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Carbon stock in agroforestry coffee plantations with different shade trees in highland area, Thailand

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ABSTRACT

Agroforestry has become an important land use type in northern, Thailand. It is vital to study agroforestry systems due to their ability to sequester carbon. This study investigates plantations that are located in the agricultural highland development station, northern Thailand, and it evaluates the above ground and soil carbon storage of agroforestry coffee plantations with different dominant shading trees, including *Pinus Kesiya* and *Morus* spp. These agroforestry systems were also when compared with a coffee plantation without shading trees. Biomass and carbon were estimated for trees and coffee shrubs using allometric equations. The total carbon stock for the site dominated by *Pinus Kesiya* was 359.36ton.ha^{-1}, while for site dominated by *Morus* spp. it was 8.81 ton.ha^{-1}. In the Sun coffee site the ecosystem carbon stock was 0.75 ton.ha^{-1}. Empirical relationships of age versus DBH and height versus DBH of *Coffea canephora* showed a positive linear relationship. Linear regression analysis of age and DBH produced a slope coefficient of 0.7138.

***Key words** : Agroforestry systems, Carbon stock, Highland, Biomass, Coffee plantation*

Introduction

Climate change and food safety are topics commonly reviewed talked throughout the world. According to the Intergovernmental Panel on Climate Change (IPCC 2014), the projected warming towards the end of the 21st Century will increase by 1.7–4.8 °C. Increases within the emissions of Greenhouse Gases (GHGs), greenhouse emission (CO_2), alkane series (CH_4) and inhalation anesthetic (N_2O), area unit conducive to world global climate change (IPCC, 1992). In the final some years, the value of study on extenuation, ex. decreasing the supply or improving the sinks of greenhouse gases, specially mitigation of CO_2, has been growing caused by climate change results. Unsuitable land use activities (mainly deforestation) are the second major source of anthropogenic CO_2 emissions (IPCC 2013), and agroforestry systems appear to be a suitable management of crop production, further as for greenhouse gas mitigation through a rise in carbon stocks (Schroth *et al.*, 2002).

In agroforestry systems, trees or shrubs are grown around or among crops or pasture land (Nair, 1993), and the recognition of this method as a greenhouse gas– mitigation strategy beneath the city Protocol has attained it the proper to be a part of the strategy for biological carbon sequestration (Nair *et* *al*., 2009). Coffee agroforestry has emerged as a promising landuse system for reducing or offsetting deforestation (Soto-Pinto *et al.*, 2010; van Noordwijk *et al.*, 2002; Mikaela *et al*., 2012), although at the same time sequestering carbon and adding to climate change minimization (Dossa *et al*., 2008; Soto-Pinto *et al*., 2010; Mikaela *et al*., 2012). Provided improved carbon (C-) sequestration that happens with tree planting and the training of agroforestry farming, shade grown coffee systems (''coffee agroforests'') have been known as feasible afforestation and reforestation (A & R) methods below the Clean Development Mechanism (CDM) of the Kyoto Protocol (IPCC 2000; UNFCCC 2007; Mikaela *et al*., 2012). Coffee (*Coffee* spp.) is very significant funding crop harvested in an area of little more than 100,000 km^2 (Lewin *et al*; Leff *et al*. 2004; Lenka *et al*., 2016). It is generally developed below the shade of trees. Forming typical agroforestry (Wintgens, 2004; Lenka *et al*., 2016). The growing of coffee in agroforestry systems (AF) is additional maintainable and can improve the possibility of carbon fixation, creating this system a good approach to help mitigate global climate change (Geovanna *et al*., 2020). Shade trees provide numerous benefits; there is an added value of wood production, which can be expressed (Batjes and Sombrok, 1997; Hergoulaæh *et al*., 2012; Häger 2012; Lenka *et al*., 2016). Ecological conditions influence the phenology of the coffee crop. The geological area (latitude and longitude) of the estate brings about contrasts in the photoperiod and episode sun powered radiation, with ramifications for the yield cycle. The mix of elevation and scope gives particular climatic conditions, influencing warm and water systems, which inuence the profitability and nature of coffee (Da Matta, 2004). The reduction of atmospheric CO_2 can occur by reducing emissions or by their capture (Sommer and De Pauw, 2011). Carbon stocks in biomass and soil vary on the plant species, soil environment, and climatic situations. Thus, the goal of the current study was to measure the carbon stocks in the plant biomass and soil of an agroforestry system composed of coffee with rubber trees and evaluate it to an open-grown farming of coffee (Geovanna *et al*., 2020).

In Thailand, Coffee (*Coffea* spp.) is very significant funding crop harvested in an area of little more than 100,000 km^2 (Lewin *et al*. 2004; Leff *et al*. 2004). It is typically developed below the shade of trees, creating standard agroforestry systems (Wintgens 2004). Shade trees offer numerous benefits; there is an added benefits of wood production, which can be indicated either in conditions of woody biomass or carbon fixation (Batjes and Sombroek, 1997; Hergoulaæh *et al.,* 2012; Häger, 2012), and these plantations may additionally act as a important sanctuary for forest biota, such as birds, insects, mammals and reptiles (Perfecto *et al*., 1996; Moguel and Toledo, 1999).

It is critical to assess carbon stocks provided by agroforestry ecosystems under different shade trees as an additional ecosystem service. The purpose of this study would be to compare the ecosystem carbon storage ability of agroforestry coffee plantations with different shade trees and without shading, in both aboveground and carbon that is belowground. The outcomes of the study may subscribe to the preservation and planting of shade trees for the benefit of carbon sequestration. Evaluating the carbon storage capacity of coffee agroforestry systems with various shade tree species will play a role in an improved comprehension of the role why these ecosystems can play in REDD+ programs because, as stated by Schmitt-Harsh *et al*. (2012), quantifying and understanding carbon budgets of shade-grown coffee systems will become necessary when it comes to development of sound climate change mitigation strategies.

Materials and Methods

Study area description

This study was conducted in Phuphayak agricultural highland development station, Chalermprakirt district, Nan province Thailand (Fig. 1). The average annual rainfall in this humid mountain forest zone is 102.8 mm, and the average annual temperature is 26.6 $^{\circ}$C. The rainy season persists from May to September. According to the FAO (Food and Agriculture Organization), soils in this region are classified as Aeric Tropaqualfs, fine-silty, mixed. The main economic activity in the Phuphayak agricultural highland development station is agriculture, mostly from coffee production. Phuphayak agricultural highland development station is one of the most important areas for coffee production in Thailand; its landscape is characterized by shaded coffee plantations with forest.

The following agroforestry coffee plantations were selected for study: Phuphayak agricultural highland development station, which was divided into three parts; a first part *Pinus* site shaded by *Pinus* spp. and *Morus* site shaded by *Morus* spp. and non-shards part (Sun coffee site). In the past, these sites were used as deforest. Currently, they are maintained as typical agroforestry systems (except the Sun coffee site) *with Coffee arabica* as the principle crop with sparse stands of shading forest trees.

The coffee plantations Phuphayak agricultural highland development stationis located in Chalermprakirt district, Nan province (Fig. 1 and Table 1). The *Pinus* site forms one part of this plantation shaded predominantly by *Pinus Kesiya*. It represents a typical shaded coffee plantation in this region as regards management and tree species composition and the *Morus* site forms one part of this plantation shaded predominantly by *Morus* spp, *Musa* spp and *Mangifera* spp. The other part of Phuphayak agricultural highland development station is Sun coffee serving as a reference coffee plantation without shading. The field has highland topography with an average slope angle of 20^{δ} – 30^{δ}.

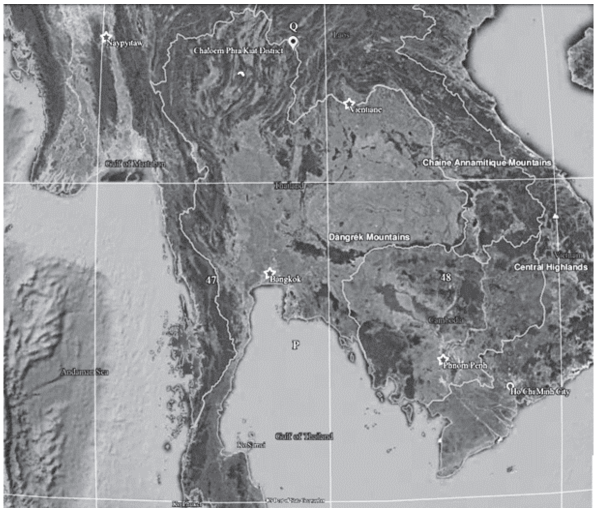

Fig. 1. Location of study location Phuphayak agricultural highland development station Nan province, Thailand

Tree measurement, biomass and carbon stock estimation

Field measurement were conducted in 2020. Diameters at breast height (DBH; measured at 1.30 m) of all tree species ≤ 10 cm were measured at each study site. In total 613 trees were measured in the *Pinus* site, 828 in the *Morus* site and 508 In the Sun site. The dry aboveground biomass of shade trees wasestimated using available allometric models applicable for the species present at the studied plantations. In the case of Pinus spp., *Morus* spp., *Musa* spp., *Mangifera* spp. and *Coffea canephora* the corresponding specific allometric models were used. For all other trees, the generic allometric model developed for Thailand (Table 2), as it as found to be best suited for our study. The belowground tree biomass component was estimated using the regression equations for predicting root biomass density used by Cairns *et al.,* (1997) (Eq. 1)

$$Y\ (\mathrm{Mg\ ha^{-1}}) = \exp\,[-1.0850 + 0.9256 * (\mathrm{In}\ ABD)] \quad ..\ (1)$$

Where *ADB* is the aboveground biomass density

For calculations with errors the method of stan-

Table 1 Selected plantations their location, area, mean attitude, dominant tree species and age

Plantation	Site	N	E	Altitude (m.a.s.l)	Dominant tree species	Stand age (year)
Pinus site	*Pinus Kesiya*	19.30.805	101.13.141	1,028	*Pinus Kesiya*	8
Morus site	*Morus* spp	19.30.839	101.13.162	985	*Morus* spp	15
Sun site	Sun coffee	19.30.349	101.12.824	1,019	*Coffea canephora*	15

Table 2. Allometric models used for aboveground biomass calculation for individual tree species

Species group	Allometric model	References
Pinus spp.	$W_S = 0.02698\ (D^2H)^{0.946}$ $W_B = 0.00018\ (D^2H)^{1.455}$ $W_L = 0.00072\ (D^2H)^{1.094}$	Chattacha, 1981
Morus spp	$W_T = 6.666 + 12.826\ (H)^{0.5}\ (\ln H)$	Pearson *et al*., 2005
Musa spp	$AGB = 0.0303\ (D)^{2.1345}$	Arifin, 2001
Mangifera spp	$W_S = 0.0509\ (D^2H)^{0.919}$ $W_B = 0.0089\ (D^2H)^{0.977}$ $W_L = 0.0140\ (D^2H)^{0.669}$	Tsutsumi *et al*., 1983

dard deviation was used (2)

$$Z = x + y \longrightarrow \Delta z \quad .. (3)$$

Coffee plant measurement and biomass and carbon stock estimation

Field measurements of coffee shrubs were conducted in 2020. In total, 15 rectangular sample plots of 100 m^2 were established to monitor coffee plants. Plots were located randomly in the systematic grid of squares, and the heights of all coffeesh rubs were measured. The dry above ground biomass of coffee plants (BC) was estimated based on the model developed in Segura *et al*. (2006). We used this equation (Eq. 4) because it was applicable for coffee plants using plant height as the sole independent variable in the logarithmic form

$$\mathrm{Log}_{10}(B_C) = -0.779 + 2.338 * \mathrm{Log}_{10}(H) \quad .. (4)$$

Results

Dendrological and mensuration data

Some of the dominant species in the *Pinus* site based on basal area (BA) were as follows: *Pinus kesiya* and *Coffea canephora* (Table 3). *Morus* site was dominated by *Morus* spp, *Musa* spp, *Mangifera* spp. and *Coffea canephora* (Table 3). Sun site was dominated by *Coffea canephora* (Table 3). The hectare indices of counts together with stand basal part of trees and coffee shrubs when you look at the plantations are documented in Table 4. As for tree density, it was highest at the *morus* site and lowest at the sunsite. The *Pinus* site also had the largest stand basal area. Inversely to above, the highest density of coffee shrubs was present at the sun site.

The density of major canopy timber trees (≥10 cm DBH) varied between 508 and 828 stems per hectare (sph) Mean DBH was between 13.35 and 114.65cm.

Empirical relationships of age versus DBH and height versus DBH of *Coffea canephora* showed a positive linear relationship. Linear regression analysis of age and DBH produced a slope coefficient of 0.7138, indicating that each year increase in age increases the diameter of the species on average by 0.7138 cm. The coefficient was significant at the 1 % level (df = 993). The R^2 value indicates that age explains 71 % of the variance in diameter. Height increases because of the increase of DBH steeply at first and then almost levels off. The relationship obtained between DBH and height was also significant at the 1 % level, with a coefficient of determination 0.65 (df = 993).

Biomass and carbon stock

The aboveground dry biomass of shade trees varied between 31.70 kg (*Morus* spp) and 7340.06 kg (*Pinus kesiya*) per tree (DBH ≥ 10 cm). The biomass of coffee plants was approximately two orders of magnitude smaller, with amean of 0.75 kg per coffee plant. The estimated total aboveground biomass and belowground biomass was 624.10 ton and 141.55

Table 3. Tree species composition based on count and stand basal area (BA) representation

Species	*Pinus* site		*Morus* site		Sun site	
	Count (%)	BA (%)	Count (%)	BA (%)	Count (%)	BA (%)
Pinus kesiya	18.48	99.70	0	0	0	0
Coffea canephora	81.52	0.30	78.18	5.17	100	100
Morus spp	0	0	16.57	32.88		
Musa spp	0	0	2.63	0.03	0	0
Mangifera spp	0	0	2.63	61.92	0	0

Table 4. Tree and coffee plant counts per hectare stand basal area and mean tree height

Parameter	Unit	*Pinus* site	*Morus* site	Sun site
Tree density	Tree/ha	613	828	508
Mean DBH (±)	cm	114.65±8.75	23.84±1.58	13.35±5.52
Range of DBH	cm	92-131	21-26	3.4-33
Mean H (±)	m	20.40±2.56	1.76±0.06	1.81±0.26
Range of H	m	14-25	1.45-1.89	0.8-2.9

The ± sign shows the standard error in no particular direction (right and left of the mean value) ton, respectively for the *Pinus* site, 13.85 ton and 3.89 respectively for the *Morus* site, 1.08 ton and 0.51 ton, respectively for the sun site.

A comparison of the tree carbon stock in shade site on agroforestry coffee plantations studied yielded approximately aboveground carbon stock 293.33ton.ha^{-1} and belowground carbon stock 66.53 ton.ha^{-1}for *Pinus* site, aboveground carbon stock 6.51 ton.ha^{-1} and belowground 1.80 ton.ha^{-1} for *Morus site* and aboveground carbon stock 0.51 ton.ha^{-1} and belowground 0.24 ton.ha^{-1}for Sunsite in Table 5. The distribution of carbon stocks for dominant tree species by 10-cm diameter classes is shown in Fig. 2.

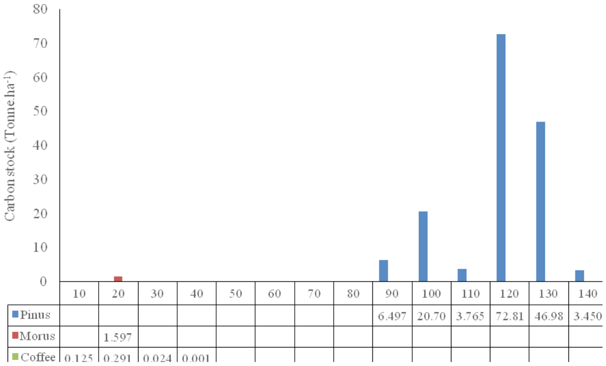

Fig. 2. Distribution of carbon stocks in 10-cm diameter classes for *Pinus* spp., *Morus* spp. and *Coffea canephora*

Carbon dioxide absorption

When determining the carbon stock in tree biomass to assess the carbon dioxide absorption, it was found that Phuphayak agricultural highland development station had an average 3368. 42 ton CO_2 ha^{-1}. The estimated carbon dioxide absorption 360.57ton CO_2 ha^{-1}for *Pinus* site, 0.45 ton CO_2 ha^{-1} for *Morus* site and 0.03ton CO_2 ha^{-1}forSun site in Table 5.

The regression equation for *Pinus kesiya* carbon stockof agroforestry coffee plantations showed a positive linear relationship. Multiple linear regression analysis of carbon stock versus height and DBHLinear regression analysis of age and DBH produced a slope coefficient of 0.976, *Morus* spp carbon stockmultiple linear regression analysis of carbon stock versus height and DBHLinear regression analysis of age and DBH produced a slope coefficient of 0.739 and *Coffea canephora* multiple linear regression analysis of carbon stock versus height and DBHLinear regression analysis of age and DBH produced a slope coefficient of 0.979 in Table 6. The regression equation for *Pinus kesiya* carbon dioxide absorption in agroforestry coffee plantations showed a positive linear relationship. Multiple linear regression analysis of carbon dioxide absorption versus height and DBHLinear regression analysis of age and DBH produced a slope coefficient of 0.704,

Table 5. Carbon dioxide absorption of agroforestry coffee plantations with different shade trees in highland area, Thailand

	Pinus site	*Morus* site	Sun site
Aboveground carbon stock (ton.ha^{-1})	293.33	6.51	0.51
Belowground carbon stock (ton.ha^{-1})	66.53	1.80	0.24
Total carbon stock (ton.ha^{-1})	359.36	8.81	0.75
Carbon dioxide absorption (ton CO_2.ha^{-1})	360.57	0.45	0.03

Table 6. Regression equation for carbon stock and carbon dioxide absorption in agroforestry coffee plantations with different shade trees in highland area, Thailand

Carbon stock (kg C.ha^{-1})	Carbon dioxide absorption (tonCO$_2$.ha^{-1})	
Pinus spp	Carbon content (kg) = -3452 + 98.73 H (m) + 32.33 DBH (cm.) $R^2 = 0.976$	CO_2= -10304 + 235.8 H (m) + 120.6 DBH (cm.) $R^2 = 0.704$
Morus spp	Carbon content (kg) =-33.15 + 10.25 H (m) + 1.4513 DBH (cm.) $R^2 = 0.739$	CO_2= -121.6 + 37.60 H (m) + 5.322 DBH (cm.) $R^2 = 0.740$
Coffea canephora	Carbon content (kg) = -0.44266 + 0.50549 H (m) - 0.002298 DBH (cm.) $R^2 = 0.979$	CO_2= -1.2105 + 1.2428 H (m) + 0.03196 DBH (cm.) $R^2 = 0.493$

Morus spp carbon dioxide absorption multiple linear regression analysis of carbon dioxide absorption versus height and DBH Linear regression analysis of age and DBH produced a slope coefficient of 0.740 and *Coffea canephora* multiple linear regression analysis of carbon dioxide absorption versus height and DBH Linear regression analysis of age and DBH produced a slope coefficient of 0.493 in Table 6.

Discussion

The disappearance of a great number of tropical forests at all latitudes could guide to an increase in GHG emissions if maintainable management and conservation guidelines are not applied (Dixon, 1995). In Thailand, this downside is evident because to the quick rate of deforestation and it is apparent that agroforestry systems are one of the possibilities that can mitigate GHG emissions from harvest production. Our research from the northern Thailand finds that agroforestry systems are significant for carbon mitigation. Our results show that carbon stocks are greater in agroforestry coffee plantations than in the coffee plantations without shade.The contrast in carbon stocks between agroforestry and sun plantations range from 358.61 ton C.ha^{-1} (the Sun site coffee compare with the *Pinus* site) to 8.06 ton C.ha^{-1} (the Sun site coffee compare with the *Morus* site) More authors documented the following differences between carbon stocks in agroforestry plantations and sun coffee plantations : Hergoulac´h *et al*. (2012) found adifference of 15.4 Mg ha^{-1} (for coffee–Inga association), Dossa *et al*. (2008) 123.6 Mg ha^{-1} (forcoffee–Albizia association) and 20.4 Mg ha^{-1} (the Sun coffeesite compared with the Inga site) to 77.8 Mg ha-1 (the Sun coffee site compared with the P*inus* site) Lenka Ehrenbergerova´*et al*. (2016). Agroforestry systems store more carbon than open space plantations, but it is and essential to diagnose the submission of carbon in the ecosystem. In our research the quantity of carbon in tree biomass is higher than the quantity shown in more reports. In Häger's study (2012), shade tree carbon storage in an organic agroforestry coffee plantation was 23.2 Mg ha^{-1} (shaded by Dracaena fragrans and Yucca guatemalensis) and in the study of Häger (2012) for an Inga shaded agroforestry system, it was only 13.9 Mg ha^{-1}. It should be recognized that the biomass reports do not include problem elements. For example, only the standard error associated with the allometric model of Chave *et al*. (2005) is 12.5 % and adding sampling and measuring errors would further improve the total doubt bounds. But this is natural in all comparable studies. The benefits of agroforestry systems for decreasing the CO_2 in the atmosphere is not only the direct near-term C storage in trees and soils but also the possible to offset direct GHG emissions connected with deforestation and subsequent shifting agriculture (Dixon 1995). For growers, it is significant to know how much hardwood they could produce in an agroforestry system and what they will do with it. In our research, we studied plantations shaded by introduced and local tree species. The hardwood of Pinus trees is normally used as firewood by the plantation owners, and the wood of *Pinus* spp. is offered as building content. Both uses are very significant because they decrease pressure on the rainforests from the local community. Agroforestry systems enjoy an important character in fixing carbon in agricultural landscapes that have lost their original forest cover. They are significant in tropical areas that have been struggling over the past century from excellent rates of change as they are debased by human activities. The quantity of sequestered carbon depends on the tree species used for shading.

Conclusion

Our study, performed in Thailand, suggests that the coffee agroforestry plantations shaded by presented tree species (*Pinus* spp.) perform better with regard to carbon storage than those shaded by the local tree. The outcome should be usually suitable to agroforestry coffee plantations with organic official certification, where the coffee is grown at a similar elevation, in a equivalent climate and with similar soil conditions. The carbon sequestration possible can also be regarded in REDD+ programs in which Thailand could join. However, it is also significant to examine and assess the impact of presented tree species on biodiversity, soil fertility, hydric function and look of coffee conditions in order to make sound management choices on the tree species used for shading.

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