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Carbon, Nitrogen, Phosphorus, and Potassium Content Partitioning of Cocoa Tree Parts in Serian, Sarawak

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Abstract

Many claim that commodity plantations release carbon stock and thus contribute to climate change effects. Yet, studies on cocoa carbon stock and nutrients are limited, especially in Malaysia therefore, objective of this study was to determine if there were any significant differences of carbon stock in five different tree parts of cocoa, namely branches, main stem, main roots, fibrous roots, and leaves. Twenty cocoa trees (aged 10 years old) at Kpg Muara Ahi, Serian Sarawak were destructively sampled in March, 2016, and cut into five tree compartments prior to analysis by using CHN and AAS Analyzer. Mean comparison was carried out by using one-way ANOVA SPSS 21.0 software. Total cocoa carbon stock was 27.32 Mg C ha^{-1} which branches contributing 47% from the total carbon (12.92 Mg C ha^{-1}), followed by main stem (5.42 Mg C ha^{-1}), taproot (4.05 Mg C ha^{-1}), fibrous root (2.49 Mg C ha^{-1}) and leaves (2.44 Mg C ha^{-1}). Branches and main stems contained higher total carbon stock due to high total biomass (kg), however, main root showed significantly ($p<0.01$) highest in carbon content with 42.58% in terms of per tree parts. As for the nutrient content, leaves showed significantly ($p<00.1$) the highest in nitrogen, phosphorus and potassium content compared to other tree parts with N 2.55 ± 0.04 ppm; P 0.20 ± 0.006 ppm and K 2.68 ± 0.24 ppm, respectively. From the study, it showed that cocoa tree does help in storing carbon. By knowing N, P and K partitioning within cocoa tree, this enable further study to be done especially in applying fertilizer for optimum yield.

Keyword: Biomass, carbon stock, *Theobroma cacao*, nutrients

INTRODUCTION

Climate change has been a debated topic in this century due to unforeseen natural disasters incidents globally. Major steps have been taken into consideration to slow down climate change effect as climate do play an important role in plantation, agriculture and forestry. Though many claimed that commodity plantations contribute to greenhouse gases (GHG) emission, Somarriba *et al*. (2013) accredited cocoa plantation to have significant capability in carbon stocking, hence, contributing in mitigating climate change.

Carbon content is generally estimated by 50% from total biomass (Ciais *et al*., 2011; IPCC, 2003). Determination of total biomass (including above- and belowground biomass) is important prior to estimating carbon stock. Biomass allocation may vary according to time, tree species and environment (Poorter *et al*., 2011) and it may affect the carbon content as well. Tree biomass can be estimated by two methods; non-destructive sampling (allometry equation) and destructive sampling. Though destructive sampling labour-intensive and time consuming, it was chosen as it provide near to precise data on biomass (Vishum & Jayakumar, 2012; Dossa *et al*., 2008), carbon stock and nutrient contents per tree compartments compared to estimation by using general allometry equation (based from tree height, (m) and girth at diameter, (cm)) (Picard *et al*., 2012). Picard *et al*. (2012) stated that biomass estimation is highly precise if the tree stratification of tree is finer. This study is important especially for cocoa industry in Malaysia as there are limited studies done within Southeast Asia (Somarriba *et al.,* 2013).

Nitrogen (N), phosphorus (P) and potassium (K) are the macronutrients needed for plant growth. Potassium functions in osmoregulation, carbohydrate translocation, protein synthesis, enzyme activation, cell expansion, and stomatal regulation (Pallardy, 2008). By knowing the allocation of these macronutrients, further research on fertilizer application in order to optimize productivity by reducing fertilizer loss through leaching or run off is needed. As plant leaves readily absorb mineral nutrients, foliar application has been widely used as a method of fertilization (Johnson *et al*., 2001).

MATERIALS AND METHODS

Study Area

The soils of Samarahan series are included to Bijat family and Gley soils based on soil classification units. Samarahan unit is covered by mainly secondary growth (shifting cultivation-wet rice) and generally between 20-0 feet above sea level. Under the Sarawak Soil Classification System, Samarahan Series is found in small interior valleys surrounded by hills formed by sedimentary rocks and comprises soils which have formed in sediments derived from argillaceous rocks which have not been enriched by magnesium, calcium or potassium from tidal water (Andriesse, 1972).

Research study was conducted at Kpg Muara Ahi, Serian, Sarawak on March, 2016. Study area is classified as red yellow podzolic soil (Teng, 2004). It was cocoa plantation integrated with other crops such as banana (*Musa* sp.), durian (*Durio zibethinus*) and rubber (*Hevea brasiliensis*) trees as shaded trees. Twenty matured cocoa trees aged ten years were chosen as the samples representing one hectare cocoa plantation. UNFCC (2015) stated that small study plots are efficient in representing relative homogenous area or even-aged plantation. No chemical or fertilizer input had been applied to the cocoa in the previous four months.

Biomass Determination

Biomass determination was carried out by destructive sampling whereas belowground biomass was excavated and aboveground biomass was felled at 5 cm from soil surface. Prior tree cutting, tree girth circumference (mm) and height (m) until it highest shoot was recorded and tarpaulin was placed at possible tree felled area. Placement of tarpaulin was to reduce tree samples loss and easy demarking process of leaves and branches of the tree. Leaves were stripped from branches, branches and main stem cut into 30 cm log, the fresh weight (kg) were measured on the field (to reduce moisture loss) using a pan top weighing scale. Root systems (taproots and fibrous roots) were excavated by using excavator and directly transferred to Cocoa Development and Research Centre, Kota

Samarahan, Sarawak to be brushed off and washed (in case of fine soil attach to it) to weighed process. Fresh weight (kg) of all tree compartments was recorded.

Every compartment (main stem, branches, taproots and fibrous roots) of a cocoa tree cut into 5 cm disc as a sample for oven-dried at 105°C for a week (at constant weight), while leaf samples were oven dry at 60°C for 48 hours. The ratio, $DW_S : FW_S$ was used to convert FW_C to the dry weight of tree component DW_C using the relation as in Snowdown *et al.* (2002):

$$DW_C = \left(DW_S \right) \text{ x } FW_C$$

Whereas,
DW_S : samples dry weight (g)
FW_S : samples fresh weight (g)
DW_C : component (disc) dry weight (g)
FW_C : component (disc) fresh weight (g)
*cocoa tree compartments biomass was calculated and extrapolated to a per hectare basis.

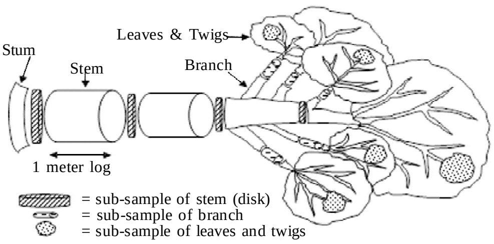

Figure 1. Dividing the trees (Karyati, 2013)

C, N, P, and K Content Determination

Oven-dried disc from each tree compartments were finely grind (0.02 mm) of 10 g for each replicate, total of 3 replicates (n = 3) samples were analysed by using AAS Analyzer. Another 10 g of finely grind (0.02 mm) samples (n=3) was analysed for carbon content (%) by combustion method using CHN Analyzer. Total carbon content per compartment determined;

Total carbon content (Mg C ha^{-1}) =

Carbon content (by CHN Analyzer, %) x biomass (g) x 1000 trees/ha

Mean comparison was carried out by using one-way ANOVA SPSS 21.0 software.

RESULTS AND DISCUSSION

Since this study used destructively sampled method, total actual biomass (tree aboveground, TAGB and belowground, TBGB) for 20 destructively sampled cocoa trees was 134.5 kg which branches contributed to the highest biomass with 61.9 kg (46%) followed by main stem, taproot, leaves and fibrous root with 19.2 kg (14%), 15.5kg (12%) and 12.3 kg (9%), respectively. The biomass (dry-weight basis) partition according to tree compartments was showed in Figure 2. From the result, TAGB (leaves, main stem and branches) recorded 102.9 kg out of 134.5 kg representing only 76.5% of TAGB, lower percentage than Zuidema *et al*. (2005) claimed. This may be due to the high density of main stem. This was agreed by work of Mohammed *et al*. (2015) which also found that stumps of cocoa with stand age less than 15 years contributed the highest biomass.

As Picard *et al.* (2012) stated that biomass estimation is highly precise if the tree stratification of tree is finer, thus in this study, cocoa tree were cut into five main compartments; leaves, main stem, branches, taproots and fibrous roots. Low biomass 7.5 Mg ha^{-1} observed for this study area as it was monoculture cocoa plantation with only banana as integration plants. This was synchronized with Isaac *et al*. (2006) finding in which mono-cocoa had lower biomass (22.8 Mg ha^{-1}) compared to cocoa under shaded tree of 41.4 Mg ha^{-1}. In addition, only cocoa trees above- and belowground biomass were taken into consideration due to sampling time constraint.

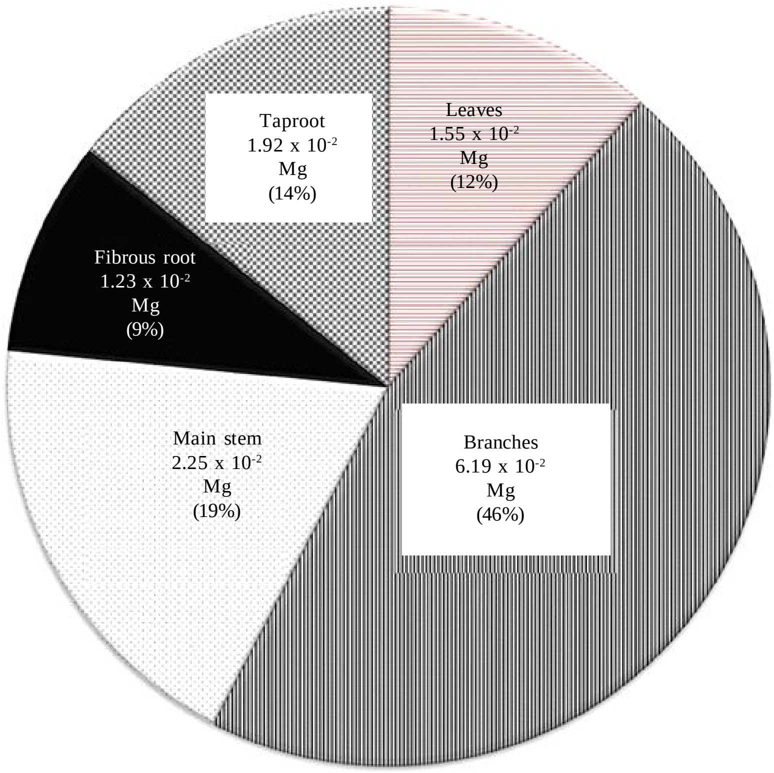

Figure 2. Biomass allocation of 20 cacao trees by five different compartments of Kpg Muara Ahi, Serian, Sarawak

Figure 3 showed carbon stock per tree compartments. Result showed that taproots had the significantly highest C content with 42.58% followed by main stem, branches, fibrous roots and leaves by 41.68%, 41.59%, 41.54% and 32.52%, respectively. While, there were no significantly differences between C stock in main stem, branches and fibrous roots. C content observed were relatively lower than widely used carbon stock estimation ranging from 45–50% of dry weight basis biomass (Losi *et al*., 2011; Djomo *et al*., 2003). Though leaves had significantly the least C stock with only 32.52%, it also play an important role in carbon storing as supported by Ofori-Frimpong *et al*. (2007) that cocoa litter-fall contribute to 97% compared to shade trees by the pruning or fallen leaves in cocoa plantation.

Table 1 showed total above-, below ground biomass (dry-weight basis), carbon stock every tree compartment for exact 20 trees sampled and conversion value to per ha (Mg ha^{-1}) and (Mg C ha^{-1}), respectively. Total carbon stock of one-hectare (including above- and belowground) cacao trees was 27.32 Mg C ha^{-1} consisting of 20.78 Mg C ha^{-1} and 6.54 Mg C ha^{-1} of belowground C stock. It was relatively lower compared to Smiley & Kroschel (2008), as aboveground C stock of 15 years cocoa-gliricidia in Sulawesi, Indonesia was 31 Mg C ha^{-1}. This may be due to the shade trees also taken into consideration in carbon stock estimation whereas in this study, only cacao was measured. However, contradicted to Isaac *et al*. (2007) findings of 8 and 15 years old cacao system in Ghana, only 10.3 Mg C ha^{-1} and 16.8 Mg C ha^{-1} recorded, respectively.

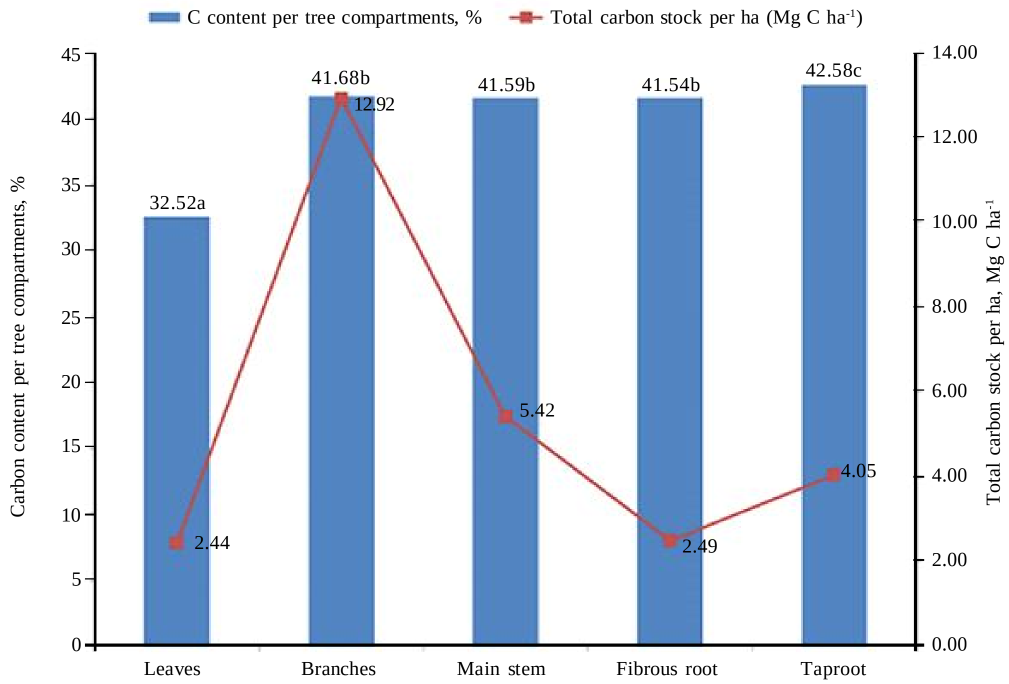

Figure 3. Carbon content per tree compartments (%) at y_1-axis (on the left) and total carbon stock per hectare (Mg C ha^{-1}) at y_2-axis (on the right) 20 cacao trees in Kpg Muara Ahi, Serian, Sarawak

Even though taproots significantly had the highest carbon content (42.58%) in terms of tree compartment, branches contributing the most in total carbon stock as showed in Table 2. with 12.92 Mg C ha^{-1} (0.47%) from total of 27.32 Mg C ha^{-1}. This was due to the high accumulative branches biomass as the actual carbon content (%) multiply with its biomass.

Leaves showed significantly the highest N, P and K content (ppm) compared to other tree parts as showed in Table 2. with 2.55 ppm, 0.20 ppm and 2.68 ppm, respectively. This may due to the transpiration process which enables N, P and K being transported from soil into root systems before its. Higher N, P, and K content within leaf (Figure 4) may indicate that progressive growth process is on-going (Ewel & Mazzarion, 2008) for the cocoa tree as the age of tree was ten years old, which the productive age for cocoa.

Ewel & Mazzarino (2008) suggest the declined or increased of foliar N uptake was directly proportional with N mineralization rate. Therefore, this support that N were transferred at fast rate via transpiration process thus, less N content observed at other tree parts. Camila *et al*. (2015) suggested that distribution of adsorbed N depends on different form of N absorbed; NO_3^- would be partitioned to a larger extent to shoots while N absorbed in organic forms to a larger extent to roots. This explained on significantly higher N content within leaves compared to other compartments as recorded in Table 2.

Significantly high K content within leaves (2.68 ppm) was observed. This phenomenon also supported by Smith (2009) which found that 19% of tree total K content was during leaves fully expanding. In addition, that finding explained that K were higher on leaves and will decreased once fruits are

Table 1. Total biomass (Mg C ha^{-1}) and total carbon stocks (Mg C ha^{-1}) of 20 trees in a 10 years old cocoa system and conversion to per ha area of by tree compartments

Tree compartments	Total biomass		Total C stock	
	of 20 trees, Mg	conversion to per ha (Mg ha^{-1})	of 20 trees, Mg C	conversion to per ha (Mg C ha^{-1})
Leaves	1.5×10^{-2}	0.75	0.05	2.44
Branches	6.2×10^{-2}	3.10	0.26	12.92
Main stem	2.6×10^{-2}	1.30	0.11	5.42
Fibrous root	1.2×10^{-2}	0.60	0.05	2.49
Taproots	1.9×10^{-2}	0.95	0.08	4.05
TOTAL	13.4×10^{-2}	6.70	0.55	27.32

*Conversion of total biomass (Mg ha^{-1}) and carbon stock per hectare (Mg C ha^{-1}) area is assumed by cocoa tree stand in one hectare is 1000 trees.

Table 2. Nutrient contents of five different tree compartments of 10 years old cacao tree in Kpg Muara Ahi, Serian, Sarawak

Tree parts	Nutrient contents		
	N (ppm)	P (ppm)	K (ppm)
Leaves	2.55 ± 0.044a	0.20 ± 0.006a	2.68 ± 0.074a
Main stem	0.65 ± 0.033b	0.10 ± 0.007b	1.34 ± 0.050bc
Branches	0.34 ± 0.180c	0.07 ± 0.003c	1.14 ± 0.041bc
Fibrous root	0.79 ± 0.033d	0.09 ± 0.029bc	0.96 ± 0.044c
Taproot	0.48 ± 0.082e	0.08 ± 0.005bc	1.38 ± 0.050b

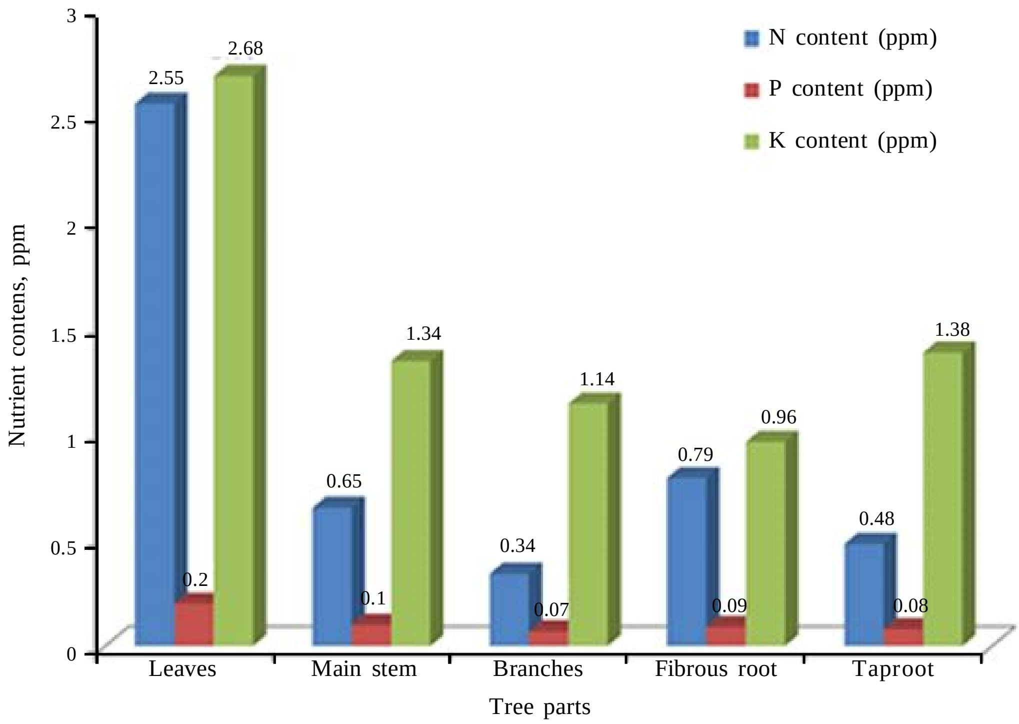

Figure 4. Nitrogen (N), phosphorus (P) and potassium (K) content in five compartments of 10 years old cacao tree in Kpg Muara Ahi, Serian, Sarawak

developed (Niederholzer, 1991), as this study tree sampling done, it was out of cacao peak fruiting season (March, 2017). This result was supported by Parvej *et al*. (2013) on soy bean varieties showed 60% of total plant K before flowering and the proportion of K residing in the leaves gradually decreased with time. Besides that, potassium is mobile within plant parts enabling K to be transported easily to leaves area (Fromm, 2010) by transpiration process.

Similar pattern can also be observed for P content which leaves had significantly the highest followed by main stem, fibrous roots, taproots and branches with 0.20 ppm, 0.10 ppm, 0.09 ppm, 0.08 ppm and 0.07 ppm, respectively. The results were in line with Smith (2009) research study on pecan trees as P content in leaves were the highest ranging from 100 to 136 g/tree P contributing 28% to 32% of the tree's P content. Thus it proved that leaves are the main P source for a tree prior to fruiting season (Smith, 2009).

CONCLUSION

As a conclusion, a one hectare cacao tree (of 10 years old cacao systems) planted at standard planting design (3 m x 3 m) consist of 6.70 Mg ha^{-1} total biomass (above- and belowground biomass). It significantly can store carbon approximately up to 27.32 Mg ha^{-1} which branches contribute to the most carbon due to its biomass weightage. However, as per tree compartments, taproots had the highest carbon content (42.58%) and leaves had the highest N, P and K content with 2.55 ppm, 0.20 ppm and 2.68 ppm, respectively.

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