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Bioenergy and carbon sequestration potential from energy tree plantation in rural wasteland of North-Eastern India

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ABSTRACT

In this study, carbon sequestration potential *via* energy tree plantation in the rural wasteland of Assam, India was estimated under two different plantation species scenarios,*viz.,* (i) *Acacia nilotica*, and (ii) *Bambusa tulda*. Furthermore, CO_2 emission reduction potential in local tea industries by replacing coal with bioenergy available from the energy plantation was also investigated. It was observed that plantation of *B. tulda* could sequester more carbon than *A. nilotica*. Both the plantations could generate adequate bioenergy to substitute coal in tea industries. Over a 50-year time period, using bioenergy as a replacement to coal in tea industries could result in significant negative CO_2 emission. Compared to *A. nilotica*, higher emission reduction is achievable from *B. tulda* bioenergy feedstock. It is also recommended to undertake further study through site-specific data coupled with life-cycle assessment for precise understanding of carbon sequestration potential of bioenergy plantation.

1. Introduction

Tree plantations are artificial forests that differ from natural forests in terms of their structure and function[Bauhus et al., 2010]. Plantation is defined as 'forests of introduced species and in some cases, native species, established through planting or seeding, with few species, even spacing and/or even-aged stands' [FAO's definition of plantation reported invan Bodegom et al., 2008]. This definition includes industrial plantations, small-scale home and farm plantations, agro-forestry plantations, and plantations established forecosystem protection.Plantation helps to restore damaged ecosystem by controlling soil erosion, improving soil health and productivity, regulating hydrological cycle and preserving biodiversity. Plantation of selected tree species can also provide fodder for cattle.Tree growing in combination with agro-forestry systems, ethno-forestry systems, individual farms, watersheds and regional landscape can be integrated to take advantage of the services provided by adjacent natural, semi-natural or restored ecosystems [Pandey, 2007]. Several tree species such as tamarisk (*Tamarix* spp.), gum tree (*Eucalyptus* spp.), leucaena (*Leucaena* spp.), cypress (*Cupressus* spp.), casuarinas (*Casuarina* spp.), mesquite (*Prosopis* spp.), neem (*Azadirachta*spp), acacia (*Acacia* spp.), teak (*Tectonagrandis*), cassia (*Casia* spp.), and bamboo (*Bambusa tulda*) have been identified as suitable plantation species [Lal, 2004; Jha and Lalnunmawia, 2003].

Energy tree plantation is the practice of planting trees and shrubs, which are harvestable in a comparably shorter time and are specifically meant for fuel use purpose. Energy tree plantation could be a more effective optionto meet energy demand and sequestercarbon than simply growing trees as a carbon store[Hall and House, 1994; Hall et al., 1991].Sustainable production of biomass energy helps in substitution of fossil energy, reduction in accumulation of GHGs and socio-economic development [Rootzén et al., 2010, Lehtonen and Okkonen, 2016; Suttles et al., 2014]. Energy plantation could also offer income generation source to poor farmers [Liu et al., 2011]. Marland and Schlamadinger [1997] reported that when high-yielding forest products are efficiently used to displace fossil fuels, greater carbon mitigation benefits could also be achieved, and the benefit increases rapidly with increasing productivity. Hedenus and Azar [2009] analyzed the cost-effectiveness of bioenergy plantations against long-rotations forests aimed at carbon capture and storage using linear optimization model. They found that under a stringent climate policy, short-rotation bioenergy plantations would be more cost effective than long rotation forest. Numbers of short-rotation plants are suitable for growing in marginal lands where input requirement (e.g. fertilizer, crop care) is minimal and thus cost per unit of production is also less.

Availability of land resources, only if we consider agricultural land for energy plantation is a major challenge. Clearing of natural forests or agricultural lands for energy plantation would only deepen the crisis relating to food, climate, and biodiversity. But, energy plantation in wasteland/degraded areas could create a win-win situation providing energy and sequestering carbon. It is reported that globally 1836 million hectares (Mha) of degraded lands are available to produce about 190 EJ of woody biomass energy annually [Nijsen et al., 2012].

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India has large tracts of unused /wastelands, both in theforest and non-forest areas which could be used for energy tree plantations. Approximately 68.35 million hectares (Mha) land in India is lying as wastelands. These wastelands comprise of non-forest lands with less fertility, like sandy land, salt-affected land, gullied and riverine land, undulating uplands, mined and industrial wastelands, waterlogged areas, and strip lands. Out of these, nearly 50% are non-forest lands, which can be made fertile again if treated properly and plantations can be made feasible.About 35 Mha of degraded lands are distributed in rural areas [MoRD, Govt. of India]. Energy tree plantations in rural wasteland areas could provide much-needed fuelwood for households. Plantation could be also used to generate decentralized electricity and supplying energy in local industries.

Assam is a North Eastern state of India. Out of the total geographical area of 7.8Mha in the state, more than 90% areas are rural dominated. Being located in the tropical region, the climate of Assam is very conducive for thegrowth of diverse vegetation. Total forest cover in the state is reported to be 1.9 Mha (25% of total geographical area) [Directorate of Economics and Statistics, Assam, 2007]. Assam is an agricultural based state and produces both food and cash crops. Among cash crops, tea production plays as a major commercial yield for Assam. About 50% of tea produced in India originates from Assam. Tea plantation covers a total area of about 0.27 Mha in Assam. Assam is still considered as a less developed state in India, despite, of its high fertile land and agriculture production. The energy crisis is regarded as one of the major reasons for sluggish development. Power crisis has badly affected the growth of industrial activities including tea industries of the state. Thus, additional generation of energy using renewable resources is very crucial for overall growth and development of Assam. Another way to overcome energy crisis is by utilizing thewastelands for energy tree plantation. About 0.87 Mha of lands,which account to be 11.19% of the total geographical area,are reported to be distributed as wastelandsin Assam [Wasteland Atlas of India, 2010]. Of this total, about 0.36 Mha are distributed as scrublands (both open and dense scrubs), and 0.34 Mha as under-utilized/ degraded forest (both scrub dominated and agricultural).

Keeping in view the above discussions, the present study is conducted in a rural area of Assam, India with theobjectives to(i) estimatecarbon sequestration potential of *Acacia nilotica* and *Bambusa tulda* plantation and, (ii) estimate potential of coal replacement and prospect of CO$_2$ emission reduction in tea industries by using bioenergy available from energy tree plantation.

2. Study area

The study area Jamugurihaat is situated in a rural landscape of Sonitpur district (Assam, India) and covers an area of 6581 ha comprising 27 villages. Geographical location of the area is 92°57′8′′ E and 26°44′4′′ N. Average summer and winter temperatures of the region are 29^0C and 16^0C, respectively. On the other hand, annual rainfall varies between 1355 to 2348 mm. Land use land cover (LULC) is primarily dominated by rice fields, followed by rural home garden forest/plantations, forest in public areas, scrub forest lands, bamboo plantation, pastures/grasslands. The bamboo plantation is a common rural household plantation of the study area.

3. Materials and method

The methodology comprises of remote sensing and GIS data, biomass allometric model, field survey data and relevant literature as described below.

3.1. Selection of land for plantation

The term scrub forest landis used to define degraded forest areas inside notified forest of India with less than 20% forest cover [Wasteland Atlas of India, 2010]. Such lands are generally found in the fringe areas of forest. Distributions of such areas outside notified forests are also observed in the present study region. These lands (scrublands) are currently not beingused to its optimum.

3.2. Selection of plant species for plantation

Two different plantation scenarios using *viz*. (i) *Acacia nilotica* (acacia) and (ii) *Bambusa tulda* (bamboo) are taken into consideration for this study. Both these species are fast growing, have short rotation period, are locally available, adaptable to local soil and climatic conditions and regarded as a potential feedstock for bioenergy. Short descriptions of the plants are given below.

3.2.1. Acacia nilotica

Acacia nilotica is commonly known as *babul* in India. As per the FAO/AGP, the *A. nilotica* tree can grow to a height of 5-20 m. Its leaves are used as feed for sheep, goats, and cattle. The wood is regarded as quality timber and can be used for wood, poles, carpentry, boat and house construction. It is also considered as very good firewood and also produces good quality charcoal. Bark and pods are used in the tanning industry.

3.2.2. Bambusa tulda

It is an evergreen or deciduous, tufted, gregarious bamboo with culms usually 7-23 m high and 5-10 cm in diameter. In India, it is found in the natural forests of Assam, Bihar, Meghalaya, Mizoram, Nagaland and Tripura and cultivated in Arunachal Pradesh, Uttar Pradesh, Karnataka, and Bengal. The species also occurs in Bangladesh, Myanmar, and Thailand. This bamboo is used throughout North-East India for covering the houses and scaffolding. The tender shoots are used for making pickles. The International Network for Bamboo and Rattanhas described many economical values of *B. tulda* including its uses for the manufacture of wrapping, writing and printing paper. It is also used for making toys, mats, screens, wall plates, wall hangers, hats, baskets, and food grain containers. This is one of the five quick-growing species of bamboos preferred for raising plantations in India.

3.3. Mapping of scrublands distribution

Ortho-rectified WorldView-2 multispectral image of 2010 covering the study area is used for mapping of scrublands. World View-2 is a very high-resolution satellite image capable of providing images both at 0.5 m panchromatic (Pan) and 2.0 m multispectral (MS) resolution.

Prior to mapping, field visits have done to random locations of the study area for collection of ground control points (GCP) using handheld GPS. The image is digitally classified to map scrublands distribution in the area of interest. Maximum Likelihood Classifier (MLC) is used for classification. MLC is a supervised method of image classification commonly used with remote sensing data [Weber and Dunno, 2001]. After classification, a post-classification smoothening treatment, *i.e.*, majority filter is applied to the classified image. Post-classification smoothening is necessary to eliminate the salt and pepper effect from the result, caused by a single or small fraction of isolated pixels, leading to misclassification [Carleer and Wolff, 2004].

Finally, the classified raster image is converted to vector format and overlaid with the village boundary layer of the study area to estimatevillage wise distribution of scrublands. Such analysis is done using ArcGIS software.

3.4. Energy tree plantation

For plantation purpose, plant populations of 2770 ha^{-1} (*A. nilotica*) and 3500 ha^{-1}(*B. tulda*) and a rotation period of 5 years have been considered based on published reports [Singh and Toky,1995; Shanmughavel and Francis, 1996]. It is assumed that only 50% of the available scrublands could be utilized for energy plantation considering possible competitive uses of land in future. One fifth of the land will be planted each year so that biomass could be harvested annually from the 5th year onward.

3.5. Estimation of carbon sequestration potential

Carbon sequestration involves the net removal of CO$_2$ from theatmosphere and its storage in long-lived pools of carbon. Such pools include the aboveground plant biomass, belowground biomass such as roots, soil microorganisms, and also the relatively stable forms of organic and inorganic carbon in soils and deeper subsurface environments, and the durable products derived from biomass such as timber [Nair et al., 2009]. Knowledge of aboveground biomass of a tree is important to estimate aboveground carbon sequestration potential since approximately 50% of the aboveground biomass is carbon [Drake et al., 2003; Chave et al., 2008].

Both aboveground and belowground carbon sequestration potentials are determined based on allometric model and available literature [Takimoto et al., 2008; Nath et al., 2010;Baruah, 2011].

3.5.1.Carbon sequestration potential of A. nilotica

For estimation of aboveground biomass of *A. nilotica*, following biomass allometric regression model developed by Chave et al.[2005] is used.

$$In(AGB) = a + bIn(D) + In(\rho) \tag{1}$$

where, *AGB* is aboveground biomass, tonne; *a* and *b* are the model's fitted parameters where $a = -1.083$ and $b = 2.266$; *D* is diameter at breast height, cm; and ρ is the wood specific density of acacia tree, g cm^{-3}.

D is assumed to be 7cm after 4th year of the plantation. The value of *D* is taken based on the average value of *D* reported for 4 years old *A. nilotica* plantation in Haryana, India [Singh and Toky, 1995]. The value of ρ is taken as 0.64 gcm^{-3} based on thestandard database [Local Data for Wood Density].

Using eq. (1), above ground biomass per *A. nilotica* tree and subsequently for the whole plantation is estimated. Above ground carbon sequestration is assessed assuming 50% of the above ground biomass is carbon.

On the other hand, we could not obtained reliable information on below ground carbon sequestration potential of *A. nilotica* grown under Indian condition. Therefore, the value of 24 t C ha^{-1} in soil system of *A. nilotica* dominated (68%) live fence agro-forestry system in West African, as reported by Takimoto et al. [2008], is used in this study.

3.5.2. Carbon sequestration potential of B.tulda

Biomass accumulation in bamboo varies widely depending upon soil and agro-climatic factors. Bamboo plantation in Sonitpur, Assam produces16 kg aboveground biomass per bamboo [Baruah, 2011]. Thus, above ground bamboo biomass yield is 56 t ha^{-1} (considering 3500 numbers of bamboo ha^{-1}), equivalent to 28 t C ha^{-1} considering 50% above ground biomass as carbon.

On the other hand, in a related study in Assam, Nath et al. [2010] reported that bamboo could sequester 57.30 tC ha^{-1}at soil depths of 30 cm. This valueis used to estimate below ground CO_2 sequestration potential of the bamboo plantation.

3.6. Estimation of biomass energy available from plantation

The information (i) area under plantation and (ii) above ground biomass yield can give an estimate of biomass feedstock availability for fuel generation. Available energy biomass feedstock is estimated considering (i)90% of the harvested biomass will be used as energy feedstock (ii) heating values of *A. nilotica* and *B. tulda* as19.57 MJkg^{-1} [Goel and Behl, 1996] and 16.27 MJ kg^{-1}[Baruah, 2011], respectively. The consideration of 90% availability is because some parts of the harvested biomass such as leaves and small branches can't be collected. These parts could again return to the soil system for carbon sequestration benefit. However, this is not accounted in the present study.

3.7. Potential CO_2 emission reduction in tea industries via bioenergy

Two tea estates (TE) *viz*. Dikoraiand Topia, located near the study area are considered to test the emission reduction benefit of bioenergy by replacing coal as a source of thermal energy in tea processing. Coal used in the tea industries of Assam has low heating value and high sulfur content. Coal is preferred by tea industries because of availability and low cost than furnace oil.

Globally, coal burning is the major source of greenhouse gas emissions. CO_2 emission from tea industries could be avoided, if coal is replaced by bioenergy. The combustion of biomass also releases CO_2, but the emitted amount is again re-absorbed by new tree growth. However, the carbon neutrality assumption can't be applied to all biomass types. Biomass carbon neutrality is a debatable issue because of unclear explanation of carbon payback time of different biomass feedstock pools, biogenic carbonflow, changes in soil carbon dynamic and indirect land use change impact of biomass. However, crop residues or short-rotation energy crops can qualify the carbon neutrality term under the assumption that the emitted CO_2 would be immediately and fully re-absorbed by the re-growing plantation. Further, feedstock grown on marginal land requires less resource inputs and can help sequestering more carbon in the soil system.

For this study purpose, coal equivalent biomass fuel demand for the two tea estates is estimated using following parameters:

(i) area under tea plantation, ha (ii) tea yield, kg of made tea per ha land, (iii) specific coal consumption, kg per kg of made tea and (iv) replacement factor expressed as kg of biomass fuel per kg of coal. Standard calorific values are used to estimate the replacement factor.

Areas under tea plantation in Dikorai and Topiatea estates are estimated to be as 1018 ha and 166 ha, respectively. Average tea production is 1.8 t ha^{-1}and specific coal demand is 0.8 kg kg^{-1} made tea (~20.69 MJ kg^{-1} made tea), respectively [Rupajulie TE, personal communication, December 2011]. Here, specific coal demand is the amount of coal required to produce a certain amount of ready to serve tea (*i.e.* made tea).

Coal based CO_2 emissions from the tea industries are estimated taking IPCC's default emission factor for sub-bituminous coal used in stationary combustion industries as 96.1 t CO_2 TJ^{-1}[IPCC,2006].

For long-term emission reduction benefit in tea industries with coal replacement by bioenergy, net emission budget for 50 years life cycle is estimated assuming business as usual scenario as per following equation. Carbon fraction for CO_2 is taken as 0.27.

$$NE_{50} = (C_{AGB} - C_{atm} - C_{coal}) \times 50 \qquad (2)$$

where, NE_{50} is net emission in 50 years, tonne; C_{AGB} is carbon sequestration in above ground biomass, tonne; C_{atm} is carbon sequestration from the atmosphere (both above and below ground carbon); C_{coal} is expected carbon emission from coal burning in absence of plantation biomass.

4. Results and discussion

4.1. Spatial distribution of scrublands

Spatial distribution of scrub lands in the study area is shown in Fig.1. Out of the total geographical area of 6581 ha, 706 ha of lands are classified as scrub land (10.73%).If 50% of the lands are used for plantation, net scrub lands availability will be 353 ha.

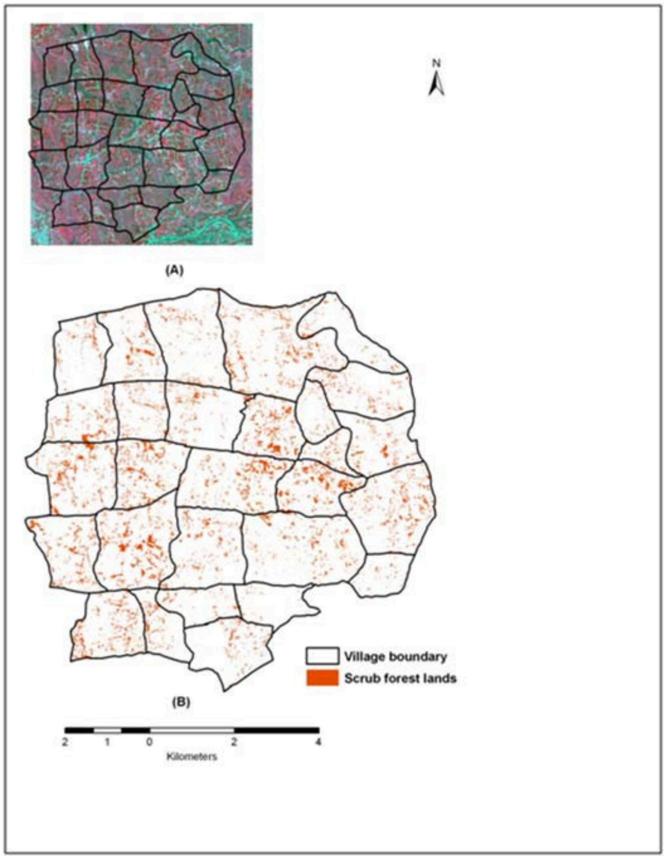

Fig.1. Spatial distribution of scrub forest lands in the study area (Jamugurihaat, Sonitpur district)

There is variation in village-wise distribution of scrubland among the villages, rangingfrom 5.95 to 51.47 ha. Village wise availability of scrubland for bioenergy plantation is presented in Table 1.

4.2. Above ground and below ground carbon sequestration potential

4.2.1. Carbon sequestration potential of A. nilotica

Using eq. (1), above ground biomass per *A. nilotica* tree is estimated as 17.82 kg. Thus, above ground biomass is 49.86 t ha^{-1}(equivalent to above ground carbon of 24.93 t ha^{-1}). Overall, above ground biomass production in the study area is 3483 t yr^{-1} after the first rotation period and then subsequently every year. This is equivalent to above ground carbon sequestration of 1742 t yr^{-1}. On the other side, below ground carbon sequestration potentialin the study area is1694 t yr^{-1}(considering soil carbon sequestration as 24 t ha^{-1}). Thus, overall carbon sequestration in the whole study area is 3436 t yr^{-1}. The plantation tree carbon budget for all the villages is presented in Table 2. Variations of village wise potential of aboveground biomass, aboveground and belowground carbon of *A. nilotica* exists as shown in Table 2. The variations are mainly attributed to the variations of land area. However, there could be other factors contributing such variations as discussed below.

Table 1. Village wise distribution of scrublands for energy tree plantation

Village name	Village area, ha	Scrubland, ha	Scrubland for plantation, ha
Bebejia	235.32	21.43	10.72
Borigaon	197.96	34.40	17.20
Chamardoloni	116.89	10.14	5.07
Dekasundar	231.82	39.16	19.58
Dhakarigaon	495.02	16.95	8.48
Dikarai pam	104.98	44.66	22.33
Garikuri	201.71	9.41	4.71
Hatbor	237.10	26.15	13.08
Hukaigaon	139.94	8.55	4.28
Karchantola	196.30	49.29	24.65
Katanibasti	179.07	15.08	7.54
Kumar gaon	241.16	23.77	11.89
Madhavbarhampur	258.00	16.10	8.05
Major chuk	298.52	34.62	17.31
Mohmara	133.13	14.37	7.19
Nag-sankargaon	350.64	37.14	18.57
Nal-tali	212.44	16.42	8.21
Nandikeswar	202.54	23.56	11.78
Niz-borbhagia	357.62	51.47	25.74
Pachigaon	235.07	29.63	14.82
Sangiamajorchuk	166.30	15.14	7.57
Sarubhogia	325.67	50.99	25.50
Solaguri	215.67	21.03	10.52
Talakabari	311.15	30.00	15.00
Talakabaripathar	150.07	5.95	2.98
Talakabaribangali	448.50	43.45	21.73
Uparkuri	338.69	16.99	8.50
Total	**6581.27**	**705.85**	**352.92**

Aboveground biomass (or carbon) may vary from site to site depending on a number of factors including site characteristics, land use types, plantation species, stand age, and management practices [Montagnini and Nair, 2004; Nair et al., 2009]. For example, aboveground carbon sequestration by *Eucalyptus* spp. ranges between 3.0 to 5.3 t ha^{-1} in Africa, 16 to 18 t ha^{-1} in Asia and 39 to 42 t ha^{-1} in India [Koskela et al., 2000]. Variations in aboveground carbon content in the range of 20.5 to 102.6 tha^{-1} in 10 plantation tree species are also reported by Montagnini and Nair [2004]. The highest known total biomass carbon density (living plus dead) of 1867 tha^{-1} in the world is reported from *Eucalyptus regnans* forest (>100 years old) of the O'Shannassy Catchment of the Central Highlands of Victoria, southeastern Australia [Keith et al., 2009].

Literature related to belowground (soil) carbon sequestration in agro-forestry systems is very less. In terms of soil organic carbon content, land-use systems can be ranked as forests >agro-forests> tree plantations > arable crops [Nair et al., 2009].Variations in belowground (soil) carbon sequestration potential among different plant species are also reported in literature. For example, in a study by Takimoto et al.[2008], it is found that parkland (*Faidherbia albida*) agro-forestry system sequester 33.3 tcarbon ha^{-1},while live fence (*Acacia nilotica*, *A. senegal*, *Bauhinia rufescens*, *Lawsoniainermis*, and *Ziziphusm auritiana*) sequester 24 tcarbon ha^{-1}. Soil carbon sequestration potential of *Gmelina arborea* agri-silviculture system in Chhattisgarh, India is reported as 27.4 t ha^{-1} [Swamy and Puri, 2005]. In the case of tree-based pastures system in Florida (USA), soil carbon sequestration range in between 6.9 and 24.2 t ha^{-1} [Haile et al., 2008]. On the other hand, in maize-maize cropping system (3 years) and maize-bean cropping system (5 years) of humid tropical Costa Rica, the average soil carbon as found as 118 and 116 t ha^{-1}, respectively [Koskela et al., 2000]. Thus, wide ranges of variations are reported in literature mainly influenced by soil, plant and climatic conditions. The estimated values of the present investigation could be considered as an index for planning.

4.2.2. Carbon sequestration potential of B. tulda

Bamboo plantation could produce 56 t ha^{-1} of aboveground biomass (equivalent to 28 t ha^{-1} aboveground carbon). Therefore, on anannual basis, aboveground biomass production in the study area is 3953 t yr^{-1}, equivalent to 1976 t yr^{-1} aboveground carbon. In the case of belowground carbon sequestration, the annual potential is 4044 t yr^{-1}carbon at the rate of 57.3 tcarbon ha^{-1}. Thus, overall carbon sequestration in the whole study area is 6021 t yr^{-1}. Village wise potential distribution of aboveground biomass, aboveground carbon and belowground carbon of *B. tulda* in the study area is given in Table 3.

Table 2. Village wise distribution of aboveground biomass, above and belowground carbon of *A. nilotica* plantation

Village	Aboveground biomass, tonne	Aboveground carbon, tonne	Belowground carbon, tonne
Bebejia	106	53	51
Borigaon	170	85	83
Chamardoloni	50	25	24
Dekasundar	193	97	94
Dhakarigaon	84	42	41
Dikarai pam	220	110	107
Garikuri	46	23	23
Hatbor	129	65	63
Hukaigaon	42	21	21
Karchantola	243	122	118
Katanibasti	74	37	36
Kumar gaon	117	59	57
Madhavbarhampur	79	40	39
Major chuk	171	85	83
Mohmara	71	35	34
Nag-sankargaon	183	92	89
Nal-tali	81	41	39
Nandikeswar	116	58	57
Niz-borbhagia	254	127	124
Pachigaon	146	73	71
Sangiamajorchuk	75	37	36
Sarubhogia	252	126	122
Solaguri	104	52	50
Talakabari	148	74	72
Talakabaripathar	29	15	14
Talakabaribangali	214	107	104
Uparkuri	84	42	41
Total	**3483**	**1742**	**1694**

Wide variations in carbon sequestration potential among the bamboo species are also reported. In a study by Ly et al.[2012] in Vietnam, aboveground carbon in bamboo is found as 17 tha^{-1} and belowground carbon as 92 t ha^{-1} at 70 cm soil depth. Aboveground carbon in China's moso bamboo (*Phyllostachys pubescens*) is in the range of 27 to 77 t ha^{-1}[Lou et al., 2010]. In *Phyllostachys pubescens* bamboo of Kyoto Prefecture, Central Japan, above and belowground carbon is 78.6 t ha^{-1} and 101.2 t ha^{-1}, respectively [Isagi et al., 1997].

Table 3. Village wise distribution of aboveground biomass, above and belowground carbon of *B. tulda* plantation

Village	Aboveground biomass, tonne	Aboveground carbon, tonne	Belowground carbon, tonne
Bebejia	120	60	123
Borigaon	193	96	197
Chamardoloni	57	28	58
Dekasundar	219	110	224
Dhakarigaon	95	47	97
Dikarai pam	250	125	256
Garikuri	53	26	54
Hatbor	146	73	150
Hukaigaon	48	24	49
Karchantola	276	138	282
Katanibasti	84	42	86
Kumar gaon	133	67	136
Madhavbarhampur	90	45	92
Major chuk	194	97	198
Mohmara	80	40	82
Nag-sankargaon	208	104	213
Nal-tali	92	46	94
Nandikeswar	132	66	135
Niz-borbhagia	288	144	295
Pachigaon	166	83	170
Sangiamajorchuk	85	42	87
Sarubhogia	286	143	292
Solaguri	118	59	121
Talakabari	168	84	172
Talakabaripathar	33	17	34
Talakabaribangali	243	122	249
Uparkuri	95	48	97
Total	**3953**	**1976**	**4044**

4.3. Potential CO$_2$ emission reduction through fuel substitution in tea industries

Annual tea production ofDikorai and Topia TE are estimated as 1832.4 and 298.8t yr^{-1}, respectively with corresponding coal demand for tea drying as 1465.92t yr^{-1}(~36809.25 GJ yr^{-1}) and 239.04 t yr^{-1} (~6002.29 GJ yr^{-1}), respectively. Thus, overall annual coal energy demand is 42811.55 GJ yr^{-1}. If biomass is opted to replace coal, identical amount of energy has to be supplied by theplantation biomass.It is observed that availability of bioenergy from both the plantationswould to be sufficient to replace 100% coal as shown in Table 4. If *A. nilotica* were considered, 3135t yr^{-1} fuelwood (~61352 GJyr^{-1}) would be available. On the other hand, if *B. tulda* were selected, 3557 t yr^{-1}fuelwood (~57880 GJyr^{-1}) would be available. Therefore, besides fulfilling energy demand in tea industries, the remaining biomass feedstock could be used for other fuelwood or non-fuelwood purposes.

Use of biomass for non-fuelwood uses such as ornamental designs, construction material would ensure temporary storage of carbon. Similarly, while uprooting the bamboo roots for land preparation for next plantation, the uprooted parts could also be used for non-fuel purposes. The ornamental design of bamboo root is an attractive local business in Assam.

Table 4. Village wise bioenergy potential from *A. nilotica* and *B. tulda*

Village	*A. nilotica* Biomass, tonne	*A. nilotica* Available energy,GJ	*B. tulda* Biomass, tonne	*B. tulda* Available energy,GJ
Bebejia	95	1863	108	1757
Borigaon	153	2990	173	2821
Chamardoloni	45	881	51	831
Dekasundar	174	3404	197	3211
Dhakarigaon	75	1473	85	1390
Dikarai pam	198	3882	225	3662
Garikuri	42	818	47	772
Hatbor	116	2273	132	2144
Hukaigaon	38	743	43	701
Karchantola	219	4284	248	4042
Katanibasti	67	1311	76	1237
Kumar gaon	106	2066	120	1949
Madhavbarhampur	72	1399	81	1320
Major chuk	154	3009	174	2839
Mohmara	64	1249	72	1178
Nag-sankargaon	165	3228	187	3046
Nal-tali	73	1427	83	1346
Nandikeswar	105	2048	119	1932
Niz-borbhagia	229	4474	259	4221
Pachigaon	132	2575	149	2430
Sangiamajorchuk	67	1316	76	1241
Sarubhogia	226	4432	257	4181
Solaguri	93	1828	106	1724
Talakabari	133	2608	151	2460
Talakabaripathar	26	517	30	488
Talakabaribangali	193	3777	219	3563
Uparkuri	75	1477	86	1393
Total	**3135**	**61352**	**3557**	**57880**

For prevailing business as usual scenario, annual CO$_2$emission from the two tea industries isestimated to be 4114 t yr^{-1}for the production of 2131 t yr^{-1} made tea (1.93 kg CO$_2$ emission kg made tea^{-1}). If bioenergy is used as a substitute for coal in tea industries, on annual basis net negative CO$_2$ emission using *A. nilotica* and *B. tulda* would be about “10.39 and “19.09 kt yr^{-1}(kilo tonneyr^{-1}) CO$_2$, respectively. Thus, net negative emission budget over a 50 year time period would be about –519 kt for *A. nilotica* and “955 kt CO$_2$ for *B. tulda*.

5. Conclusions

This study demonstrated carbon sequestration potential of *Acacia nilotica* and *Bambusa tulda* plantation in rural wastelands of Assam. Carbon sequestration potential of *B. tulda* is observed to be higher than *A. nilotica* and therefore, plantation of *B. tulda* would be more beneficial if carbon sequestration is primarily targeted. Both the plantations could generate adequate bioenergy to replace the use of coal as thermal energy source in two local tea industries. Further, coal replacement with bioenergy in the two tea industries can lead to significant emission reduction (negative emissions) in the long-run. However, carbon sequestration of trees varies with climatic conditions, soil characteristics, plantation techniques and biomasses. Site-specific data could not be generated in this study and some parameters are based on literature. Therefore, future study having site-specific data coupled with life cycle assessment is suggested for precise understanding of carbon sequestration potential of bioenergy plantation.

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