KHAYA (*Khaya senegalensis*): IS IT A POTENTIAL PLANTATION FOREST SPECIES FOR CLIMATE CHANGE MITIGATION IN SRI LANKA?

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ABSTRACT

Carbon sequestration by tree is imperative in tumbling atmospheric carbon dioxide level. Hence, forest plantations are considered highly efficient systems for carbon sequestration, which *plays a vital role in climate change mitigation. While, carbon sequestrations of forest plantations were little focused in Sri Lankan context, present study aims to validate its potential, using Khaya plantations in Anuradhapura and Kurunegala divisions of Sri Lanka. Variables, i.e. tree height and tree diameter were measured non-destructively at identified age classes to estimate biomass using allometric equations. DL_{1b} being the sole agro ecological region in Anuradhapura, resulted less variation in biomass distribution through age classes, whereas it was irregular in Kurunegala, visualizing the climate variation of the different agro ecological regions (DL_{1b}, IL_3, IL_{1a}, IM_{3b}) within the division. Greater biomass of Khaya recorded in Kurunegala was attributed to moisture rich growing conditions, whereas lower biomass in Anuradhapura resulted with less annual rainfall and prolonged drought, indicating the strong association of biomass with environmental stress. Greater root:shoot ratio (R/S) of Khaya was observed in Anuradhapuara, while R/S had decreased through age classes in both divisions. The average above ground carbon sequestration of Khaya i.e. 88.98 and 127.92 tonnes per ha in Anuradhapura and Kurunegala divisions were well ahead of the IPCC's benchmark of plantation forests in 'Tropical Dry' climate i.e. 30 tonnes per ha, indicating its potential of climate change mitigation, besides the timber use. The total amount of carbon sequestered by existing Khaya plantations amounted to 21,785.25 and 27,969.10 tonnes in Anuradhapura (741.92 ha) and Kurunegala (475.20 ha) divisions, respectively. Despite the greater extent, Khaya in Anuradhapura assimilated less carbon due to stressful conditions imposed by climate and being in younger age classes. While, carbon estimates enable economic valuation of forest plantations in the context of carbon crediting, the regional baseline carbon estimates of Khaya generated by present study can be effectively utilized for carbon budgeting programmes, until further validated with comprehensive survey of individual trees and by developing allometric relationships specific for Khaya senegalansis.*

Key words**:** *Khaya senegalensis*, Carbon sequestration, Climate change mitigation, Biomass, Age classes

Introduction

Forests have the ability to absorb large quantities of atmospheric carbon dioxide for their photosynthesis and sequester carbon in their biomass (Chambers *et al*., 2001). As forests make up large ecosystems, with high biomass volumes, they can play an important role in mitigating the emissions of CO_2. Increased forest cover on earth by increased establishment of tree plantations on cleared land in the tropics has long been suggested as a way of reducing the rate of increase in atmospheric CO_2 (Dyson, 1997). In that sense, fast growing tree plantations are considered highly efficient carbon sinks, having potential to reduce the rate of global warming and the resultant climate change (Brown *et al*., 1996; Cannell, 1996; Sathaye & Ravindranath, 1998; Malhi & Grace, 2000; White *et al*., 2000; Schulze *et al*., 2000; Baker *et al*., 2004; Grace & Meir, 2009; Lewis *et al*., 2009), largely contributing to climate change mitigation.

As the forest plantations form an important option for climate change mitigation (IPCC, 2007; Nabuurs *et al*., 2007), the ability of these plantations to sequester carbon has received renewed interest. Thus carbon sequestration projects in developing nations could receive investments from companies and governments wishing to offset their emission of greenhouse gases through the Kyoto Protocol's Clean Development Mechanism (CDM) (Fearnside, 1999).In addition to their industrial timber products, the importance of forest plantations has increased substantially during the last two decades, in view of the increased awareness on global climate change and the role of forest in regulating the global carbon cycle (Dixon *et al*., 1994; Clark *et al*., 2003; Clark, 2004a; Houghton, 2005).

In the Sri Lankan context, very few studies were focusing on the concepts of carbon sequestration in forest plantations and carbon stocks as indicated by the standing biomass, have not been estimated yet. Estimation of carbon stocks will enable economic valuation of Sri Lankan forest plantations to explore possibilities of financial gains through mechanisms such as United Nations Reducing Emissions from Deforestation and Degradation in Developing countries programme (UN-REDD) (Gibbs *et al*., 2007; Ravels, 2008; Scewartzman *et at*., 2008) and carbon trading under Kyoto Protocol's Clean Development Mechanism (CDM) (Fearnside, 1999).

Khaya, also known as African mahogany is a newly introduced plantation tree species to Sri Lanka by the Forest Department of Sri Lanka in 1994, with the main aim of timber production. Although the timber properties and its potential uses under Sri Lankan conditions are not well known, *Khaya* has gained wide appreciation in the Dry Zone reforestation programmess for its better establishment, faster growth and low risk from elephant damage (Alawathugoda, 2009). Besides timber production, *Khaya* delivers environmental benefits such as site amelioration, reducing greenhouse effects by sequestering carbon dioxide from atmosphere, reducing soil erosion, *etc*. Hence, *Khaya* would be an attractive alternative in climate change mitigation, while capturing the financial gains under UN-REDD or CDM projects to enhance the economic status of the country.

Accordingly, the present study aims to quantify potential greenhouse benefits from carbon sequestration and biomass production of *Khaya* distributed in Anuradhapura and Kurunegala divisions of Sri Lanka. In accomplishing this, ground measurements of variables were obtained to premeditate the biomass and carbon masses sequestered by an individual tree to identify the possible implications of adapting *Khaya* plantations in receiving carbon payments, which would be a prospective remedy to alleviate from the economic crisis, adhere to a developing country like Sri Lanka.

Methodology

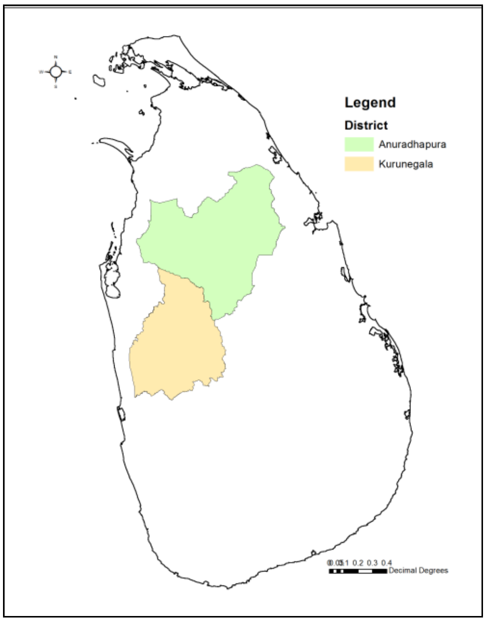
Location

Study was carried out at the selected even aged stands of *Khaya* plantations distributed in the Anuradhapura and Kurunegala divisions, representing the *Dry* and *Intermediate Zones* of Sri Lanka (Figure 1.1). Potential *Khaya* plantations of different age classes were identified through a primary land survey with the use of secondary data received from the Forest Department of Sri Lanka.

Age Classes

1-3 years	8-10 years	16-17 years
4-5 years	11-12 years	18-20 years
6-7 years	13-15 years	

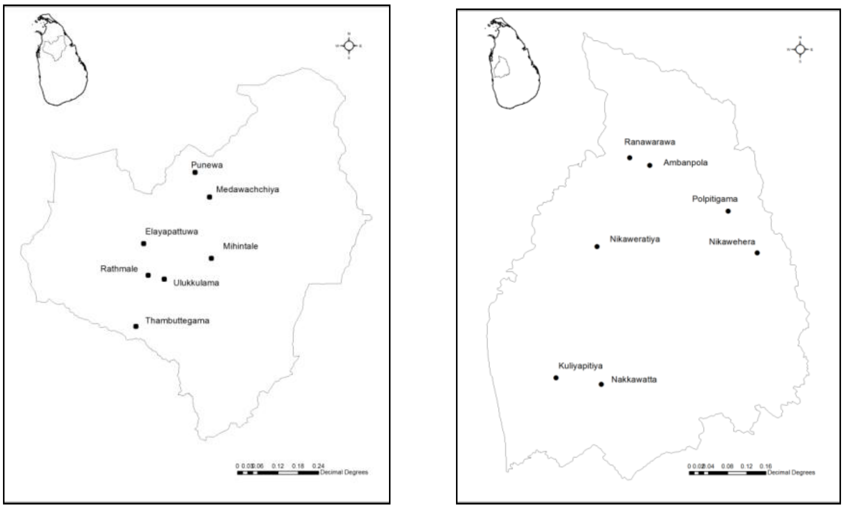
Figure 1.1: Anuradhapura and Kurunegala Divisions of Sri Lanka



Measurements

Non destructive sampling was adopted to estimate biomass and carbon mass using available allomatric equations for biomass and carbon inventory (Perez and Kanninen, 2003) at stand level. In each division, the age classes were stratified, where sampling was done in different age classes within a division. As trees are being planted in rows, square plots were demarcated as sampling plots. Minimum of two (02) sampling plots were chosen for each age class with the size of 10 x 12.5 m (0.0125 ha) to gather primary data. Data at stand level were collected from 07 locations (beats) with 14 sites (blocks and sub blocks) per each division (Figure 1.2), having total of 28 sites with 57 sample plots from the two divisions. A total of 818 sample trees (400 from Anuradhapura and 418 from Kurunegala) were subjected to the measurements of variables; *i.e*. total tree height and diameter at breast height (*dbh)* for biomass and carbon determination. Tree age was taken from the records maintained by the Divisional Forest Office of the Forest Department of Sri Lanka. Tree height was measured using a Suunto Clinometer through the indirect method using trigonometric principles, in which percentage of the slope to the top and the base of the tree were measured 20 m away from the base of the tree. Diameter tape was used to measure the diameter at breast height (*dbh*) *i.e*; 1.3 m above the ground level. GPS coordinates of each location were identified for mapping purpose.

Figure 1.2: Study Locations (beats) in (a) Anuradhapura and (b) Kurunegala Divisions



(a) **(b)**

Calculations

Allomatric equations were used to estimate the biomass and carbon (Perez and Kanninen, 2003) at stand level as follows.

LOG Ya = -0.815+2.382*LOG (*dbh*)
Yb = exp (-1.0587+0.8836*lnYa)

Ya = above ground biomass of trees (kg/tree)
dbh= diameter at breast height (cm)
Yb = below ground biomass of trees (kg/tree)

Biomass carbon content was estimated by using a stand coefficient of 0.5 (IPCC, 1996). Biomass and carbon values were then scaled to ha basis, considering thinning age at 7, 15, and 20 years with the stand stock of 1600, 800 and 400 trees per ha prior to each thinning, respectively. Other reserves like wood debris, understory species were considered having negligible biomass and carbon values and therefore not taken into account for biomass and carbon estimations.

Data Analysis

Analysis of Variance (ANOVA) was used to test the age class, divisional differences between variables; *i.e.* above ground biomass, below ground biomass and total biomass. Mean separation was done using Least Significant Difference (LSD). Nonlinear regression by dynamic fitting was done to predict the missing data. Analyses were performed with SAS System (SAS version 9.0) and Minitab (Minitab 16).

Results and Discussion

Above Ground, Below Ground and Total Biomass

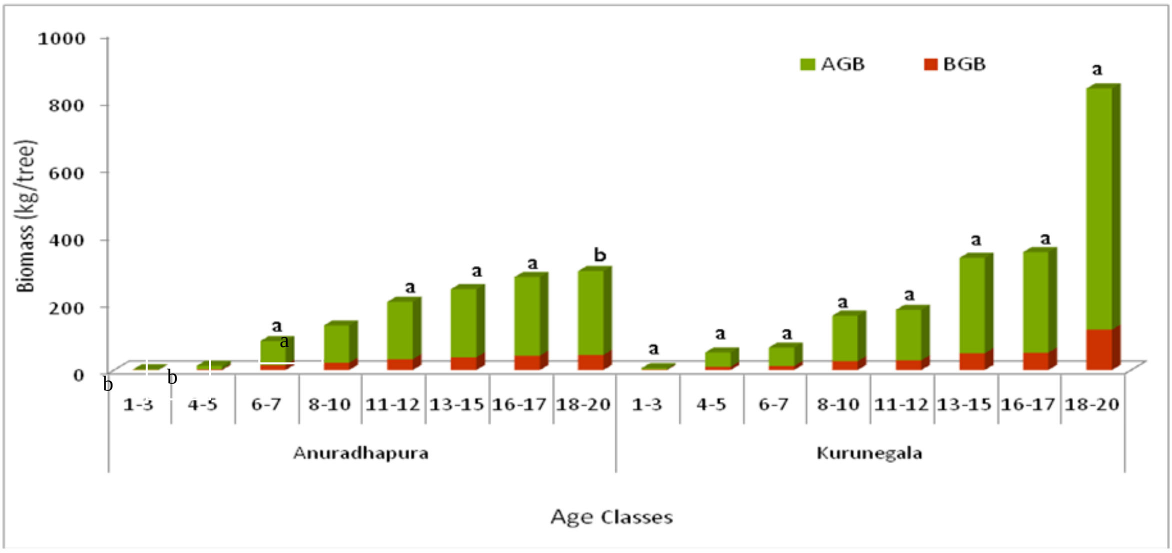
Khaya plantations in Kurunegala were distributed in agro ecological regions (AER) DL_{1b}, IL_3, IM_{3b} and IL_{1a}, with annual rainfall of >900 mm, 1200 mm, >1200 mm and 1400 mm, respectively, where as in Anuradhapura they were in agro ecological region DL_{1b} with an annual rainfall of >900 mm and experiences drought/rain free conditions during *Yala* season (Punyawardhana, 2008) (Table 1.1).

Table 1.1: Agro Ecological Regions of Selected Sites

Age Class	**Anuradhapura**			**Kurunegala**		
	Range	**Beat**	**AER**	**Range**	**Beat**	**AER**
1-3	Anuradhapura	Ulukkulama	DL_{1b}	Galgamuwa	Ambanpola	DL_{1b}, IL_3
				Kuliyapitiya	Kuliyapitiya	IL_{1a}
4-5	Anuradhapura	Ulukkulama	DL_{1b}	Galgamuwa	Ambanpola	DL_{1b}, IL_3
	Anuradhapura	Rathmale	DL_{1b}	Melsiripura	Polpithigama	DL_{1b}, IL_3
6-7	Anuradhapura	Mihintale	DL_{1b}	Galgamuwa	Ranawarawa	DL_{1b}
	Anuradhapura	Mihintale	DL_{1b}	Galgamuwa	Ambanpola	DL_{1b}, IL_3
8-10	Anuradhapura	Rathmale	DL_{1b}			
	Thambuttegama	Thambuttegama	DL_{1b}			
11-12				Melsiripura	Nikawehera	IL_3
13-15				Galgamuwa	Ambanpola	DL_{1b}, IL_3
				Kuliyapitiya	Kuliyapitiya	IL_{1a}
16-17	Anuradhapura	Elayapaththuwa	DL_{1b}	Melsiripura	Polpithigama	DL_{1b}, IL_3, IM_{3b}
	Medawachchiya	Punewa	DL_{1b}	Mahawa	Nikaweratiya	DL_{1b}, IL_3
18-20	Medawachchiya	Punewa	DL_{1b}	Kuliyapitiya	Nakkawatta	IL_{1a}

A significantly greater, above ground biomass (AGB), below ground biomass (BGB) and total biomass (TB) of *Khaya* at tree level were recorded for many age classes in Kurunegala, attributing to moisture rich growing conditions. In contrast, less annual rainfall and prolonged drought resulted in a significantly lower tree level biomass in Anuradhapura. Irregular biomass distribution through age classes was observed from Kurunegala (Figure 1.3), visualizing the climate variation of different agro ecological regions (DL_{1b}, IL_3, IL_{1a}, IM_{3b}) within the division, whereas DL_{1b} being the sole agro ecological region in Anuradhapura (Figure 1.3), resulted less variation. Similarly, De Costa and Suranga (2012) mentioned that carbon stocks of forest plantations obviously vary with their age, and biomass accumulation would be slow in the young plantations until they establish their canopy cover to maximize radiation interception and photosynthesis.

Figure 1.3: AGB and BGB in Anuradhapura and Kurunegala Divisions



- Means with same letters in Anuradhapura and Kurunegala divisions are not significantly different at $P \leq 0.05$ as determined by Least Significant Different (LSD)

Khaya plantations representing the age class 6-7 and 11-12 in Kurunegala division were located in the agro ecological regions DL_{1b}, and IL_3, which are comparatively drier, where as other *Khaya* plantations in Kurunegala were distributed in the agro ecological regions with higher annual rainfall (Table 1.1). This reason out the lower AGB, BGB and TB per tree recorded from age classes 6-7 and 11-12 in Kurunegala division (Table 1.2). Further, *Khaya* plantations representing the age classes 4-5 and 18-20 in Kurunegala were located only in the agro ecological region IL_{1a}, which experiences a >1400 mm annual rainfall, thus contributed to significantly greater biomass at tree level (Table 1.2).

De Costa and Suranga, (2012) observed that carbon estimates are related to the environmental conditions of the respective sites and regions, inferior forest management and/or inferior site quality such as lower soil fertility of sites all of which have influences. Further, in combination with higher precipitation, which promotes greater photosynthesis, and lower temperature, which reduces respiration, are responsible for high carbon sequestration rates in plants. Confirming the above, *Khaya* in Kurunegala division recorded greater AGB, BGB and TB for many age classes.

Table 1.2: Mean AGB, BGB and TB per Tree in Anuradhapura and Kurunegala Divisions

	Anuradhapura			Kurunegala		
Age Class	**AGB Kg/tree**	**BGB Kg/tree**	**Total Biomass Kg/tree**	**AGB Kg/tree**	**BGB Kg/tree**	**Total Biomass Kg/tree**
1-3	1.59^b	0.48^b	2.07^b	4.44^a	1.26^a	5.70^a
4-5	9.90^b	2.59^b	12.49^b	42.61^a	9.47^a	52.08^a
6-7	71.16^a	14.64^a	85.80^a	$*54.70^a$	$*11.91^a$	66.61^a
8-10	110.54^a	21.70^a	132.24^a	135.22^a	26.10^a	161.32^a
11-12	$*170.18^a$	$*32.33^a$	202.51^a	149.89^a	28.75^a	178.64^a
13-15	$*202.56^a$	$*37.61^a$	240.17^a	283.29^a	49.60^a	332.89^a
16-17	233.58^a	42.49^a	276.07^a	298.34^a	51.53^a	349.87^a
18-20	248.88^b	44.83^b	293.71^b	716.30^a	119.80^a	836.10^b

- Means with same letters in parallel columns in Anuradhapura and Kurunegala divisions are not significantly different at $P \leq 0.05$ as determined by Least Significant Different (LSD)
- * Values predicted by non linear regression

Root:Shoot Ratio

Root:shoot (R/S) ratios are of high value in providing the estimates of below-ground plant biomass from above-ground biomass and have become a core method for estimating root biomass from the more easily measured shoot biomass. Mean root:shoot ratio had decreased over the age classes in both divisions, while *Khaya* grown in Anuradhapura had comparatively higher root:shoot ratio than in Kurungala (Table 1.3).

Table 1.3: Mean R/S ratio of Khaya at Anuradhapura and Kurunegala Divisions

Age Class	Anuradhapura		Kurunegala	
	R/S Ratio (%)	**StDev**	**R/S Ratio (%)**	**StDev**
1-3	39.84[a]	10.13	30.08[b]	4.97
4-5	27.16[a]	1.96	22.66[b]	1.13
6-7	22.04[a]	2.46	21.78[a]	-
8-10	20.73[a]	1.90	20.13[a]	1.95
11-12	19.00[a]	-	19.64[a]	1.20
13-15	18.57[a]	-	18.71[a]	1.97
16-17	18.67[a]	1.09	18.65[a]	1.69
18-20	18.59[a]	1.25	16.44[b]	1.30

- Means with same letters in parallel columns in Anuradhapura and Kurunegala divisions are not significantly different at $P \leq 0.05$ as determined by Least Significant Different (LSD)

Similarly, Mokany *et al.*, (2006) reported that root:shoot ratios had decreased significantly with the related factors of age in both forests and woodlands while root:shoot ratio had decreased significantly as annual precipitation increases. As *Khaya* plantations in Kurunegala located in the agro ecological regions which experiences comparatively high annual rainfall (IL_3, IM_{3b}, IL_{1a}) than Anuradhapura (DL_{1b}), they had lower root:shoot ratios for many age classes than in Anuradhapura. This trend supports existing hypothesis and experimental evidence that root:shoot ratio become lower as moisture availability increases (Gower *et al.*, 1992; Brand, 1999 and Schenk and Jackson, 2002).

Carbon Sequestration

The average carbon sequestration of *K. senegalensis* calculated for the present study were 88.98 and 127.92 tonnes per ha in Anuradhapura and Kurunegala divisions, while they were 63, 75, 70 and 33 tonnes per ha for major *Dry Zone* plantation forest species, *i.e. Tectona grandis, Swietenia macrophylla, Acacia auriculiformis* and *Eucalyptus camaldulensis,* respectively (De Costa and Suranga, 2012). Those figures are higher than IPCC (2003)'s estimate of benchmark average carbon sequestration of plantation forests in the 'Tropical Dry' climate zone, which is 30 tonnes per ha. This confirms that, among major forest plantation species in Sri Lanka, *Khaya* ranked top in carbon sequestration capacity, basically being a deciduous evergreen tree of wide, dense and expanding canopy with many branches. Further, *Khaya* recorded a greater carbon sequestration capacity in Kurunegala compared to Anuradhapura, owing to moisture rich growing conditions.

The total amount of carbon sequestered by the existing *Khaya* plantations in Anuradhapura (741.92 ha) and Kurunegala (475.20 ha) divisions amounted to 21,785.25 tonnes and 27,969.10 tonnes, respectively (Table 1.4). Despite the greater extent, *Khaya* in Anuradhapura assimilated less carbon due to being in younger age classes and stressful conditions imposed by the climate. Further, greater carbon sequestration capacity of *Khaya* plantations in Kurunegala division for each age class had resulted in greater carbon stocks in Kurunegala, even with low extent of hectares.

Biomass and carbon masses estimated for each age class of *Khaya* in the present study can be considered as the first overall estimation of biomass and carbon mass, in Sri Lanka (Table 1.4). Despite their approximate nature, these estimates can be used as basic data in carbon budgeting programmes. Further, these estimates can be fine tuned to make them more accurate by increasing the frequency of measurements of *dbh* and height, and by developing specific allometric relationship for *K. senegalansis*.

Table 1.4: Biomass and Carbon Mass of Khaya in Anuradhapura and Kurunegala Divisions

	Anuradhapura					Kurunegala				
Age Class	**Biomass per tree (Kg/tree)**	**Biomass /ha (Tonnes/ha)**	**Extend (ha)**	**Total biomass (Tonnes)**	**Total C (Tonnes)**	**Biomass Per tree Kg/tree**	**Biomass/ha (Tonnes/ha)**	**Extend (ha)**	**Total biomass (Tonnes)**	**Total C (Tonnes)**
1-3	2.07	3.31	325.90	1078.73	539.36	5.70	9.12	109.00	994.08	497.04
4-5	12.49	19.98	90.00	1798.20	899.10	52.08	83.33	86.20	7,182.87	3,591.44
6-7	85.80	137.38	189.41	26,021.15	13,010.57	66.61	106.58	136.40	14,536.97	7,268.48
8-10	132.24	105.79	105.81	11,193.64	5,596.82	161.32	129.06	38.10	4,917.03	2,458.51
11-12	202.51	162.01	0	0	0	178.64	142.91	14.00	2,000.77	1,000.38
13-15	240.17	192.14	0	0	0	332.89	266.31	24.50	6,524.64	3,262.32
16-17	276.07	110.43	19.80	2,186.51	1,093.26	349.87	139.95	13.50	1,889.30	944.65
18-20	293.71	117.48	11.00	1,292.28	646.14	836.10	334.44	53.50	17,892.54	8,946.27
Total			741.92	43,570.51	21,785.25			475.20	55,938.20	27,969.10

Conclusions

A significantly greater biomass of *Khaya* at tree level was recorded for many age classes in Kurunegala, attributing to moisture rich growing conditions, while less annual rainfall and prolonged drought resulted a significantly lower tree level biomass in Anuradhapura. Irregular biomass distribution through age classes was observed from Kurunegala, associated with the climate variation of the different AERs (DL_{1b}, IL_3, IL_{1a}, IM_{3b}) within the district, whereas DL_{1b} being the sole AER in Anuradhapura, resulted less variation, indicating that biomass accumulation is related to the environmental conditions of the respective sites and regions. The average carbon sequestration of *K. senegalensis* were 88.98 and 127.92 tonnes per ha in Anuradhapura and Kurunegala divisions, which is well ahead of the IPCC's benchmark of plantation forests in 'Tropical Dry' climate and major plantation forest species, thus confirming the potential of *Khaya* in climate change mitigation. Existing *Khaya* plantations in Anuradhapura (741.92 ha) and Kurunegala (475.20 ha) sequestered the 21,785.25 tonnes and 27,969.10 tonnes of carbon.

Nonetheless, the prime aim of establishing forest plantations is to satisfy the timber or fuel wood demand of the nation, they can be further valued by analyzing the carbon sequestration ability with their potential use in climate change mitigation, to tap the economic benefits through UN-REDD and CDM projects. Biomass and carbon estimates in present study for each age class of *Khaya* in Anuradhapura and Kurunegala divisions may be considered as regional baselines for forestry carbon projects. They can be used to premeditate the total biomass carbon with the existing inventory data of the Forest Department in a cost effective manner, until new information is generated. These estimates can be further validated with comprehensive survey of individual trees and by developing allometric relationships specific for *K. senegalansis.*

In conclusion, the consideration of expanding the forest plantations, specially with *K. senegalensis* would be ideal to achieve a win-win solution by entering into the carbon budgeting of forest plantations with minimal cost factor. Sri Lanka being a developing country, this would be a prospective approach to alleviate itself from the economic crisis. As future implications, carbon estimation with remote sensing could be tested with the premeditated data generated through this study, which would be a better option to avoid on-site measurements of tree dimensions, which are time consuming and labour intensive.

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