.35 Tg and total soil carbon stock of the system was found to be 12.29 Tg (Table 6). On the contrary, Char area did not have forest cover, but it had extensive agricultural land, therefore, lot of erosion and degradation was observed in patches which resulted in poor soil conditions (Table 5). The total soil carbon stock was recorded to be 3.65 Tg for CA which was very low as compared to agricultural soils of other systems except HL where area under agriculture was lowest (70.30 sq km).

**Total carbon stock (TCS):** Total biomass carbon stock (BCS) was found to be highest for HAFF (9.66 Tg) followed by (Table 4) HL (3.85 Tg), HAFP (2.46 Tg) and CA (0.0026 Tg). Although, total

**Table 7 :** Total carbon stock of different agro-eco systems under both forest and agricultural land use

| AES | Basal area (sq km) | Biomass carbon (BC)(Tg) | Soil carbon (SC)(Tg) | Total carbon stock (TCS)(Tg) |
|---|---|---|---|---|
| **Forest** | | | | |
| HAFF | 2.64 | 7.92[a] | 0.06[b] | 7.98[a] |
| HAFP | 0.026 | $0.53 \times 10^{-4a}$ | $3.2 \times 10^{-4\,a}$ | $3.73 \times 10^{-4a}$ |
| HL | 143.62 | 3.20[c] | 7.17[c] | 10.37[c] |
| **Agriculture** | | | | |
| HAFF | 1194.29 | 1.70[b] | 41.85[b] | 43.55[b] |
| HAFP | 800.42 | 2.40[c] | 13.08[c] | 15.48[c] |
| HL | 70.30 | 0.64[a] | 0.35[a] | 0.68[a] |
| CA | 161.82 | 0.55[a] | 3.65[b] | 4.20[b] |

a,b,c= means across column under each land use in different agro-ecosystems in all carbon pool that do not share a letter are significantly different

BCS was higher under HAFF but forest BCS was highest for HL (2.46 Tg) and that for agricultural land was highest for HAFP (9.60 Tg) which might be due to more area coverage (Bhattacharyya *et al.,* 2007; Brown *et al.,* 1993) of forest as well as agricultural land in the respective agro-ecosystems of the district.

On the other hand, SCS for forest (Table 7) was also highest under HL (7.17 Tg) followed by HAFF (0.061 Tg) which showed a good correlation between biomass of plants and soil carbon stock in the present investigation. These findings were supported by Baruah *et al.,* (2017). While total carbon stock of the district was highest (Fig. 4) for HAFF (51.53 Tg) followed by HAFP (15.48 Tg) and HL (11.38 Tg) agro-ecosystem for Jorhat district. These finding were supported by Solomon *et al.* (2017) signifying importance of aerial distribution of land use on carbon stock.

The present carbon stock under different agro-ecosystems of Jorhat district was highest for HAFF, followed by HAFP, HL and CA. Therefore, there are lots of opportunities to stimulate carbon build up in all the agro-ecosystems, especially in CA where present carbon stock was lowest. For improvement of carbon sequestration efficiency, it is very important to develop some strategies or methodologies which improve carbon sequestration by reducing $CO_2$ emission and have ability to elevate soil health.

At present day scenario, location specific treatments are more important than any other generalized strategies for resolving issues relating to carbon sequestration. Moreover, these treatments should be in accordance with climate resilient perspective which not only improves carbon reserve but also restore soil productivity and ultimately increase production per unit area. Along with improving carbon reserve, demand for monitoring the changes in carbon stock over years is increasing for developing effective methodology for carbon sequestration in different land uses under different agro-ecosystems; therefore, monitoring aspect should be included in future research.

## Acknowledgement

The authors are very thankful towards the support and good response of the forest professionals who helped during data and sample collection. Moreover, support of Department of Soil Science, Assam Agricultural University for arranging vehicle and providing labour is much appreciated.

## Add-on Information

**Authors' contribution: R. Baruah, B.K. Medhi, D. Bhattacharya and D.K. Patgiri**.

**Research content:** The research content is original and has not been published elsewhere

**Ethical approval:** Not Applicable

**Conflict of interest:** The authors declare that there is no conflict of interest.

**Data from other sources:** Not Applicable

**Consent to publish:** All authors agree to publish the paper in *Journal of Environmental Biology*.

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