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Assessing the Potential Contribution of Latex from Rubber (Hevea Brasiliensis) Plantations as a Carbon Sink

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Abstract:
Sequestered carbon is stored in carbon pools such as aboveground carbon, belowground carbon, carbon in the soil organic matter, dead wood and litter, however, the contribution of latex to carbon sequestration is overlooked. A comparison of aboveground, belowground and latex carbon pools for rubber was conducted as the focus of this study. Comparing three carbon pools, aboveground carbon had a significantly higher carbon sequestration capacity with an effect size of 75% whilst sequestered carbon by both the belowground carbon pool and the latex carbon pool had no significant differences between them with a recorded effect size of 4% each. Although the carbon sequestered by belowground pool was higher initially, than the carbon in the latex, the opposite occurs as the age of the plantation increases. The carbon found in the latex is no different from the carbon contained in the belowground pool, thus, latex is equally important for carbon accounting on rubber plantations.

Keywords: *Carbon pool, latex, aboveground, belowground, rubber, carbon, plantation*

1. Introduction

Rubber (Hevea brasiliensis) is a fast growing perennial tree which can attain a diameter at breast height (dbh) of about 35 cm, a height of about 40 m, and grows well in tropical areas in tropical climates (Charoenjit, Zuddas, Allemand, Pattanakiat, & Pachana, 2015). Due to its fast-growing nature, it is associated with high level of biomass and poses as a great prospect in sequestering carbon over its lifetime(Nguyen, 2013). According to (Brahma, Nath& Das, 2016), its biomass carbon stock is comparable or even more than many tropical and subtropical forestry and agroforestry systems.

Due to the increasing demand of natural rubber and its commercial consistency, rubber plantations have attracted the interests of policy makers as well as cultivators in secondary and degraded forests restoration. Globally, massive expansion of rubber plantations have been recorded in the world's sub-tropical and tropical areas over the past 50 years (Chen et al., 2016). This rapid development of rubber plantations is recorded in Southeast-Asia, the Amazon Basin and Africa with an estimated total planted area of 10 million hectares (M ha) out of the estimated 4 billion hectares (B ha) coverage for total world forests (FAO, 2010).A typical case of rubber afforestation and reforestation is in Columbia where highly degraded lands have seen rubber cultivation of 1,500 hectares (World Bank, 2005).

Primarily managed for latex extraction, Heveaplays significant role in vegetation carbon stock management and climate change mitigation (Brahma et al., 2016).The Afforestation and Reforestation program under the Clean Development Mechanism (AR-CDM) targeted at improving terrestrial carbon sinks to reduce emitted carbon, provides a boost incentive for planted forests(Watson, 2009).Rubber on large scale production are accounted for as planted forests (Egbe, Tabot, Fonge & Bechem, 2012)and contributes to development by financial gains and carbon emissions reduction.

A plethora of studies (eg. Cheng, Wang, & Jiang, 2007; Feng, Liu, Jiang, & Li, 2013; Maggiotto et al., 2014; Munasinghe, Rodrigo, & Gunawarden, 2014; Petsri, Chidthaisong, Pumijumnong, & Wachrinrat, 2013) have considered different carbon stocks in rubber plantation- aboveground biomass (AGB), including rubber trees and understory plants; belowground living biomass (BGB), and soil organic carbon (SOC) – at different genotypes and geographic locations. However, none of these studies considered the potential contribution of latex as a carbon sink (Blagodatsky, Xu, & Cadisch, 2016). Blagodatsky et al., (2016) argued that, collected latex needs to be taken into account as well for calculating the carbon sequestration potential in rubber plantation.

Although the latex is harvested, the carbon in the latex is stored over longer years and not released into the atmosphere (Liu & Han, 2009). Latex has a very long shelf life with no definitely known period of degradation, therefore, carbon stored in latex and latex products will be stored for a longer time. According to Dr L. M. K. Tillekeratne, Former Director, Rubber Research Institute of Sri Lanka, “a 100% natural latex foam mattress of density 85 with dimensions 100 X 200 X 15 cm absorbs 684.97 kg of CO_2 than what is emitted to the atmosphere during its production(Rubber Research Institute of Sri Lanka, 1985). Hence, consuming Natural Rubber latex-based cushions and mattresses instead of the synthetic foam based counterparts helps to minimize global warming in a big way”(Tillekeratne, 2016).

The omission of the latex carbon content as a carbon pool for rubber plantations renders the carbon potential assessment incomplete (Blagodatsky, Xu & Cadisch, 2016). Hence, this study serves the purpose of assessing the potential contribution of latex from rubber plantations as a carbon sink relative to aboveground and belowground carbon pools.

2. Materials and Methods

2.1. Study Area

The study area is located in a section of the Ghana Rubber Estate Limited’s (GREL) rubber plantation field located at Abura around Agona the District capital of the Ahanta West District of Ghana. The total surface area spans 1,492.39 ha of mature rubber plants under tapping and they have varying ages due to different years of planting. The current spatial extent (4º 53´N - 4º 48´N and 2º 7´ 30” W and 2º 47´W) of the rubber plantation cannot expand since the total land concession available to the company has been fully utilized. The terrain is relatively flat with few slopes as the highlands are in the range of about 100m - 152.4m according to the Western Regional Coordinating Council as cited in (Danso-Manu, Poku & Fayorsey, 2013). Acrisol and ferralsol soil types are usually found around the few highland areas (Driessen, Deckers & Spaargaren, 2001). The well drained acidic soil in the area has 76% sand, 22% clay and gravels at 10 - 60 cm deep which has been a major support in rubber plantation establishment in the area (Wauters, Coudert, Grallien, Jonard, & Ponette, 2008).The major seasons are two which include the rainy and dry seasons. Rainfall pattern is from April – July and December–March with 1200mm -1800mm per annum, as dry periods last October–November and August–September at an average of 24^{o} C and 27^{o} C per annum(Wauters et al., 2008).

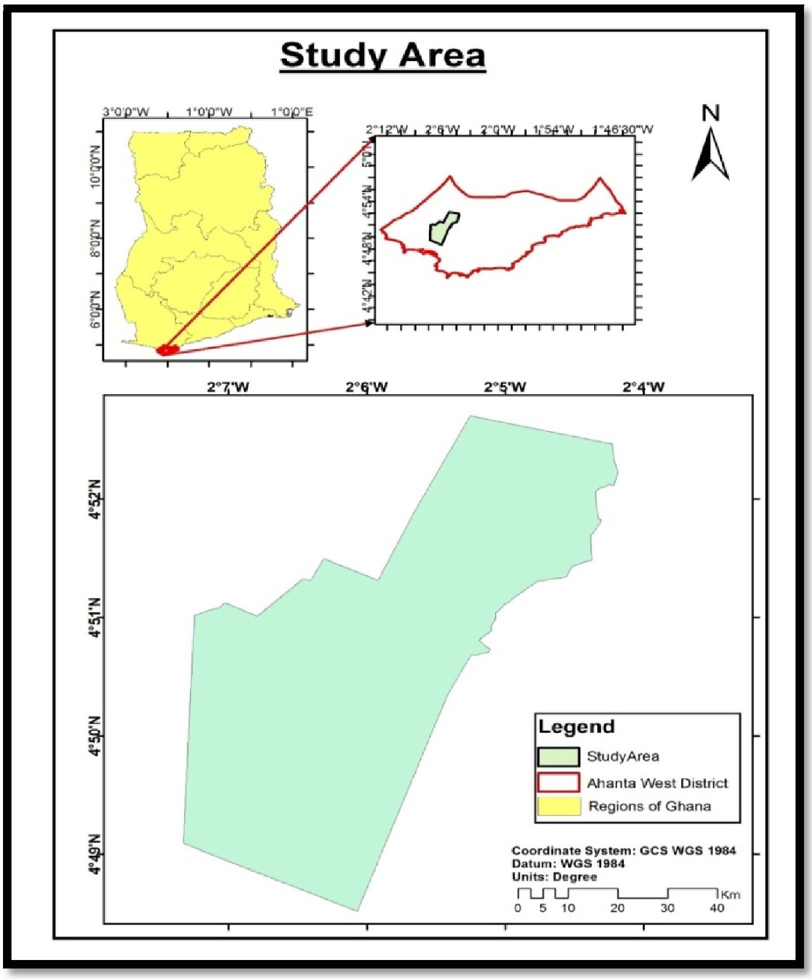

Figure 1: Study Area

2.2. Field Data Collection

Due to the homogeneous structure of the plantation and the differences in age, the stratified random sampling design was adopted for the study (Omair, 2014). Stratification of rubber plantations with respect to age for biomass/carbon studies have been widely adopted and used because differences in tree parameters existinthe different planting years.(Wauters et al., 2008; Charoenjit et al., 2015). Eight different strata with respect to ages were identified from data made available by GREL as 22, 21, 20, 19, 17, 12, 11 and 9 with varying tree densities per plot.A total of 25 sample points (Figure 2) were laid in the study area out of 100 blocks.

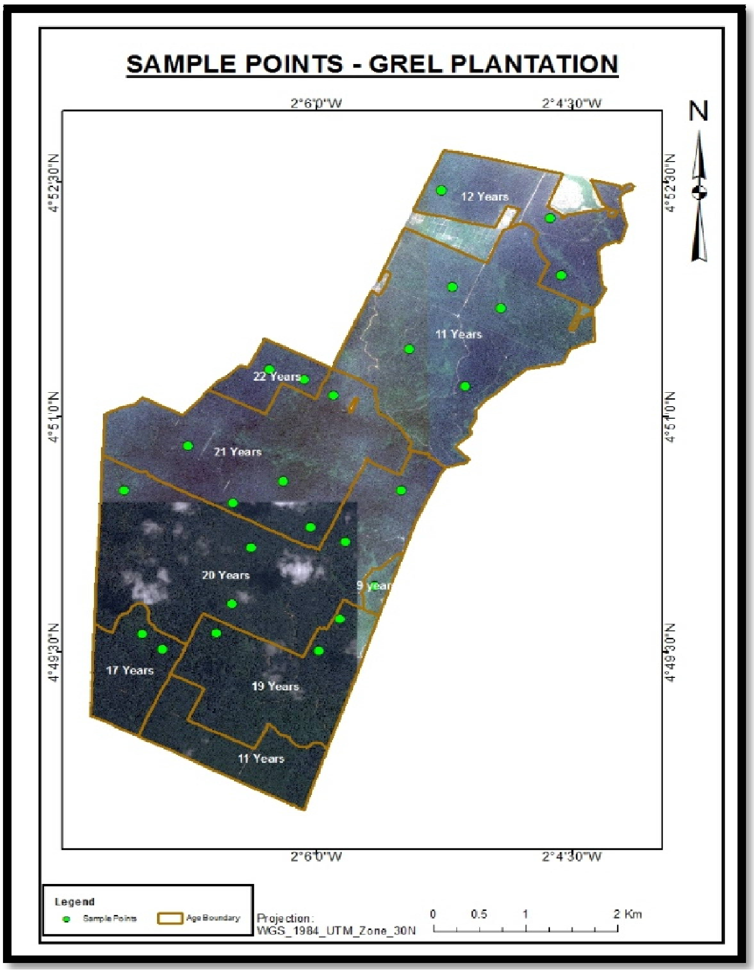

Figure 1: Sample Points

Circular plots (Figure 3) of radius 12.62m (500m^2) were laid with the aid of the surveyor's tape. Within each plot the diameter at breast height of 170cm (DBH_{170}), Canopy Projection Area (CPA) of individual trees, and the planting density were measured. To ensure consistency, a 170cm stick was used to aid in identifying the diameter at breast height of 170cm (DBH_{170}).

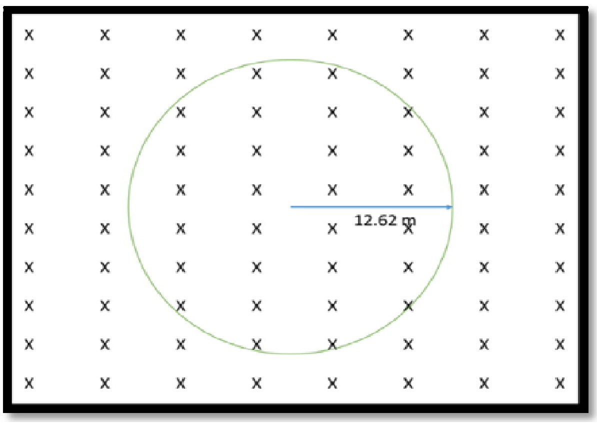

Figure 2:500 M^2 Circular Plots

A summary of the field DBH collected for the various ages is presented as Figure 3.

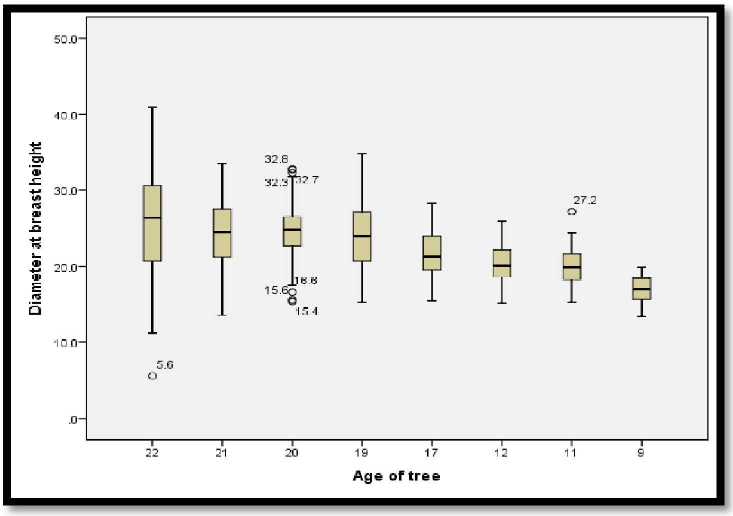

Figure 3: Field DBH Data

2.3. Secondary Data from GREL

The following data was obtained from management of GREL:

- different age categorization of rubber stands (9 years to 22 years)
- Total latex production per age per block in Table 1.
- Average Dry Rubber Content (DRC) fraction of latex production (Table 2).

Age	Plots	Area (Ha)	Trees	Total Latex (kg)
22	K6	11.71	4881	387128.97
	K5	13.48	5246	434811.15
21	K4	11.13	3498	277343.04
	N4	15.34	4811	388348.70
	N7	14.16	5665	366484.14
	O3	15.21	5027	438901.33
	O5	14.93	5539	461358.83
20	P4	14.12	6273	407351.24
	P8	9.88	3787	215428.90
	O2	11.29	2943	204144.42
	R4	13.65	5719	340976.38
	M1	14.59	4521	309261.58
19	Q1	8.26	2052	122589.97
	S4	9.2	2860	133040.83
	R1	8.58	2588	155776.11
17	T5	11.93	4774	191319.70
	T6	5.01	1894	74746.95
12	E2	30.71	13244	227989.13
	E5	32.08	15056	306011.77
	F1	35.07	14818	270143.59
11	G2	48.11	21981	319850.41
	G3	26.63	12352	175552.03
	H1	70.86	33731	555532.23
	H3	50.66	22448	322888.17
9	P1	34.74	13718	135805.53

Table 1: Latex production

Month	Average DRC
January	61.94
February	62.24
March	64.84
April	63.11
May	60.22
June	59.90
July	58.38
August	58.00
September	57.22
October	62.00
November	57.83
December	60.00

Table 2: Monthly Average DRC

2.4. Above/Below Ground Carbon Estimation

About eight (8) allometric equations have been developed for rubber plantations in the world for above ground biomass and two (2) for below ground biomass measurements (Yuen et al., 2016). An example is 'AGB = exp (-2.289 + 2.649 ln (DBH) -0.021 (DBH)^2) which utilizes only dbh was used by Kongsager et al. (2013) for carbon estimation for tropical tree crops including rubber plantations in Ghana. For the scope of this work, site specific allometric equations for the Hevea brasiliensis specie was preferred because they are associated with higher levels of accuracy (Goetz et al., 2009). The aboveground and belowground carbon were estimated using site specific allometric equations developed by Wauters et al., (2008). This required that the DBH_{170} is first converted to circumference (C_{170}) (Eqn. 1).

$C_{170} = \pi * DBH_{170}$………………………. (1)

Aboveground carbon was for each age category was computed by estimating foliage carbon (Eqn. 2) and stem carbon using equation (Eqn. 3) and subsequently summed up:

$\ln Y = -6.118 + 1.857 * \ln C_{170}$…………. (2)

$\ln Y = -7.260 + 2.904 * \ln C_{170}$……….. (3)

Belowground carbon (roots) for each age category were computed using C_{170} (Eqn. 4) since there exist a shoot to root relationship based on the stem size.

$\ln Y = -4.996 + 1.872 * \ln C_{170}$…………… (4)

$EXP^{(\ln Y)}$ was applied to the results of each carbon pool computed to obtain the real carbon values.

Tree girth measured at a height of 170 cm was used due to the bark removal, the values collected for the development of the equations were circumference to arrive at the carbon results.

2.5. Computations and Analysis

To facilitate carbon estimation and comparison among the three carbon pools (aboveground, belowground and latex) there was the need to rescale the latex production to plot level. Rescaling the total latex production to the plot level will bring it in harmony with field dbh data collected. Thus, a simple mathematical computation of (0.05ha/Area ha) * Latex (kg).

To compute the carbon content of latex produced by a rubber tree, the Dry Rubber Content (DRC) or Total Solid Content (TSC) can be used as discussed in literature(Jayanthy & Sankaranarayanan, 2005; Petsri et al., 2013; Tillekeratne et al., 1988). In this study, the DRC was used for computing the latex carbon content because that data was reliably and readily available from the supporting company (GREL).The DRC of rubber is basically polyisoprene C_5H_8 and hence a Default Factor (DF) of 0.88 t C t^{-1} of dry rubber is applied to determine the carbon content (Petsri et al., 2013). This application of DF is similar to the application of conversion factor (CF) to tree biomass to determine the carbon stock of a tree (Ratnasingam, Thiruselvam, & Ioras, 2016).The average DRC employed in the computation ofthe latex carbon content is 60.4% (i.e. the DRC fraction obtained from GREL in Table 2). To compute the amount of carbon contained in the latex per age category, the DRC was multiplied by the Default factor (DF) of 0.88 t C t^{-1}(Petsri et al., 2013).

3. Results

Age	Aboveground Carbon	Belowground Carbon	Carbon in latex
22	6329.60	623.63	867.92
21	4790.72	497.64	722.20
20	4717.14	492.48	610.78
19	3930.29	429.19	420.42
17	3363.02	400.64	411.35
12	3077.86	391.30	218.63
11	2701.85	348.25	182.41
9	1903.80	288.64	103.89

Table 3: Differences in Carbon (Kg) Per 500m^2

The results (Table 3) revealed that latex produced from stands that were 20 years and above generated over 500 kg C 500m^{-2} and above whilst latex production from stands below 20 years were less than 500 kg C 500m^{-2}. The 22-year-old stands recorded highest carbon stock in the latex (867.92 kg C 500m^{-2}) whereas 9-year-old stands recorded lowest carbon stock in the latex (103.89 kg C 500m^{-2})

Figure 5 represents the mean carbon (t C ha^{-1}) from latex computed for the different ages of the rubber plantation. The mean latex carbon content ranged from 2.08t C ha^{-1} for the 9-year-old stand to 17.36 t C ha^{-1} for 22-year-old stand. The difference in carbon for ages 22 and 21 was 2.92 t C ha^{-1}, a difference of 2.22 t C ha^{-1} was observed between ages 21 and 20, further difference of 3.81 t C ha^{-1} was recorded between ages 20 and 19, for ages 19 and 17 the difference was at 0.18 t C ha^{-1}, ages 17 and 12 recorded a difference of 3.86 t C ha^{-1}, that of ages 12 and 11 was 0.72 t C ha^{-1} and the difference between ages 11 and 9 was 1.57 t C ha^{-1}.

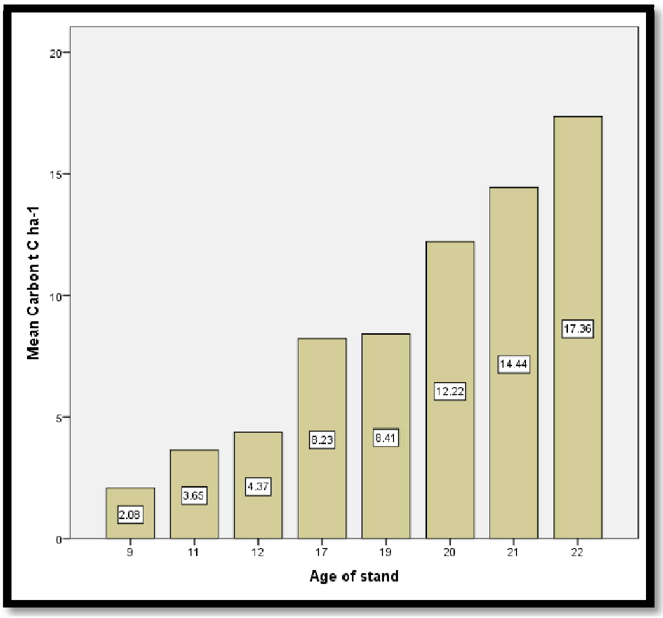

Figure 4: Differences in Carbon (T C Ha-1) From Latex per Age Class

A post-hoc multi-comparison test (whilst applying the Bonferroni correction) indicated that the mean latex carbon for age class 22 was significantly different from age classes 20 at p=0.007, 19, 17,12, 11 and 9 at p=0.000. For age 21, the significant difference in latex carbon was recorded in comparison to age classes 19, 17, 12, 11 and 9 at p=0.000 and the latex carbon for age group 20 was observed to be statistically different from age groups 12, 11 and 9 at p=0.000. From Table 4 where the significant differences among the different years are shown, the positive sign denotes significant differences and the negative sign shows non-significant difference between the ages. Age 22 was significantly different from ages 20, 19, 17, 12, 11 and 9. Age 20 was significantly different from 12, 11 and 9 years, beyond which no significant differences are recorded.

AGE	22	21	20	19	17	12	11	9
22	-	-	+	+	+	+	+	+
21		-	-	+	+	+	+	+
20			-	-	-	+	+	+
19				-	-	-	-	-
17					-	-	-	-
12						-	-	-
11							-	-
9								-

Table 4: Summary of Pairwise Multi-Comparison of Latex Carbon (T C Ha^{-1}) with Bonferroni Correction
(+) significant difference
(-) no significant difference

The field measured diameter at breast height of 170m (DBH_{170}) used for the aboveground carbon (AGC) and belowground carbon (BGC) computation is shown in Figure 5. At the plot level of 500m^2 the mean DBH_{170} for the youngest rubber stand of 9 years is given as 16.96cm which is 4.89% less than the highest DBH_{170} (25.78cm) for the 22-year-old rubber stand. The difference between the highest $DBH_{170}$and the least DBH_{170} is 8.82cm and this exists for the ages of 9 and 22 years.

Age	Area (ha)	Carbon per ha (t C ha^{-1})		
		AGC	BGC	Latex
22	45.91	126.60	12.47	17.36
21	293.84	95.81	9.95	14.44
20	342.07	89.78	9.50	12.45
19	86.07	87.11	9.24	9.13
17	60.89	67.26	8.01	8.22
12	171.30	61.56	7.82	4.37
11	457.68	54.04	6.97	3.65
9	34.74	38.08	5.77	2.08

Table 5: Sequestered Carbon According to Carbon Pool

From Table 5, AGC recorded higher sequestered carbon values relative to belowground carbon below (BGC) and latex carbon. At age 9, AGC recorded a higher carbon content of 38.08 t C ha^{-1} compared to 5.77 t C ha^{-1} for BGC, and 2.08 t C ha^{-1} to latex. At age 19 (10 years after), AGC recorded a higher carbon content of 87.11 t C ha^{-1} in comparison to 9.24 and 9.13 t C ha^{-1} for BGC and latex, respectively. At age 22, AGC recorded 126.6 t C ha^{-1}, BGC recorded 12.47 t C ha^{-1}, and latex recorded 17.36 t C ha^{-1}. The decreasing root to shoot ratio was observed for the ages 9, 11, 17, 19, 20, 21 and 22 were found to be 0.152, 0.129, 0.127, 0.119, 0.106, 0.106, 0.104 and 0.098 respectively for the individual years.

From Figure 6, the AGC towers high above the BGC and Latex carbon content across all the ages. The BGC is higher than the Latex carbon at the initial ages of 9 to 12 years, however, as the stand age increases, the carbon from the latex begins to increase more than BGC from age 17 and above. The differences in carbon among the 3 pools at age 9 are 82.91%, 12.56% and 4.53% respectively for AGC, BGC and latex carbon. At age 17 AGC recorded 80.56% whilst BGC and Latex carbon recorded 9.59% and 9.85% indicating that aboveground carbon was still high, whilst latex carbon hand slightly overtaken BGC by 0.26%. By age 22 the sequestered carbon for AGC, BGC and Latex carbon recorded 80.93%, 7.97% and 11.1% respectively which meant that AGC was still higher than BGC and Latex with a difference of 72.96% and 69.83%. Latex carbon which was less than BGC by 8.03% at age 9 is 3.13% higher at age 22.

A Shapiro Wilk's normality F (75) = 0.748, $p< 0.05$ showed that the distribution was not normal. A Kruskal Wallis test for the differences in carbon pools revealed a statistically significant difference among the three carbon pools, Chi-Square (3, N = 75) = 49.436, p = .000. Aboveground carbon ranked highest (Mean=63), latex carbon ranked second highest (Mean=26.44), with belowground carbon assuming the third rank (Mean=24.56).

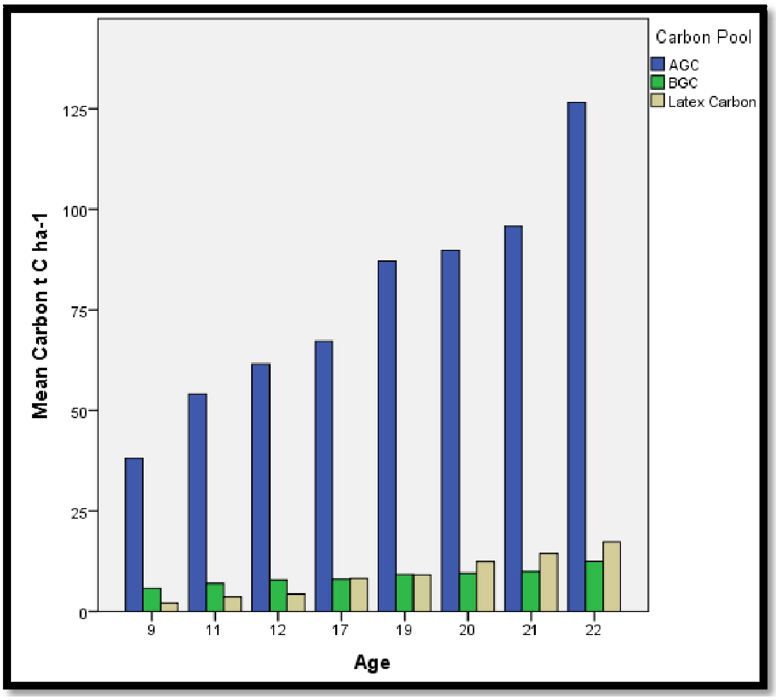

Figure 5: Comparison of Carbon from Different Carbon Pools (AGC, BGC and Latex) for Different Ages

Post-hoc comparisons whilst controlling for the Bonferroni effect indicated that there was significant difference between aboveground carbon and belowground carbon Chi-Square (1, N = 25) = 36.766, p = .000; r = 0.75 which represents a 75% strong effect size. The same significant difference was recorded between aboveground carbon and latex carbon content. On the contrary, there was no significant difference between latex carbon content and belowground content as the results showed Chi-Square (1, N = 25) = 0.208, p = 0.648; r = 0.004 which represents a smaller effect size of 4%.

4. Discussion

Aboveground and belowground carbon pools are traditionally accepted pools in carbon accounting, however, latex is not, therefore the comparison is necessary to help expand knowledge on latex carbon and the possibility of its inclusion to the carbon pools.

The findings of this study on the comparison of aboveground carbon (AGC), belowground carbon (BGC) and latex carbon indicated that as the rubber tree grows and accumulates more age in years, the carbon pools also accumulate more carbon Nguyen (2013). The differences in sequestered carbon by the pools indicated that aboveground carbon pool is significantly associated with higher amounts of carbon relative to BGC and latex carbon across different age categorisations(Satakhun et al., 2013). The differences in AGC in comparison to both BGC and latex carbon content widens with age(Egbe et al., 2012; Negash & Kanninen, 2015). Belowground carbon on the other hand and carbon from latex comparatively do not have significant differences in sequestered carbon. Carbon from belowground biomass was found by this study to be relatively higher than carbon from latex at the age of 9 years when latex carbon is low, however, carbon from latex increases above carbon from the belowground as the age of the plantation increases.

The variations in the carbon sequestered by the various pools could be attributed to the fact that various methods used in the carbon computation for the aboveground and belowground carbon on one hand and the latex carbon on the other hand. Nonetheless, the findings made by this research that aboveground carbon is highest in terms of sequestered carbon relative to all the other pools is consistent with the findings made by Maggiotto et al., (2014). Aboveground biomass has higher carbon relative to the belowground and latex pools. The decrease in root to shoot ratio as the age increases is no different from the findings of (Wauters et al., 2008; Petsri et al., 2013) who reported that shoot to root ratio decreased with age. Petsri et al., (2013) indicated that as the carbon content increased in the biomass of the rubber tree the latex carbon equally increased yet there existed significant differences between the carbon sequestered by the living tree and the carbon sequestered by the latex. This supports the findings made by this study that although carbon content for latex is no different from carbon from the belowground carbon pool, aboveground carbon by far remains the highest carbon pool. Additionally, in a presentation of the components of carbon budget in a review of carbon balance on rubber plantations, Blagodatsky et al., (2016) reported that as AGC increased, latex carbon increased but belowground carbon was on the decline. Thus, carbon from latex can be considered as a pool due to its significant levels comparable to belowground carbon, however, aboveground carbon still holds the greatest component of sequestered carbon for rubber plantations.

5. Conclusion

Carbon from latex increases as more latex is produced by the rubber trees as they grow older. The results indicated that latex carbon from rubber stands above 20 years of age were significantly higher than latex from rubber stands that are below 20 years at p=0.000.Aboveground was significantly higher in terms of sequestered carbon with an overall effect size of 75% at p=0.000 relative to the remaining carbon pools. However, no significant difference was recorded for belowground carbon and latex carbon as their effect size was of 4% for each at p= 0.648. Hence, rubber can be counted as viable in carbon sequestration and could prove useful for afforestation and reforestation purposes.

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