Journal of Environmental Protection, 2018, 9, 912-931
http://www.scirp.org/journal/jep
ISSN Online: 2152-2219
ISSN Print: 2152-2197

Assessment of Growth, Carbon Stock and Sequestration Potential of Oil Palm Plantations in Mizoram, Northeast India

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How to cite this paper: Singh, S.L., Sahoo, U.K., Kenye, A. and Gogoi, A. (2018) Assessment of Growth, Carbon Stock and Sequestration Potential of Oil Palm Plantations in Mizoram, Northeast India. *Journal of Environmental Protection*, **9**, 912-931.
https://doi.org/10.4236/jep.2018.99057

Received: July 12, 2018
Accepted: August 11, 2018
Published: August 14, 2018

Abstract

A study was conducted to assess growth, carbon stock and sequestration potential of oil palm plantations along a chronosequence in Mizoram, Northeast India for which a total of 148 oil palms drawn from different age group plantations (1 to 11 years) were sampled for their biometric parameters and assessment of carbon stock through partial non-destructive methods. All the growth parameters of oil palm (trunk height, crown depth, total height, trunk diameter) and biomass drew from different parts of the palm showed a significant ($p < 0.05$) progressive growth along a chronosequence. Crown biomass was observed higher (65.00%) in younger age groups 1 - 3 years, while the trunk with old frond bases biomass showed a larger percentage (67.96%) in the older oil palm aged 4 - 11 years. All the linear correlations between the growth variables with age and biomass were observed significant at $p < 0.01$. Total above ground biomass (AGB) was highly correlated with the trunk height ($r = 0.985$), total height ($r = 0.994$) and age ($r = 0.973$). On an average, portioning of biomass and carbon stock was in the order: AGB > belowground biomass (BGB) > standing litter biomass > deadwood biomass > understorey biomass. AGB, BGB and deadwood biomass followed an increasing trend while understorey biomass decreased with age. An 11-year oil palm plantation accumulated 111.96 Mg ha^{-1} biomass with a carbon density of 49.90 Mg C ha^{-1} and could sequester 3.70 Mg C ha^{-1} $year^{-1}$ in 10 years after planting in Mizoram, Northeast India. The findings showed considerable carbon storage with comparative higher values in oil palm plantations than shifting cultivation fallows. This will enable policy and decision makers in framing climate change mitigation and adaptation policies regarding the extension of oil palm plantations in Mizoram.

Keywords

Oil Palm, Above Ground Biomass, Carbon Stock, Carbon Sequestration

Potential, Northeast India

1. Introduction

Increasing levels of greenhouse gases (GHGs) concentration, mainly CO_2 in the atmosphere, is a major concern responsible for climate change in the current global environment scenario. Carbon storage in the tropical ecosystems has been disturbed through land-use and land-cover change releasing greenhouse gases (C emissions) with a relative value ranging 10% - 13% annually [1]. Forestry and agroforestry systems which incorporate tree crops render a significantly larger sequestration potential for longer periods than compared with normal agricultural crops [2]. Tree crop plantations mainly in developing countries provide a long-term reduction in GHGs levels through sequestration and also provides work, income, and food, especially the smallholder systems [3] [4] [5].

Elaeis guineensis Jacq. have been introduced in Mizoram, Northeast India under a joint venture of Government of India and State of Mizoram. Oil palm plantations in Mizoram was started in 2004-2005 with the State Department of Agriculture as a nodal agency under schemes like the New Land Use Policy (NLUP) as an alternative land use to divert farmers practicing the traditional shifting cultivation. The promotion of oil palm under the scheme was to decrease GHGs emissions, increase local production of biofuels and to ensure energy security and creation of jobs in the state. The oil palm plantations were restricted to shifting cultivation fallows and other degraded lands and focused to support the marginal and small land holders. Extensive studies on the botanical and cultivation aspects of oil palms had been carried out owing to its commercial importance and their rapid expansion may well be a cause of deforestation in many countries of Southeast Asia [6]. Conversion of forests into oil palm plantations has aggravated environmental issues such as biodiversity losses and net emission of carbon dioxide responsible for global warming [7] [8]. In addition, carbon storage and soil fertility get affected as soil organic carbon (SOC) contents become lower under oil palm than under primary or secondary forest [9].

However, oil palm shows a wide "management swing potential" acting both among the best and worst in terms of emission saving. It is best if grown on already deforested lands and the worst when grown on deeply drained soils from freshly felled forest [6] [10] [11] [12] [13] [14]. Oil palm plantations are suggested to generate economic benefit as well as contribute to carbon storage in a more sustainable way if planted in areas of low productivity or on degraded land [7] [15] [16]. Various studies on carbon sequestration of oil palm plantations in Southeast and East Asia have been reported [17] [18] [19] [20]. Researchers estimate oil palm biomass and volume by destructive sampling which is tedious and time consuming while some of the studies are based on non-destructive methods in which allometric equations developed from data extrapolation with destructive measurements on a few palms of each age groups were used to relate biomass to age or height of palm trees [17] [21]. Studies on oil palm biomass have been also reported from South America [16] [22]. Biomass and its proximate analysis of different oil palm components have also been reported from Malaysia [23]. As per studies conducted by Indian Council of Agricultural Research (ICAR)-Indian Institute of Oil Palm Research (IIOPR), annual dry matter production and carbon sequestered by oil palm were 36.25 $Mg \cdot ha^{-1} \cdot year^{-1}$ and 11.63 $Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ respectively. However, there is a complete lack of our understanding as to how this ongoing oil palm plantation in Northeast India contributes to the carbon stock and climate change mitigation. The present study differs by using much simplified non-destructive sampling methodology because of restricted sampling areas for felling. Moreover, the study focuses on Mizoram in Northeast India where deforestation and shifting cultivation played a major role in C emission. As per reports, oil palm plantations in Mizoram are carried out replacing the shifting cultivation fallow lands. Thus, it is of prime importance to study the C sequestration potential of oil palm plantations with a rotational cycle of 25 - 30 years; otherwise, it would have become a full-fledged forest if left for natural secondary regeneration. The objectives of this study were to assess the growth and biomass stock of oil palm plantations; quantify carbon stock stored in both biomass and soil; and estimate the carbon sequestration potential in different aged oil palm plantations of Mizoram, Northeast India.

2. Materials and Methods

2.1. Study Area

The present study was carried out in selected oil palm plantations along a chronosequence located in Kolasib district (lat. 92˚30'31"E to 92˚54'00"E; long. 23˚57'34"N to 24˚22'21"N) of Mizoram, Northeast India (**Figure 1**). The state has an undulated topography with over 80% of the total geographical area being hilly with steep slopes. The soils of Mizoram are dominated by sedimentary formations with loam to clay loam texture possessing Udic soil moisture regime [24]. Mizoram experienced short winter and long summer with heavy rainfall ranging 2000 - 3200 mm annually. Mizoram has a forest cover of 86.27% of its total geographical area which is 18,186 km^2 with a decline of 562 km^2 from its assessment in 2015 [25]. Agriculture is the main occupation and shifting cultivation continues to be the predominant practice, affecting as much as 2618 km^2 or about 14% of the state area [26].

2.2. Sample Plot Design and Growth Measurements

Circular sample plots with 10 m radii, consisting of 4 - 5 palms were established in oil palm plantations of different age groups with planting age ranging from 1 to 11 years located in Kolasib district of Mizoram. In total, 148 individual oil palms at various age stages were measured from the 33 sample plots, 3 plots for each age group, from January to February 2017. The girth of the trunk at 10 cm

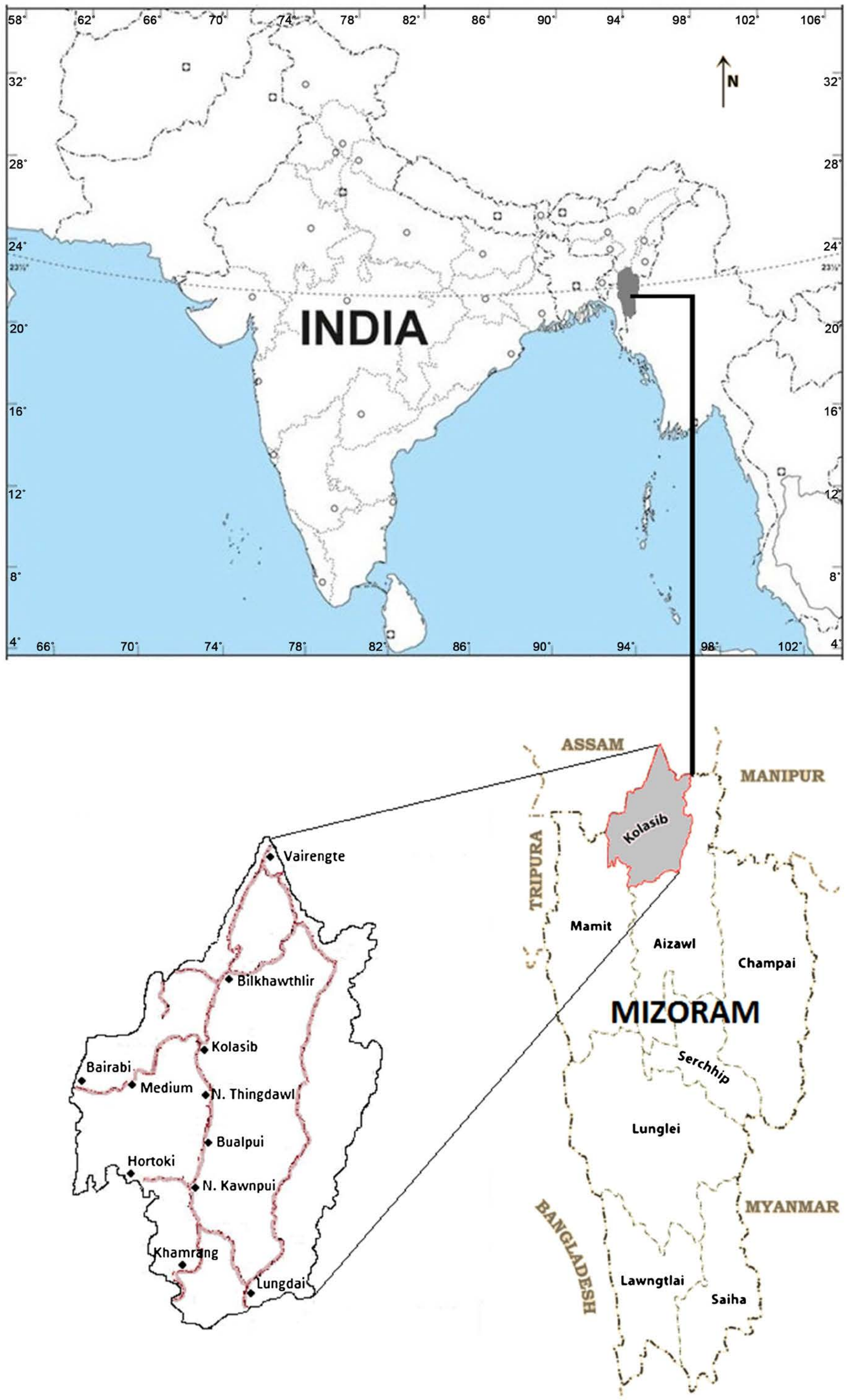

Figure 1. Location of study site in Mizoram, Northeast India.

above ground level (G_{10}) to determine Trunk diameter (D) was measured with a tape in m. Trunk height (H_1) from ground level was measured upto the lowest leaf maintained in the canopy and Total height (H_2) to the tip of the leading shoot were measured with the help of a straight bamboo pole attached with measuring tape in m. The total number of fronds (N) present in the palm were counted and recorded. A sample of the middlemost frond from the crown maintained was harvested from each palm selected and separated into petiole, rachis, and leaflet. Fresh weight of all harvested material was recorded and a sub sample of 100 g each was bagged to be oven dried at 80˚C for 48 h to determine dry matter. Likewise, the number of frond base attached to the trunk in each of the palms was also counted and one random sample from each palm was taken to determine the average dry weight for each age category.

2.3. Oil Palm Biomass

Using partially destructive sampling, oil palm biomass ($Mg·ha^{-1}$) was estimated from five pools: Above ground biomass (AGB), Below ground biomass (BGB), Understorey biomass, Litter biomass and Deadwood biomass [27]. The total AGB of oil palm was estimated from three components: Trunk, Frond and Old Frond Base remaining on the stem.

Trunk biomass was estimated, assuming a cylindrical shape of the trunk as:

$$\text{Trunk biomass, } T_b\left(kg\cdot palm^{-1}\right) = 0.25\times\pi\times D^2\times H_1\times\rho \quad (1)$$

where D is the trunk diameter in m, H_1 is the trunk height in m, and ρ is oil palm density in $kg·m^{-3}$ (with an average value of 395) [28].

Frond Biomass was estimated by calculating the total number of fronds and taking a sample of the middlemost frond to determine the average dry weight of a representative single frond [29] as:

$$\text{Frond Biomass, } FB\left(kg\cdot palm^{-1}\right) = N\times DW \quad (2)$$

where N is number of fronds, DW is the dry weight of single frond in kg calculated as 1.146 × ($DW_{petiole}$ + DW_{rachis} + $DW_{leaflet}$), 0.1416 = correction factor as part of the petiole is still attached to the trunk [29].

Old Frond bases which remained on the stem were counted and its biomass was estimated from the dry weight of the sample representative frond taken as:

$$\text{Old Frond bases Biomass, } FB_s\left(kg\cdot palm^{-1}\right) = N\times DW \quad (3)$$

where, N is number of old frond bases present on the trunk, DW = dry weight of single frond base in kg.

Above ground biomass (AGB) of oil palm was thus determined using:

$$AGB\left(kg\cdot palm^{-1}\right) = T_b + FB + FB_s \quad (4)$$

Below ground biomass (BGB) of oil palm was estimated from AGB values by adopting a root to shoot ratio of 0.30 [30] as:

$$BGB\left(kg\cdot palm^{-1}\right) = 0.30\times AGB \quad (5)$$

The AGB and BGB were then expressed in $Mg·ha^{-1}$ considering a uniform density of 143 $palms·ha^{-1}$ (planted at 9 m triangular spacing) in all the oil palm plantation age groups.

Understorey vegetation and standing litter stock were estimated from 1 m × 1 m sample plots [31]. All of the understorey vegetation was uprooted and litter was collected separately. The results from oven-dried samples were scaled up to a hectare basis using the effective sampling area. Deadwood in oil palm plantations mainly comprised of the pruned frond piles. Total number of pruned fronds (N_{pf}) present in the sample plot was recorded and a random representative sample frond from each plot was estimated for its oven dried biomass weight (DW_{pf}). Pruned frond/Deadwood biomass was then calculated as:

$$\text{Deadwood} = N_{pf} \times DW_{pf} \tag{6}$$

2.4. Soil Organic Carbon (SOC) and SOC Stock

In each plot, three sampling points were selected randomly and soils were collected at two depth classes: 0 - 20 and 20 - 40 cm. The three sub samples at each plot and depth class were bulked to get one composite sample for each depth class per plot. The soil samples were air-dried, grounded, passed through 2 mm sieve and stored in air-tight plastic bags. All the analyses were done by taking three replicates from each depth at a given site. Soil Bulk density was determined by soil corer method [32]. Bulk density of fine soil was then estimated by deducting coarse rocky fragments percentage obtained after sieving through a 2 mm sieve. Soil organic carbon was determined by Walkley-Black rapid titration method [33]. Soil organic carbon density (Mg C ha^{-1}) was computed as follows [34]:

$$\text{SOC} = \sum_{\text{horizon}=1}^{\text{horizon}=n} \text{SOC}_{\text{horizon}} = \sum_{\text{horizon}=1}^{\text{horizon}=n} \left([\text{SOC}] \times \text{Bulk density} \times \text{Depth} \times (1 - \textit{frag.}) \times 10 \right)_{\text{horizon}} \tag{7}$$

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

2.5. Carbon Stock and Sequestration Potential of Oil Palm Plantation

The carbon content of oil palm trunk, BGB components, and understorey vegetation was assumed the default value of 0.47, and 0.40 for the standing litter stock and deadwood [34]. Carbon content in the other different parts of oil palm was determined from the sub samples by grinding them in a Wiley mill and 2 g of the powdered sample being ignited at 550˚C for 6 h in a muffle furnace [35]. The ash content (the inorganic elements in the form of oxides,%) left after burning was weighed and carbon content was calculated by using the following equation:

$$\text{Carbon content}(\%) = 100 - \{\text{Ash}(\%) + 53.28\} \tag{8}$$

Carbon stock in different biomass components was obtained after multiplying the biomass with their respective carbon content values and summed up to obtain the total carbon stock expressed in Mg·C·ha^{-1}. Total carbon storage in oil palm plantation areas in Mizoram was calculated from the recorded data.

Carbon sequestration was then estimated from differences in carbon stock values of different age plantations, expressed in Mg·C·ha^{-1}·year^{-1}. In this study, carbon stock values at different age plantations of oil palm were supposed to have been accumulated by the system in a chronosequence, hence the difference in stock levels indicate the sequestration potential and an average annual carbon fixation rate expressed Mg·C·ha^{-1}·year^{-1}.

2.6. Statistical & SWOT Analysis

Analysis of data was performed using software MS Excel 2007 and SPSS 17.0 for windows. Test of significance for the means of above ground biomass and other oil palm biometric parameters among the various age groups was undertaken by one way ANOVA. Multiple comparison tests (Tukey HSD) were used to compare wherever statistical significance was obtained. SWOT (Strength, weakness, opportunities and threat) analysis was also conducted to assess the suitability of NLUP for promoting oil palm in the area and their environmental sustainability.

3. Results and Discussion

A total of 10,100 ha of land located at low elevation with gentle slope have been identified as a potential area for oil palm cultivation in Mizoram and out of which 23,358 ha were already covered under oil palm plantations in Mizoram, Northeast India as on March 2016 (Table 1). Oil palm plantations in Mizoram,

Table 1. Year-wise Area covered (ha) under Oil palm plantation in Mizoram, Northeast India.

Year	Name of Districts							Area (ha)
	Kolasib	Lunglei	Mamit	Serchhip	Lawngtlai	Aizawl	Saiha	
2005-06	82	28	-	-	-	-	-	110
2006-07	24	-	-	-	-	-	-	24
2007-08	543	15	267	-	-	-	-	825
2008-09	964	218	476	42	-	-	-	1700
2009-10	997	806	697	342	-	-	-	2842
2010-11	489	500	474	310	105	-	-	1878
2011-12	478	562	350	250	300	26	-	1966
2012-13	1039	750	928	327	617	50	-	3711
2013-14	711	852	1300	381	957	331	-	4532
2014-15	694	927	238	216	570	102	42	2789
2015-16	437	631	402	201	980	286	44	2981
Total	6458	5289	5132	2069	3529	795	86	23,358

Northeast India were established on the farmer's land through selection of beneficiaries under the State Nodal Agency and thus, no forest areas were cleared for expansion in contrary with the case of oil palm plantation expansion in Southeast Asia, mainly Indonesia and Malaysia where large scale deforestation occurs [6]. After the enactment of The Mizoram Oil Palm (Regulation of Production & Processing) Act, 2004 to safeguard oil palm growers, the plantations were introduced in 2005-06, they are mostly in their intermediate and young age stages. Age of oil palm plantations can be categorized as: young age stage ranging from 1 - 3 years; intermediate age stage ranging from 4 - 10 years; productive age stage ranging from 11 - 20 years and mature age stage ranged over 20 years after planting [36]. Of the total area under oil palm cultivation, the percentage of young, intermediate and productive age stages were 44.10%, 55.42% and 0.47% respectively. No mature plantation above 20 years old were recorded in Mizoram. Kolasib district of Mizoram recorded the highest area (6458 ha) under oil palm plantations belonging to all the different age groups under study (1 - 11 years).

3.1. Growth Parameters

All the growth parameters of oil palm (trunk height, crown depth, total height, trunk diameter) showed a significant ($p < 0.05$) progressive growth along a chronosequence (**Table 2**). Similar was the case with the biomass drawn from different parts of the palm. In the present study, trunk height and total height were strongly correlated with age than with the trunk diameter, as was also reported from Malaysia [21]. We could not measure the diameter at breast height (DBH) for the younger palms having shorter trunk less than 1.3 m height, so in such cases, the analyses were carried out with trunk diameter at 10 cm above ground instead. Reduction of DBH with the advance of age in oil palm was reported but the reduction was not detected in the present study [21] [37]. This may be due to the young age of oil palm under study where oil palms are reported a steady increase in the bole diameter during all the initial years and the trunk practically ceases its growth in diameter subsequently with the advance of age, which may be related with the absorption of nutrients [38] [39].

Total above ground biomass of the oil palm ranged from 54.92 ± 1.21 to 562.63 ± 7.39 kg $palm^{-1}$ in 1 year and 11 years old plantations respectively. It was found that large percentage (65.00%) of the biomass was found in the crown (petiole + rachis + leaflet) in younger age groups of 1-3 years, while the trunk with frond bases showed larger percentage (67.96%) of biomass in the remaining oil palm studies aged 4 - 11 years. A linear regression calculated from above ground biomass estimated with total height of oil palm shows an increase of AGB with the increase in height (**Figure 2**). All the linear correlations between the variables were observed significant at $p < 0.01$ (**Table 3**). Total AGB was highly correlated with the trunk height ($r = 0.985$), total height ($r = 0.994$) and age ($r = 0.973$).

Table 2. Average values (±S.E. of mean) of height and above ground biomass (AGB) in oil palm plantations of different age in Mizoram, Northeast India.

	Age (years)	1	2	3	4	5	6	7	8	9	10	11
	No. of Sample, N	12	13	13	14	14	14	13	14	13	14	14
Height (m)	Trunk height	0.10 (±0.00)	0.36 (±0.01)	0.68 (±0.01)	1.09 (±0.05)	1.12 (±0.06)	1.51 (±0.02)	1.96 (±0.03)	2.48 (±0.05)	2.86 (±0.06)	3.24 (±0.06)	3.54 (±0.05)
	Crown Depth	0.72 (±0.02)	0.74 (±0.02)	0.77 (±0.02)	1.06 (±0.02)	1.20 (±0.02)	1.21 (±0.01)	1.49 (±0.01)	1.90 (±0.02)	2.24 (±0.02)	2.80 (±0.02)	4.01 (±0.01)
	Total Height	0.83 (±0.02)	1.10 (±0.02)	1.45 (±0.02)	2.15 (±0.04)	2.32 (±0.06)	2.73 (±0.02)	3.46 (±0.03)	4.38 (±0.06)	5.10 (±0.07)	6.04 (±0.07)	7.55 (±0.05)
	Trunk Diameter (cm)	41.86 (±0.69)	42.43 (±0.54)	43.41 (±0.58)	45.11 (±0.56)	47.26 (±0.49)	46.54 (±0.32)	51.04 (±0.46)	50.75 (±0.55)	54.50 (±0.37)	55.46 (±0.41)	56.84 (±0.32)
Biomass (kg/palm)	Trunk Biomass	5.67 (±0.36)	20.08 (±0.83)	39.76 (±1.56)	69.32 (±3.67)	77.91 (±4.95)	101.53 (±1.36)	158.84 (±3.91)	198.15 (±4.71)	263.92 (±6.29)	309.43 (±8.39)	354.92 (±6.86)
	Petiole Biomass	23.70 (±0.49)	28.45 (±0.99)	33.22 (±0.98)	40.89 (±0.72)	41.33 (±1.16)	45.24 (±0.95)	48.60 (±1.28)	49.14 (±1.10)	56.13 (±1.39)	74.25 (±1.42)	87.84 (±1.34)
	Rachis Biomass	7.54 (±0.46)	11.82 (±0.53)	11.63 (±0.37)	12.64 (±0.26)	13.75 (±0.41)	15.65 (±0.50)	15.87 (±0.76)	14.30 (±0.63)	19.59 (±0.69)	25.82 (±1.05)	32.89 (±0.47)
	Leaflet Biomass	11.39 (±0.38)	14.02 (±0.66)	14.63 (±0.47)	14.66 (±0.46)	19.11 (±0.58)	20.77 (±0.56)	20.75 (±0.71)	19.67 (±0.53)	21.71 (±0.69)	28.94 (±1.01)	35.53 (±0.94)
	Frond base Biomass	6.61 (±0.16)	9.02 (±0.34)	16.54 (±0.33)	28.76 (±0.22)	31.09 (±0.24)	31.56 (±0.23)	33.84 (±0.26)	39.77 (±0.30)	40.08 (±0.23)	48.23 (±0.15)	51.45 (±0.23)
	Total AGB	54.92 (±1.21)	83.39 (±1.94)	115.78 (±2.01)	166.27 (±3.67)	183.18 (±5.04)	214.75 (±2.24)	277.90 (±4.11)	321.04 (±4.76)	401.44 (±6.95)	486.67 (±8.02)	562.63 (±7.39)

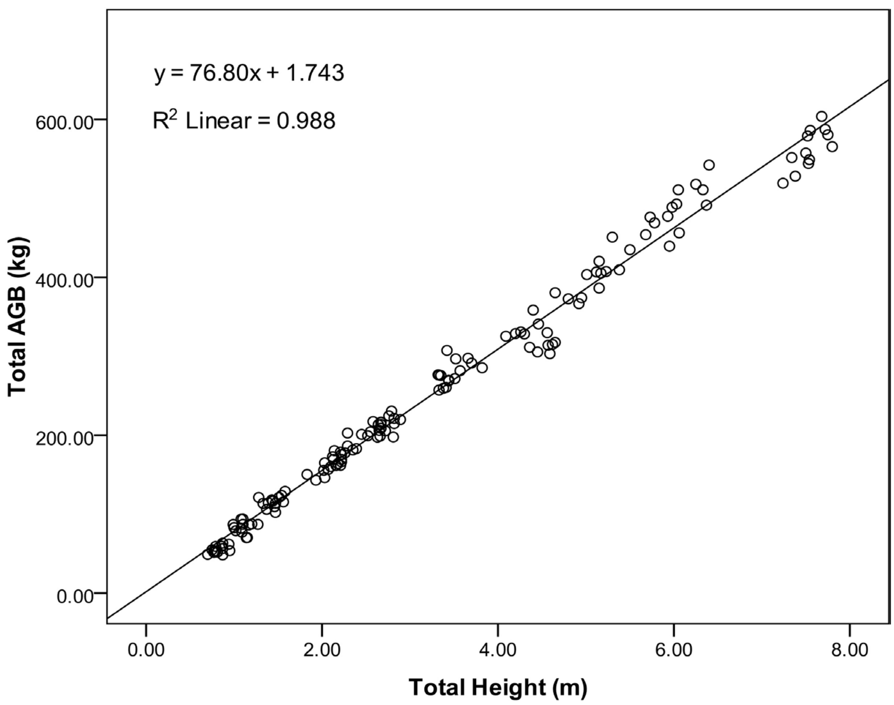

Figure 2. Relationship of AGB (kg palm^{-1}) with height (m) in oil palm plantations in Mizoram, Northeast India.

Table 3. Correlations between biometric variables of oil palm in Mizoram, Northeast India.

	Age	D	H_{trunk}	H_{crown}	H_{total}	B_{trunk}	B_{crown}	B_{fb}	AGB
Age	1								
D	0.928**	1							
H_{trunk}	0.985**	0.926**	1						
H_{crown}	0.909**	0.870**	0.920**	1					
H_{total}	0.970**	0.919**	0.983**	0.976**	1				
B_{trunk}	0.965**	0.944**	0.986**	0.951**	0.990**	1			
B_{crown}	0.911**	0.855**	0.904**	0.951**	0.944**	0.921**	1		
B_{fb}	0.972**	0.887**	0.948**	0.863**	0.927**	0.913**	0.885**	1	
AGB	0.973**	0.939**	0.985**	0.961**	0.994**	0.995**	0.951**	0.932**	1

**Significant at 0.01 level (2-tailed); D = diameter of trunk at 10 cm above ground level; H_{trunk} = Trunk height; H_{crown} = Crown depth; H_{total} = Total height; B_{trunk} = Trunk Biomass; B_{crown} = Crown Biomass; B_{fb} = Frond Bases Biomass; and AGB = total above ground biomass.

3.2. Biomass Partitioning and Carbon Content

On an average, biomass (Mg·ha^{-1}) contribution of various component pools in oil palm plantation results was in the order: above ground biomass > below ground biomass > standing litter biomass > deadwood biomass > understorey biomass (**Table 4**). AGB and BGB distribution in oil palm plantations along a chronosequence ranged from 7.85 ± 0.14 to 80.46 ± 0.48 Mg·ha^{-1} and 2.36 ± 0.04 to 24.14 ± 0.14 Mg·ha^{-1} respectively, following an increasing trend with age. Similarly, deadwood/pruned frond biomass increased whereas the biomass of understorey vegetation decreased with increasing age. The total biomass also gradually increased with age of plantation ranging from 14.22 to 111.96 Mg·ha^{-1} in 1 and 11 years old oil palm plantations respectively. AGB values of oil palm reported from studies in Southeast Asia ranged 50 to 100 Mg·ha^{-1} towards the end of rotation age varying from 20 - 25 years [40]. AGB of 45.93 Mg·ha^{-1} from an eight-year-old plantation under present study compares well with a plantation aged eight years (48.40 Mg·ha^{-1}) in Indonesia measured by using allometric equations based on palm height [41].

A lack of root to shoot data for oil palm has been stated and studies from Brazil reports that roots make up only about 15% of total biomass; however, in the present study, we adopted a suggested value of 0.30 for estimating below ground biomass [16] [29] [30]. Root biomass of oil palms in Indonesia varied from 40.10 to 54.40 Mg·ha^{-1} for 20 and 30 years stands, respectively [42]. In Indonesia, oil palm root biomass of 16.10 Mg·ha^{-1} and a total system biomass of 117.90 Mg·ha^{-1} for a 10-year-old plantation was reported, comparable to BGB of 20.89 Mg·ha^{-1} with a total system biomass accumulation of 96.60 Mg·ha^{-1} from the 10 years old plantation in the present study [42]. It is highly possible that the oil palms will accumulate more biomass in the ensuing 14 - 19 years considering a rotation age of 25 - 30 years of management practice.

The carbon content varied significantly ($p < 0.05$) when compared between different compartment of fronds and frond bases (**Table 5**). Leaflets showed the highest carbon content (42.18%) while the frond base has the lowest carbon content (37.86%). The carbon content of oil palm leaflets studied ranged from 39.56% to 44.26%. Carbon content of oil palm leaflets studied ranged from 39.56% to 44.26% which is close to findings from Indonesia [42]. However, carbon content in different parts of the frond did not show any discernable variations along oil palm chronosequence in the present study. Variations in carbon content among biomass compartments of oil palms in Indonesia was detected ranging 32.3% for fine roots to 44.2% for leaves[42]. Carbon content variation from 45% to 50% in different oil palms parts was also reported in Colombia [22]. The percentage of 50% was usually employed in many similar studies [43]. These being considered unreasonably high for oil palm, the IPCC change its default to 47% [34]. For the oil palm under study here, even the default value adopted may represent overestimation in the conversion of AGB and BGB to carbon stock.

Table 4. Biomass distribution in various compartment of different age oil palm plantations in Mizoram, Northeast India.

Age of Plantation (years)	Biomass ($Mg\ ha^{-1}$)					
	Above ground Biomass (AGB)	Below ground Biomass (BGB)	Understorey Biomass	Litter Biomass	Deadwood Biomass	Total Biomass
1	7.85 ± 0.14	2.36 ± 0.04	1.49 ± 0.02	2.42 ± 0.42	0.10 ± 0.02	14.22 ± 0.61
2	11.93 ± 0.18	3.58 ± 0.05	1.52 ± 0.01	3.10 ± 0.32	0.55 ± 0.03	20.67 ± 0.28
3	16.52 ± 0.10	4.96 ± 0.03	1.14 ± 0.02	2.61 ± 0.40	0.82 ± 0.05	26.05 ± 0.26
4	23.77 ± 0.04	7.13 ± 0.01	0.85 ± 0.01	1.84 ± 0.17	0.88 ± 0.06	34.48 ± 0.15
5	26.09 ± 0.64	7.83 ± 0.19	0.50 ± 0.03	1.88 ± 0.23	1.56 ± 0.08	37.85 ± 0.79
6	30.67 ± 0.17	9.20 ± 0.05	0.34 ± 0.03	2.36 ± 0.40	2.09 ± 0.03	44.66 ± 0.69
7	39.77 ± 0.17	11.93 ± 0.05	0.47 ± 0.05	1.86 ± 0.17	2.45 ± 0.05	56.48 ± 0.27
8	45.93 ± 0.14	13.78 ± 0.04	0.42 ± 0.02	2.50 ± 0.13	2.72 ± 0.07	65.34 ± 0.19
9	57.53 ± 0.76	17.26 ± 0.23	0.33 ± 0.03	0.85 ± 0.21	1.84 ± 0.19	77.80 ± 1.16
10	69.64 ± 0.70	20.89 ± 0.21	0.33 ± 0.05	2.06 ± 0.20	3.68 ± 0.06	96.60 ± 0.97
11	80.46 ± 0.48	24.14 ± 0.14	0.35 ± 0.03	2.16 ± 0.19	4.85 ± 0.15	111.96 ± 0.43

*values followed after ± are standard error of mean.

Table 5. Average carbon content (%) in oil palm parts of different age (1 - 11 years) in Mizoram, Northeast India.

Parts	*n*	Age of Plantation (years)											Average (%)
		1	2	3	4	5	6	7	8	9	10	11	
Petiole	2	38.98	37.94	38.86	40.63	39.05	38.93	39.70	39.05	38.37	37.45	38.63	38.87^{a}
Rachis	2	41.35	39.63	39.66	41.22	40.35	38.83	39.14	39.00	39.08	40.50	40.98	39.98^{b}
Leaflet	2	41.91	41.36	42.05	43.90	41.55	41.86	42.57	42.21	42.04	43.35	41.17	42.18^{c}
Frond Base	2	37.72	39.87	37.36	36.80	37.25	37.33	38.11	37.81	37.82	37.55	38.88	37.86^{d}
Average	8	39.99	39.70	39.48	40.64	39.55	39.24	39.88	39.52	39.33	39.71	39.92	39.72

*average values super scripted with different letters (a, b, c, d) indicate significant differences between the different oil palm parts (Tukey HSD @ 0.05).

3.3. SOC Concentration and Carbon Stock

Both bulk density of fine soil particles (≤2 mm) and SOC concentration, in the present study showed a tendency of lower values in deeper soil depth (20 - 40 cm) than those of upper soil depth (0-20 cm), irrespective of oil palm chronosequence (**Table 6**). Bulk density values did not present a significant difference ($p < 0.05$) while soil organic carbon (SOC) content showed significant differences ($p < 0.05$) along the oil palm chronosequence. Maximum SOC content (%) at both depths were observed in the one-year-old plantation, while SOC content was observed lowest at 0 - 20 cm soil depth in six years old plantation (1.43%) and nine years old plantation (0.63%) at 20 - 40 cm soil depth. A gradual decrease in SOC content was observed in the initial years of the plantation (upto 6 years after planting), after which SOC content increased in plantation when the oil palms started bearing fruits. This may be attributed to the application of fertilizers and other management practices. SOC stocks are the result of a balance of carbon inputs and decomposition. While fertilization generally leads to higher biomass production and thus higher carbon inputs to soil, liming and fertilizer application may also lead to accelerated decomposition of SOC [44] [45]. The development of SOC stocks needs to be observed under longer oil palm cultivation, as it is possible that changes in SOC stocks might have a different speed or direction than in the initial years. Management practices like fertilization, cover crops and returning residues to plantations might affect those trends and should be further investigated. Moreover, carbon storage in biomass is only temporary for the time of the land-use, while carbon sequestration into soils happens at a much longer time horizon. Thus, environmentally and economically sustainable management practices which can improve carbon storage in biomass and SOC

Table 6. Bulk Density of fine soil (≤2 mm) and SOC concentration in oil palm plantations of different age in Mizoram, Northeast India.

Age of Plantation (years)	Bulk Density (g cm^{-3})		SOC concentration (%)		SOC Stock (Mg·C·ha^{-1})	
	0 - 20 cm	20 - 40 cm	0 - 20 cm	20 - 40 cm	0 - 20 cm	20 - 40 cm
1	0.57 ± 0.02	0.50 ± 0.00	2.2 ± 0.03	1.23 ± 0.02	25.10 ± 0.87	12.38 ± 0.13
2	0.56 ± 0.01	0.51 ± 0.00	2.15 ± 0.05	1.23 ± 0.05	24.21 ± 0.86	12.47 ± 0.52
3	0.55 ± 0.02	0.51 ± 0.01	2.08 ± 0.01	1.17 ± 0.02	22.96 ± 0.73	11.92 ± 0.23
4	0.55 ± 0.01	0.51 ± 0.00	1.79 ± 0.04	1.04 ± 0.03	19.86 ± 0.71	10.66 ± 0.21
5	0.54 ± 0.01	0.51 ± 0.00	1.6 ± 0.03	1.02 ± 0.02	17.29 ± 0.65	10.40 ± 0.22
6	0.54 ± 0.01	0.51 ± 0.00	1.43 ± 0.04	0.82 ± 0.07	15.49 ± 0.67	8.30 ± 0.70
7	0.53 ± 0.00	0.50 ± 0.01	1.73 ± 0.03	0.78 ± 0.05	18.41 ± 0.31	7.80 ± 0.46
8	0.56 ± 0.01	0.51 ± 0.00	1.91 ± 0.08	0.67 ± 0.06	21.37 ± 1.18	6.83 ± 0.53
9	0.55 ± 0.01	0.52 ± 0.00	1.86 ± 0.05	0.63 ± 0.09	20.37 ± 0.54	6.57 ± 0.88
10	0.53 ± 0.01	0.51 ± 0.00	2.08 ± 0.04	0.79 ± 0.12	22.17 ± 0.59	8.12 ± 0.29
11	0.53 ± 0.01	0.51 ± 0.00	1.84 ± 0.06	1.07 ± 0.05	19.62 ± 0.73	10.94 ± 0.44

*values followed after ± are standard error of mean.

through nutrient cycling should be considered and investigated more. However, study results from Indonesia suggest no change in mineral soil carbon stock in oil palm plantations derived from forest or non-forest [46].

Total carbon stock showed a progressive increase with an increase in the age of oil palm plantation (**Table 7**). Overall, the total carbon stock ranged 43.48 ± 0.04 to 80.46 ± 0.78 $Mg{\cdot}C{\cdot}ha^{-1}$ in 1 to 11 years old oil palm plantations. Above-ground carbon stock from the study with 32.73 $Mg{\cdot}C{\cdot}ha^{-1}$ in a 10 years old oil palm plantation is within the range of 31 to 62 $Mg{\cdot}C{\cdot}ha^{-1}$ reported from Indonesia for young cultivations of 10 years [47]. Studies from shifting cultivation fallows in Aizawl district of Mizoram reported a total biomass of 60.0 to 95.2 $Mg{\cdot}ha^{-1}$ and an average biomass carbon stock of 38.9 $Mg{\cdot}C{\cdot}ha^{-1}$, which are lower than the results from oil palm plantations in the present study [48]. The low values in shifting cultivation fallows were highly attributed by the trend of shorter fallow periods (3 - 5 years) retained by farmers. This gain in biomass carbon stock with land use change from shifting cultivation to oil palm plantation suggests the potential for carbon storage, thus aiding mitigation and adaptation of climate change. Biomass carbon stock increased significantly ($p < 0.05$) while a gradual decrease in SOC stock was observed along oil palm chronosequence. It was estimated that a total of 1106.05 × 10^3 Mg C has been stored in biomass + soil (0 - 40 cm) of oil palm plantations in Mizoram, the highest being in 3-year-old plantations (**Figure 3**). Carbon stock differences along oil palm chronosequence extrapolated as carbon sequestration potential rates indicate that oil palm plantation systems in 10 years sequester approximately 3.70 $Mg{\cdot}C{\cdot}ha^{-1}{\cdot}year^{-1}$ (**Figure 4**). Average carbon sequestration rate in biomass and soil components by oil palm plantations in 10 years were 4.39 and −0.69

Table 7. Carbon stock in oil palm plantations of different age in Mizoram, Northeast India.

Age of Plantation (years)	Carbon Stock (Mg C ha^{-1})		
	Biomass Carbon Stock	SOC Stock in 0 - 40 cm	Total Carbon Stock
1	6.00 ± 0.43	37.48 ± 0.82	43.48 ± 0.40
2	8.76 ± 0.19	36.68 ± 1.32	45.44 ± 1.32
3	11.16 ± 0.16	34.88 ± 0.96	46.04 ± 0.80
4	15.05 ± 0.12	30.51 ± 0.54	45.56 ± 0.49
5	16.37 ± 0.66	27.69 ± 0.69	44.06 ± 1.01
6	19.39 ± 0.50	23.79 ± 0.19	43.18 ± 0.36
7	25.00 ± 0.20	26.21 ± 0.33	51.21 ± 0.32
8	28.97 ± 0.15	28.20 ± 0.84	57.17 ± 0.69
9	34.79 ± 0.91	26.94 ± 0.80	61.73 ± 0.17
10	42.94 ± 0.77	30.29 ± 0.77	73.23 ± 1.41
11	49.90 ± 0.35	30.56 ± 0.13	80.46 ± 0.78

*values followed after ± are standard error of mean.

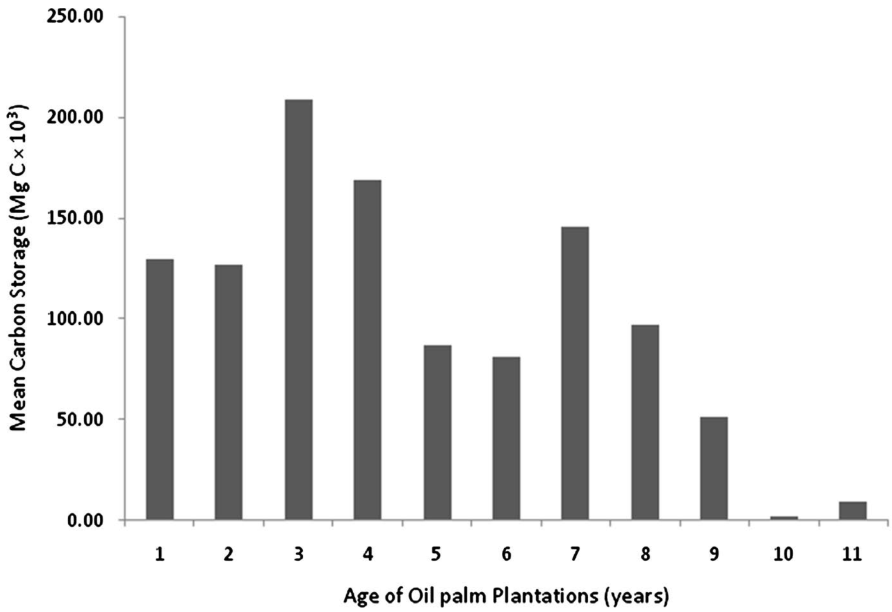

Figure 3. Carbon storage by different age oil palm plantations of Mizoram, Northeast India.

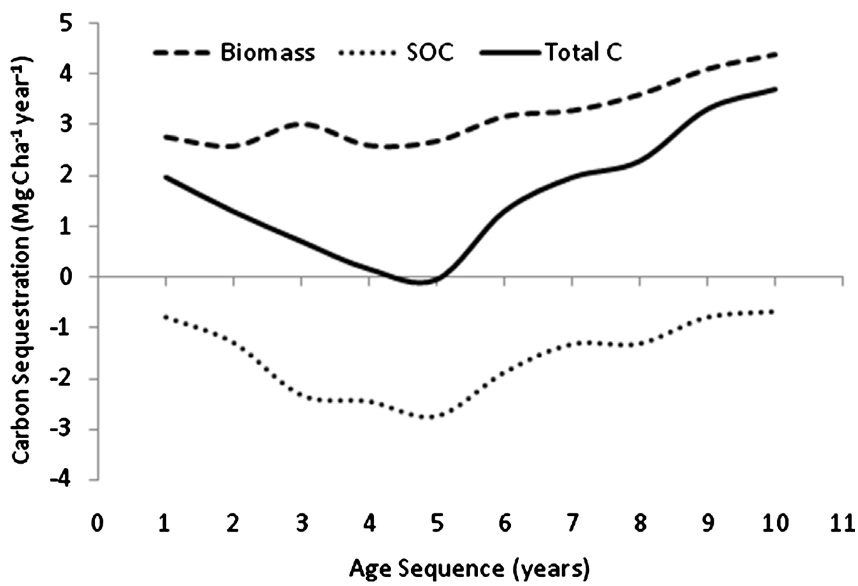

Figure 4. Carbon sequestration rate in Biomass Carbon, Soil Organic Carbon (SOC) and Total Carbon (C) pools of different aged oil palm plantations in Mizoram, Northeast India.

$Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ respectively. The computed values for carbon sequestration rates in oil palm biomass of different ages in the present study are lower than the findings from other countries reporting 5.5 $Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ in 3 years old; 5.5 $Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ in 8 years old; and 9.74 $Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ in 9 - 10 years old [42] [49] [50]. However, biomass carbon sequestration rate of 4.9 $Mg \cdot C \cdot ha^{-1} \cdot year^{-1}$ in 10 years old oil palm plantation is comparable with the results in the present study [42]. The differences in the rate of sequestration could be attributed to the variation in physical conditions in the study areas.

Besides, unlike other oil crops such as soybean, sunflower, and rapeseed, which are grown in shifting cultivation, oil palm being perennial in nature does not involve annual land clearing, soil preparation and thus resulting in lesser GHGs (greenhouse gases) emission. Oil production per unit area in oil palm is efficient as the yield per unit area is many times greater than other oil crops like soybean, thus making oil palm cultivation profitable in Brazil [51]. Studies also showed that oil palm will require 7 - 11 times less land than other oilseed crops to produce the same quantity, thus could save 97 - 159 million ha of land from being deforested for cultivation with lower yielding oil crops [52]. Oil palm plantation in Brazil served an alternative in regional economic development as it could provide employment, diversify production and diminish dependence on imported biofuel in Brazil [51].

3.4. Environmental Sustainability

The conversion of shifting cultivation and other degraded lands to oil palm cultivation is probably the most important pathway in reducing GHG emission in the area. The shifting cultivation area are known to contribute to biodiversity loss, increased soil erosion and nutrient loss, besides GHG emissions [1]. An ease establishment coupled with low cultivation cost and high product output make oil palm more profitable and most efficient crop economically as compared to other crops [53]. Oil palm plantation store more carbon than shifting cultivation and other degraded lands and besides, unlike shifting cultivation it has zero burning and biomass preservation. Growing oil palm consumption and emerging biofuel market provide tremendous potential for expansion of oil palm cultivation to alleviate poverty and to transform livelihood of many people in the state. Competitive market, lack of certification and institutional support are some of the challenges under the scheme to promote economic growth in Mizoram, northeast India

4. Conclusion

The aboveground biomass in this study was estimated using a non-destructive sampling of oil palm parts and measurements of different biometric parameters in plantations aged 1 to 11 years. The biometric variables were significantly correlated, AGB being strongly correlated with height measurements. Trunk biomass increased while crown biomass decreased with an increase in age. Stored carbon stock in oil palm plantation was also greatly influenced by age. Our result suggests that eleven years old oil palm plantation can sequester 3.70 $Mg\cdot C\cdot ha^{-1}\cdot year^{-1}$ and can have a carbon density of 80.46 $Mg\cdot C\cdot ha^{-1}$ in Mizoram, Northeast India. The decreasing trend of soil carbon stocks until the 6th year of oil palm plantation in the present study was of a special concern, as SOC had a central role in maintaining soil fertility. Changes in SOC affects, not only carbon storage in the context of climate change adaptability but also the viability of the land use system for agricultural productivity influencing costs associated with fertilizers.

Higher biomass and carbon stock in oil palm plantations than the traditional shifting cultivation of fallow lands reported from this study will further promote its expansion in degraded lands in Mizoram, Northeast India. Adoption of proper plantation measures such as avoiding land clearing by fire, avoiding drainage and erosion of top soil, using cover crops, mulch, and compost, etc. can prevent or reduce losses of some ecosystem functions thus reducing climate change [53]. The findings of the study will enable policy and decision makers in framing climate change mitigation and adaptation policies regarding the extension of oil palm plantations.

Acknowledgements

The authors thank all the oil palm growers and farmers of Kolasib district in Mizoram for help and co-operation during the field work. We also thank B. Ramnunsanga, Subject Matter Specialist (Agronomy), Directorate of Agriculture, Government of Mizoram for providing information on oil palm plantations in Mizoram. The laboratory facility provided by the Department of Forestry, Mizoram University, Aizawl is highly acknowledged.

Funding

The authors are thankful to Department of Science and Technology, Government of India, New Delhi, India for providing financial support (DST/IS-STAC/CO2-SR-227/14(G)-AICP-AFOLU-IV) to conduct field study for assessment of carbon stock and sequestration potential in major land use sectors of Mizoram.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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