

Are High Carbon Stocks in Agroforests and Forest Associated with High Plant Species Diversity?

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ABSTRACT

Conserving plant diversity and retaining terrestrial carbon stocks are targets for environmental policy and appear to be generally compatible. However, detailed information on the way both respond to agroforestry management is lacking. Rubber and fruit tree agroforestry systems combine planted trees and trees that are tolerated or actively managed that derived from natural vegetation. The research aimed to evaluate plant species diversity, vegetation structure, and C stock in rubber agroforestry system (AF) and secondary forest grown in silty clay and sandy soils in Pulang Pisau Regency, Central Kalimantan province. A number of multistrata agroforestry systems was compared to the secondary (natural) forests (SNF) of the area; these included Fruit-Based Rubber Agroforestry (AFB) of about 100 years of age, Old Rubber Agroforestry (ARO) and Young Rubber Agroforestry (ARY). The highest C stock was found in AFB (415 Mg ha⁻¹), while the average C stocks of other AF and SNF were 217 Mg ha⁻¹. A plant diversity index (H') was only weakly correlated to aboveground C stocks. Including the farmer-managed agroforests in schemes to reduce emissions from deforestation and forest degradation is relevant, as their carbon stocks match or exceed those of remaining forests in the area.

Keywords : carbon stocks; plant diversity; rubber agroforestry; soils texture

INTRODUCTION

Rapid change in forest conditions in Kalimantan is a global concern, as it leads to loss of global biodiversity as well as carbon emissions (Sumarga, Hein, Edens, & Suwarno,

2015). In the search for alternative land use systems that allow development ambitions of local communities to be realized, the various types of agroforests deserve special attention.

These forest-like land cover types consist of trees planted and/or actively managed for marketable products they provide, as well as forest species that are allowed to regenerate (Rahayu, 2009). Litter fall and nutrient cycling in agroforests can be similar to secondary forests (Hairiah et al., 2000; Hendriyani & Setiari, 2009) and beyond maintaining soil carbon stocks, the improved soil structure will reduce erosion in a long-term (Hairiah et al., 2000), and maintain a water balance similar to forests (Suprayogo et al., 2004). The ability of secondary forest and agroforests to sequester and store carbon depends on species diversity, soils condition, climate, and geography (Pandey, 2012). Agroforests thus contribute to both biodiversity conservation and carbon sequestration, but the degree to which of these functions provided to secondary forests was not sufficiently known. Lusiana, van Noordwijk, & Rahayu (2005) reported that agroforestry systems with coffee and fruit trees (11-30 years of age) in Nunukan Regency, East Kalimantan, had an aboveground C stock of about of 70 Mg ha⁻¹, while the average C stock in primary forest was about of 230 Mg ha⁻¹.

The large-scale forest fire that occurred in Pulang Pisau Regency in 1997-1998 caused substantial carbon stock loss from the forest ecosystem and had negative impact on the plant and animal species diversity. In the aftermath of the fire a part of the land was abandoned and became covered by ferns, grass and *Melastoma* forbs. Another part of the area was converted to agroforestry systems with local fruits and rubber as commercial mainstay. Older agroforests in the area allow a prospecting what this land use choice can lead to. A clear distinction exists

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between sandy and (silty) clay soils in the area, with differences in water availability, nutrient and carbon storage (Sutedjo & Kartasapoetra, 1991; IPCC, 2007)).

The objectives of this research were to evaluate plant species diversity, vegetation structure, and carbon stock of rubber and fruit tree agroforestry and secondary forest stands growing on silty clay and sandy soils in Pulang Pisau Regency, Central Kalimantan Province.

MATERIALS AND METHODS

The research was conducted from September 2013 to November 2014 at the agroforestry (AF) area which belong to local people and secondary forest at Pulang Pisau Regency. It is geographically located between 10°-0° South and 110°-120° East, and encompasses the Ramang, Hanua, Parahangan, Sigi, Pamarunan and Tuwung villages.

The climate of the area belongs to type A (highly wet) in the Schmidt-Ferguson classification, with an average rainfall of 2715 to 2890 mm year⁻¹ with three dry month and nine wet month in a year.

Observations were conducted in the agroforestry area that belongs to local farmers, stratified by two factors of variability. Factor 1 involves different land use system with variations in age: (1) Fruit-Based Rubber Agroforestry (AFB), (2) Old Rubber Agroforestry (ARO), (3) Young Rubber Agroforestry (ARY), (4) Secondary Forest (SNF). Factor 2: different soil texture: silty clay and sand. Two replicate plots for each texture by land use combination were measured, for a total of 16 plots.

The area with silty clay soils could be accessed by land (road) or water (river)

transportation while the sandy soils area could only reach over land.

Plant diversity and carbon stock were observed in a plot of 20 m x 100 m in size (Figure 1A and 1B). Plant species diversity of trees with DBH ≥ 5 cm measured at 1.3 m above the soil surface was evaluated by the Shannon-Wiener index (Shannon, 1948), while vegetation structure was analysed according to a method developed by Soerianegara & Indrawan (2005) that combines (a) species diversity (richness), (b) plant species frequency, (c) wood specific gravity (*ws*), (d) basal area (BA), (e) importance value (IV), (f) Shannon-Wiener's diversity index (*H'*).

Carbon stocks were estimated based on the biomass measurement of five carbon pools (IPCC, 2007) including trees, understorey, necromass, litter, and the soil at 0 to 30 cm depth according to RaCSA (*Rapid Carbon Stock Appraisal*) method (Hairiah, Ekadinata, Sari, & Rahayu, 2011). Tree biomass was estimated by using the allometric equations developed by Chave *et al.* (2005) for humid area (rainfalls ranged 1500 to 4000 mm year). Furthermore, wood specific gravity (*ws*) for each observed tree species, could be directly known from the list of wood specific gravity on website: (<http://www.worldagroforestry.org/sea/Products/AFModels/treenwood/treenwood.htm>).

Wood specific gravity was categorized into four classes: (1) light wood (*ws* < 0.6 g.cm⁻³); (2) medium wood (*ws* 0.6 to 0.75 g.cm⁻³); (3) heavy wood (*ws* 0.75 to 0.9 g.cm⁻³); (4) very heavy wood (*ws* > 0.9 g.cm⁻³). Roots biomass was estimated using default value of shoot: root ratio of 4: 1 (Mokany, Raison, & Prokushkin, 2006). All data obtained was analysed for patterns of variability using statistical software including Genstat (14.0) and SPSS.

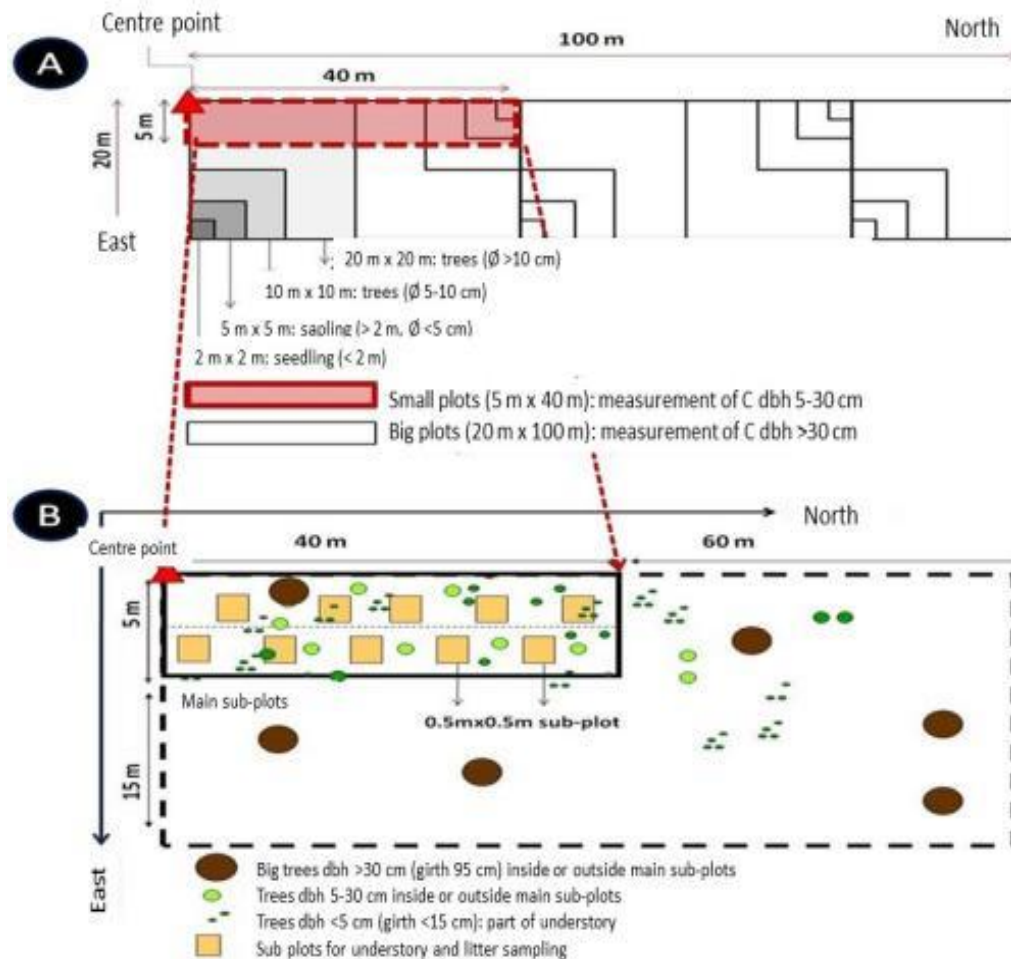


Figure 1. Plot scheme to observed plant diversity (A) and carbon stock in five carbon pools (B).

RESULTS AND DISCUSSION

History of Land Use

The Fruit-based Rubber Agroforest (AFB) had been managed for more than 100 years (it is locally called *Kaleka Lewu*). The ground layer of the agroforest is cleared ahead of the fruit ripening season to facilitate harvesting. On the silty clay soil three codominant species shared the canopy, but on the sandy soils rubber (*Hevea brasiliensis*) dominated.

In the Old Rubber Agroforest (ARO) rubber trees were about 50 years old. The vegetation showed a less intensive land management system. The Young Rubber Agroforest (ARY) had been converted from land formerly used for annual crops (rice and vegetables), approximately 15 years ago. The plots were weeded 2-3 times per year. The secondary natural forest (SNF) plots had been

intensively logged on the silty clay (accessible from the river as well as overland) and less intensive on the sandy soil (accessible overland only). Despite the more intensive disturbance, the forests on silty clay tended to be more diverse than those on sandy soils.

Species Diversity

A total of 201 tree species was identified in the study area, dominated by the families of *Aquifoliaceae*, *Bombacaceae*, *Calophyllaceae*, *Dilleniaceae*, *Dipterocarpaceae*, *Ebenaceae*, *Euphorbiaceae*, *Melastomataceae*, *Myrtaceae*, *Sapindaceae*, and *Vitaceae*. We recorded 91 plant species in the three types of agroforest on silty clay soils with 31 tree species in the secondary forest forest stands. On the sandy soils, the three agroforest types together contained 99 tree species, with only sixteen species in the secondary forest.

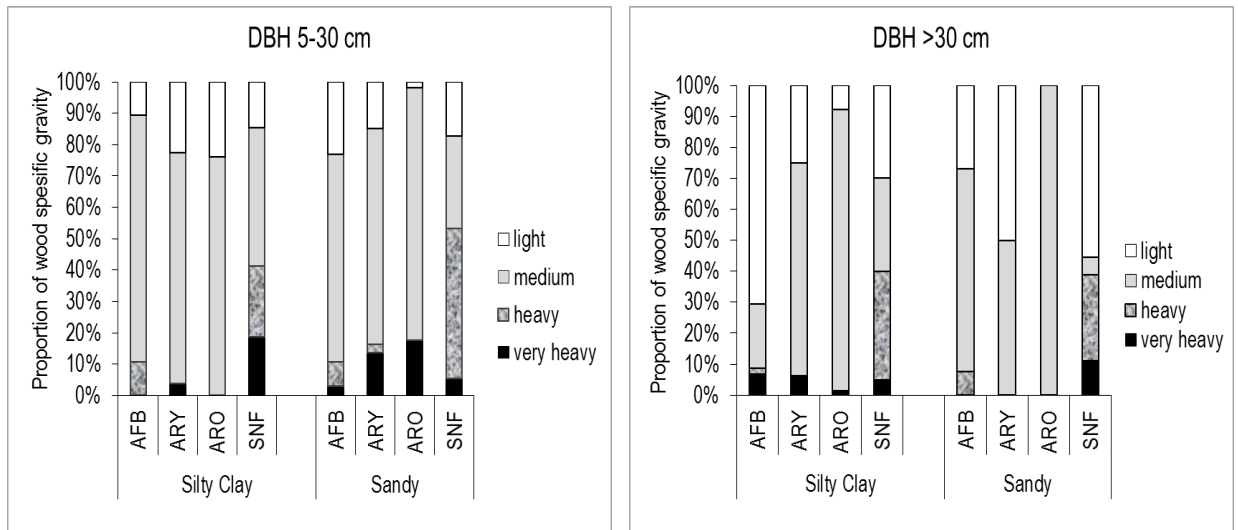
Species diversity analysis for both soil types showed a rather low diversity index (H' 1.6-2.2). The diversity index was similar for the tree and pole categories, but for the sapling and seedling H' was rather low as well, with a value of 2.2 and 1.6, respectively.

Vegetation Structure in Agroforestry Area and Secondary Forest

The highest tree density was recorded in the SNF plots on sandy soils, 838 trees ha^{-1} with $DBH > 10$ cm with an additional 1275 trees in the $DBH 5 - 10$ cm range (Table 1). On the silty clay soil tree density ($DBH > 10$ cm) was on average 15% less, but it was 60% less in the $DBH 5-10$ cm category. The highest Basal Area was observed in AFB on silty clay soils ($59 m^2 ha^{-1}$). On the sandy soils AFB also had the largest Basal Area at $38 m^2 ha^{-1}$. Eight species on the silty clay sites had an importance value in the range 53.8 to 146.4% including *Hevea brasiliensis*, *Durio zibethinus*, *Leea* sp, *Ilex*

cymosa, *Pternandra rostrata*, *Dyospiros* sp and *Baccaurea* sp. On the sandy soils five species had an importance value between 79.9 to 128.7%, including *H. brasiliensis*, *Vatica rassak*, *Nephelium lappaceum*, *Calophyllum inophyllum* and *Syzygium lineatum*.

Most of the trees with $DBH 5$ to 30 cm in the agroforests were categorized as light ($ws < 0.6 g.cm^{-3}$) to medium wood density (ws ranged 0.6 to $0.75 g.cm^{-3}$), except for ARY and ARO plots on sandy soils where trees with heavy wood with ws ranging from 0.75 to $0.9 g cm^{-3}$ were found. Heavy to very heavy wood species were commonly found in the secondary forests (Figure 2). Among trees with $DBH > 30$ cm light and medium wood species dominated on the silty clay soil. Medium wood species were more common on silty clay rather than sandy soils (Figure 3). Median ws was $0.67 g cm^3$ and $0.63 g cm^3$ on the silty clay and sandy soils, respectively.



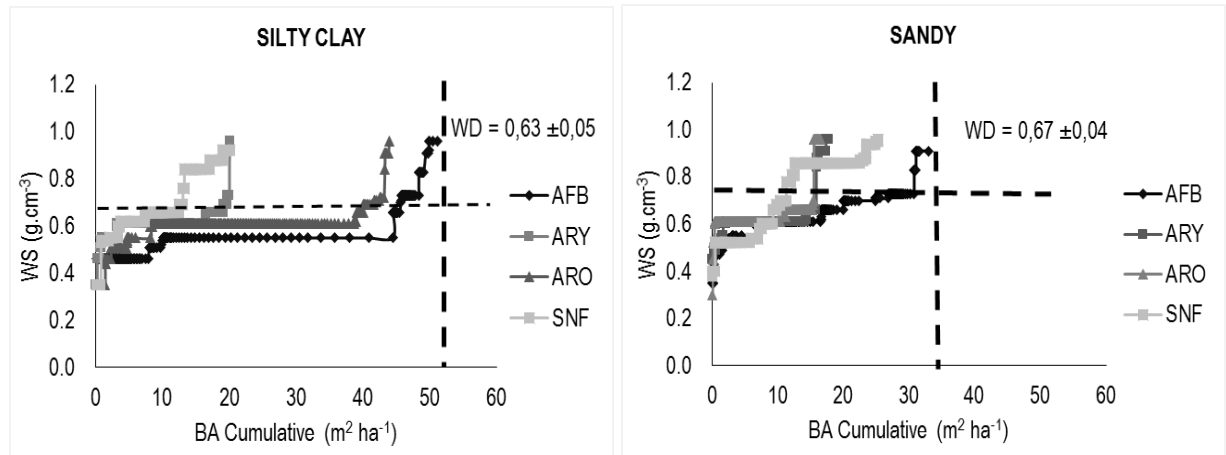
Remarks: AFB = Fruit-Based Rubber Agroforestry, ARY = Young Rubber Agroforestry, ARO = Old Rubber Agroforestry, SNF = Secondary (natural) Forest

Figure 2. Proportion of tree number (%) based on wood specific gravity (ws) classes and tree diameter

Table 1. Density, Basal area and Index of Importance Value in silty clay and sandy soils

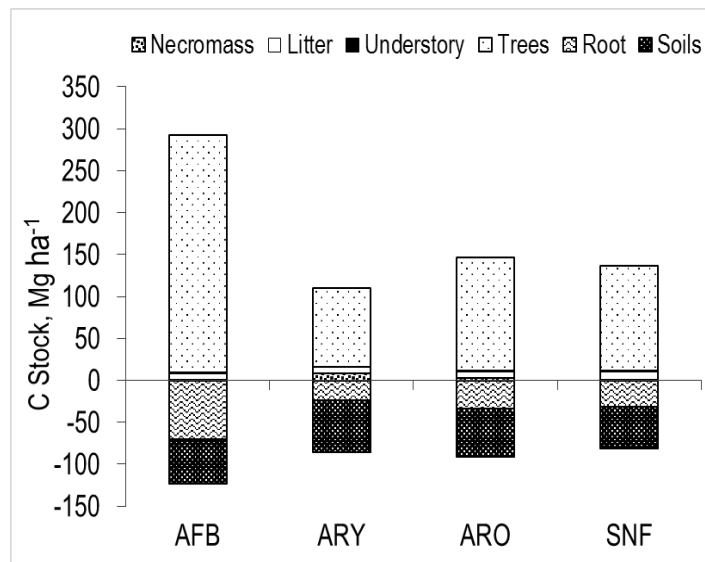
Soils Texture	Land use	Age, year	Number of tree (DBH>5 cm) species/plot	Density, no. trees ha ⁻¹ (DBH 5-10 + >10 cm)	BA (DBH>5 cm), m ² ha ⁻¹	Averaged Importance Value (%)	Dominant/Codominant Species	Benefit
Silty Clay	AFB	> 100	9.5	250 + 595	58.9	116	<i>Durio zibethinus</i> , <i>Hevea brasiliensis</i> , <i>Leea</i> sp	Fruits, timber Latex, timber Vegetable (leaf)
	ARO	50	9.5	250 + 525	22.7	146	<i>H. brasiliensis</i>	Latex, timber
	ARY	15	12.5	650 + 687.5	25.8	200	<i>H. brasiliensis</i> , <i>Ilex cymosa</i> , <i>Pternandra rostrata</i>	Latex, timber Leaf and bark for Medicine (diarea and wound) Aching pain medications (leaves, stems, roots)
	SNF	-	17	500 + 697.5	35.6	53.8	<i>Dillenia excelsa</i> , <i>Dyospiros</i> sp, <i>Pternandra rostrata</i> , <i>Baccaurea</i> sp	Eye medication (leaves) Dye Aching pain medications (leaves, stems, roots) Fruits
	AFB	> 100	17	950 + 740	37.9	79.9	<i>H. brasiliensis</i>	Latex, timber
Sandy	ARO	50	12	900 + 535	18.3	128	<i>H. brasiliensis</i> , <i>Syzygium lineatum</i>	Latex, timber Fruits
	ARY	15	14	1050 + 805	23.3	129	<i>H. brasiliensis</i> , <i>Nephelium lappaceum</i> ,	Latex, timber Fruits
	SNF	-	20.5	1275 + 837.5	25.8	109	<i>Vatica rassak</i> , <i>Calophyllum inophyllum</i>	Medicine (oil for hair) Medicine
	AFB	> 100	17	950 + 740	37.9	79.9	<i>H. brasiliensis</i>	Latex, timber

Remarks: AFB = Fruit-Based Rubber Agroforestry, ARY = Young Rubber Agroforestry, ARO = Old Rubber Agroforestry, SNF = Secondary (natural) Forest



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Figure 3. Median value for density of woods (g cm³) from all trees, which grow on agroforestry system and forest on silty clay and sandy soil



Remarks: AFB: Fruit-Based Rubber Agroforestry, ARY: Young Rubber Agroforestry, ARO: Old Rubber Agroforestry, SNF: Secondary Forest

Figure 4. Contribution of components of the total carbon stock on each land use

Carbon Stock per Area

Total carbon stock was derived as the sum of five carbon pools (tree biomass, understorey, necromass, litter, and soil organic matter). Total carbon stocks did not differ significantly ($p > 0.05$) between the soil types, but they differ among land use classes ($p < 0.01$). The highest carbon stocks were observed in AFB (415 Mg ha⁻¹) with >100 years of age

(Figure 4). The other two agroforests were not different in total carbon stock from the secondary forests (SNF), with an average of 217 Mg ha⁻¹.

Across all agroforests and the secondary forest, the tree biomass contributed 58% to the total carbon stock, and the soil between 0 and 30 cm depth a further 23%. In old weathered soils, such as ultisols, similar results have been

reported elsewhere, while Hairiah, Ekadinata, Sari, & Rahayu (2011) reported that on the volcanic soils of East Java the soil contributed up to 70% of total carbon in various forest and agroforestry types.

Relationship between Basal Area and Tree Diversity and Carbon Stock

The carbon stocks and tree species richness of the agroforests was found to be similar to the disturbed secondary forest. With the carbon stock dominated by the large trees, especially those of high wood density, the relationship between biodiversity and carbon stock is of interest (Figure 5). Tree basal area is strongly correlated with total carbon stock ($y = 8.9258x - 25.277$ with $R^2 = 0.9605$, Figure

6a), but there was no strong correlation between carbon stock and diversity index (H' ; Figure 6b), or any other measure of tree diversity tested. These findings correspond with studies elsewhere in Indonesia (Indriyani, 2011). Markum, Ariesoesiloningsih, Suprayogo, & Hairiah (2013), Kendom, Hairiah, & Sudarto (2013) reported that reduction of carbon stock in Jangkok watershed (Lombok Island) Casteel watershed (Asmad Regency, Papua) after forest conversion to agricultural lands and in conservation forest in Kotawaringin Timur Regency (Central Kalimantan) did not correlate with plant species diversity loss. It was strongly related to the decrease amount of big trees, reflected by decreasing basal area.

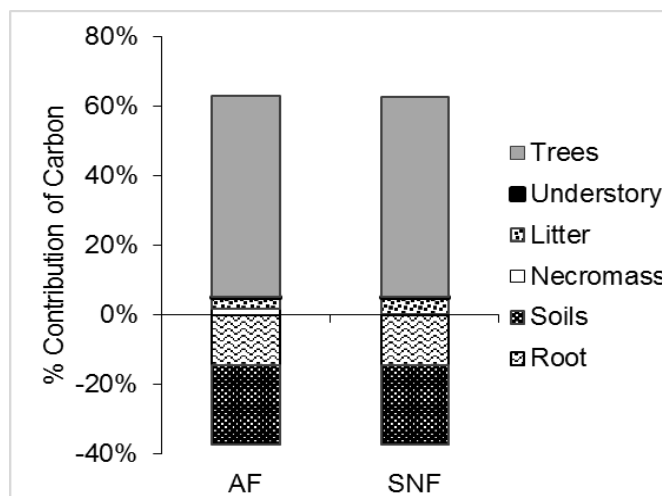


Figure 5. Percentage of contribution from each component that composes carbon stock in agroforestry system (AF) and secondary forest (SNF)

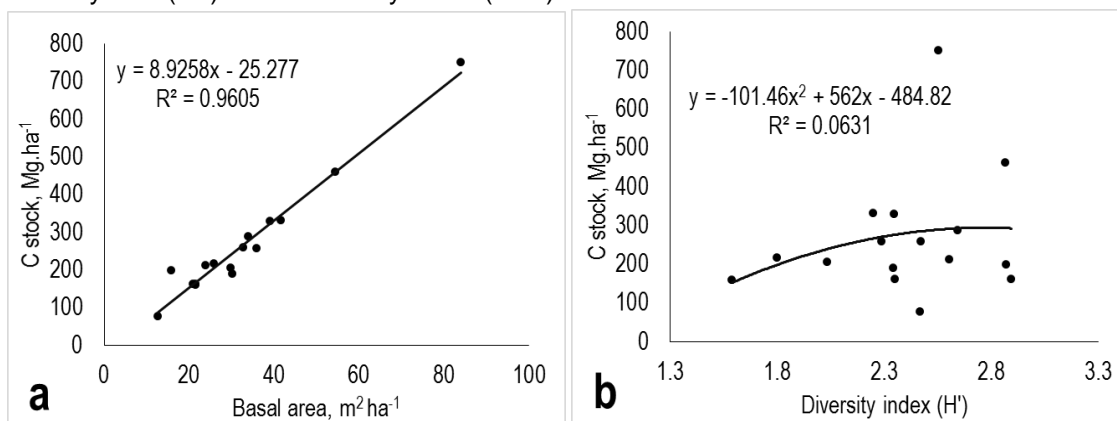


Figure 6. A. Correlation of total system C stock with basal area and B. tree species diversity

CONCLUSION

The 100-year old Fruit-based Rubber Agroforest (AFB) *Kaleka Lewu* had a total system carbon stock of 415 Mg C ha⁻¹ equivalent to undisturbed primary forest in the ecoregion. The 50-year old rubber agroforest was comparable to the remaining secondary forests. Tree biomass contributed 58 % to total carbon stocks and the soil between 0 and 30 cm depth 23% across all systems and soils. These farmer-managed agroforests need to be recognized as part of the wider efforts to reduce emissions from deforestation and forest degradation.

The sandy soil plots in all agroforest types had higher tree numbers and species diversity, but a lower basal area and carbon stock.

In total 201 tree species were found, with 11 dominant plant families. The Index of Species Diversity (H') was medium (mean H' values <3) at both areas, for all four age classes: trees, poles, sapling and seedlings.

The majority of tree with DBH below 30 cm were classified as light to medium wood density. The young rubber agroforestry (ARY) and old rubber agroforestry (ARO) on sandy soils still included trees with heavy wood, as did the secondary forest plots. Big trees (DBH >30 cm) with heavy wood were mostly found in AF on silty clay and in secondary forest at both locations.

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