Songklanakarin J. Sci. Technol.
41 (3), 580-586, May – Jun. 2019

http://www.sjst.psu.ac.th

Original Article

Estimation of carbon offset for teak plantation in lower northern Thailand

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Received: 25 June 2017; Revised: 5 December 2017; Accepted: 14 January 2018

Abstract

Teak plantations can be a potential source for carbon dioxide absorption and carbon sequestration. Many countries in tropical regions therefore have long started to promoting teak plantations and improving the quality of teak wood as this would evidently lead to higher income. This study aimed to assess the value of carbon offsets in teak plantations for teak plants at the age stages of 21, 22, 24, 25, 26, 28, 30, 31, 33, 34, 35 and 36 years. The assessment showed that teak plantations can create carbon stock in the range between 81.34 and 221.51 $tCha^{-1}$, which correlates with the age of teak, whilst the net income from carbon offset contracts over a chosen period of 5 years was estimated to be 1,161.71 USD ha^{-1} (232.342 USD ha^{-1} annually). The ability to store carbon in teak plantations has been considered highly potential for carbon trading in various markets around the world.

Keywords: carbon offset, carbon stock, carbon sequestration, voluntary carbon market, teak plantation

1. Introduction

A particular method to decrease CO_2 concentration in the earth's atmosphere is promoting plantations. Perennial plants can decrease atmospheric carbon dioxide concentration through the photosynthetic process and carbon is accumulated as plant biomass (Redondo-Brenes & Montagnini, 2006). In addition, fallen leaves and branches on the top soils are degraded by soil microorganisms and the carbon is stored as soil organic carbon (Zhang & Zhang, 2003), also known as carbon stock.

According to the agreement relating global climate change policies and practices to reduce global warming of the Kyoto Protocol, an idea of carbon market (Intergovernmental Panel on Climate Change [IPCC], 2007), using the market mechanisms to reduce greenhouse gas emissions considered as the main cause of global warming, was originated. Worldwide supports were also arisen to accommodate the idea, including the carbon trading markets such as mandatory market, compliance market, regulated market, Reducing Emissions from Deforestation and Forest Degradation in Developing Countries (REDD) Market and voluntary market.

The voluntary market in particular has had an important role in forestry sector that allows carbon to be voluntarily traded as carbon credits called Verified Emission Reduction (VER) or Carbon Offsets in order to trade in key markets such as the Chicago Climate Exchange (CCX), Climate Registry (CR), California Climate Action Registry (CCAR) and bilateral trading between buyers and development projects (Over-the-Counter: OTC). Sales contracts can be made between carbon trading organizations and farmers or departments during any participating period by calculating the carbon in soil (soil offset projects) in agricultural lands (Ignosh *et al.*, 2009) or for parts of the forestry projects in the afforestation and rehabilitation of plantations (Afforestation

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and reforestation), including farmlands for cultivating crops (Current, Scheer, Harting, Zamora, & Ulland, 2010). With the mechanism of plants to absorb carbon dioxide for their photosynthesis, carbon dioxide in the atmosphere can thus be effectively reduced throughout the lifetime of plant by storing carbon throughout its body in the form of biomass (Redondo-Brenes & Montagnini, 2006) and by degradation of micro-organisms in soil (or soil microbial biomass carbon; MBC) and in the catchment of organic carbon in soil (soil organic carbon) (Zhang & Zhang, 2003).

There have been studies to find the ways to evaluate carbon offsets in forest lands (Solberg, 1997), forest plantations and urban trees (McHale, McPherson, & Burke, 2007), including soil management for corn, soybeans (Al-Kaisi *et al.*, 2005), rice (Watkins, Hignight, & Anders, 2009) and pasture (Stephenson, Bosch, & Groover, 2004), which are effectively productive to acquire contracts for carbon credits and also used as a practical guide in soil management, enhancing biodiversity and reducing deforestation and at the same time adding more value to the economic areas (Solberg, 1997).

This is along the same line as the strategic development for teak plantations in 1992 by the Ministry of Agriculture and Cooperatives of Thailand. Plantations around the country have become the sources for carbon dioxide absorption and a potential carbon stock. This study's objective is to assess the correlation of the carbon stock quantity and soil in accordance with age of the plantation by applying a study method that involves carbon trading in voluntary market for forestry section together with an assessment of revenue derived from carbon offsets and carbon credits according to the contract process of the Chicago Climate Exchange Market.

Carbon offsets can be generated in forestry section when trees and plants store carbon through the process of photosynthesis. Carbon sequestration occurs by different forest management activities that can enhance the sequestration rate to increase carbon stock. This is evidently observed when carbon sequestration is found to be directly related to tree growth, resulting in different rates and levels of sequestration from one region to another across the different tree species and lifespan of a forest. Establishing trees on barren land or afforestation and a variety of sustainable forest management activities may be included as a part of the forestry offset projects (Ignosh *et al.*, 2009).

This study proposed to be beneficial toward agricultural lands and operators in the future trading of carbon credits. The carbon credit projects can already be seen in Thailand's teak plantations that were managed by the government sector in 2001 and the private sector in 2002, covering the areas of 194,789.29 ha and 101,014.56 ha, respectively (Royal Forest Department, 2002). The revenue evaluation from the carbon stock in teak plantation and soil organic carbon resulted to show the value of carbon trading for a project period and the income from the contracts made in voluntary market in accordance with the Chicago Climate Exchange (CCX) (Ignosh *et al.*, 2009; Current *et al.*, 2010) which was used as a case study.

2. Methodology

2.1. The study area

The study area is located in lower northern Thailand (Figure 1), covering approximately 1,302.9 hectares. The topographical aspects vary from 110 meters above the sea level in flat areas in the southeastern part to 700 meters in mountainous areas on the western edge. However, most trees were planted in a flat plain of 131-215 meters above the sea level. The local climates were tropical and subtropical with three distinctive seasons – summer, rainy and winter, with an average annual rainfall of 1748.8 mm. The different ecotypes surrounding the study area range from hilly mixed deciduous forest and dry evergreen in the western part to lowland mono agricultural crops such as tapioca, corn, and sugarcane.

2.2 The sampling sites

The plantation was established between 1977 and 1992. Soil conditions are mostly sandy derived from meta-morphic complexes of facies, banded quartzite, calc-silicate rocks, biotite schist and granite gneiss, and developed during Precambrian (Proterozoic) period. The soils are classified as coarse-loamy, kaolinitic, isohyperthermic Typic Haplustulfs (Ban Rai soil series) (Soil Survey Staff, 2014). The planting space of 4m x 4 m are for teak aged 21, 22, 21 24, 25, 26, 28, 35 and 36, and of 2 m x 8 m for 30, 31, 33, and 34.

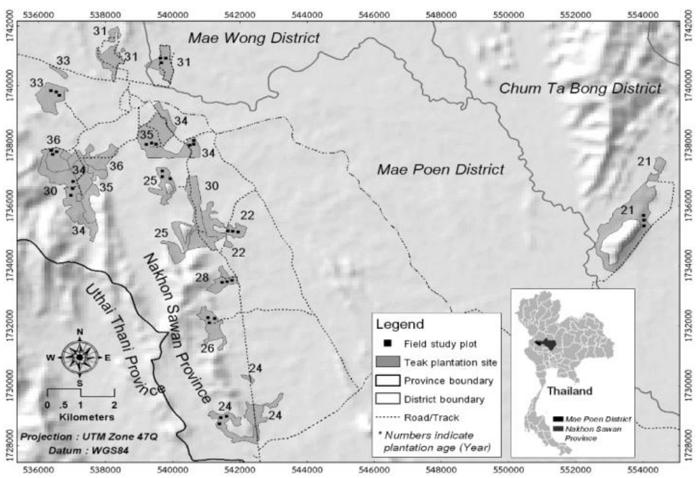

Figure 1. Location of teak plantation sites and the study plots (Boonyanuphap & Kongmeesup, 2016).

2.3. Study design and methods

Data for this study were collected during the year 2014. Three study plots in the size of 50 m x 50 m each for all teak ages were randomly selected in the teak plantation. The plots were mainly filled with teak trees whereas there were very few other tree species such as *Pterocarpus macrocarpus* Kurz, *Xylia xylocarpa* Roxb. Taub, *Cassia fistula* L. In these 50 m x 50 m plots, all trees with girth size greater than 4.5 cm at the chest-height of 1.30 m were measured. The tree height was measured using Haga Hypsometer. Five 2 m x 2 m sub-plots were placed within each 50 m x 50 m plot - one in the corners and one in the middle. Saplings and shrubs with DBH less than 4.5 cm and with height greater than 1.3 m in all five 2 m x 2 m sub-plots were cleared off at ground level. A micro-plot of 1 m x 1 m was placed in the middle of each 2 m x 2 m sub-plot to remove all plants shorter than 1.3 m, along with seedlings, undergrowth, climbers, other vegetations and standing dead trees. Litters of all plants on the surface were also collected, weighed and recorded. The samples were oven-dried at 80°C for 48 hours or until the weight remained unchanged and dry weight was determined. Teak biomass was calculated using the allometric equation of Petmark and Sahunalu (1980). The equation is as follows:

$$\mathrm{Log}W_S = 0.9797 \log(D^2H - 1.6902; R^2 = 0.9930 \quad (1)$$

$$\mathrm{Log}W_B = 0.0605 \log(D^2H - 2.06326; R^2 = 0.5967 \quad (2)$$

$$\mathrm{Log}W_L = 0.7088 \log(D^2H - 1.7383; R^2 = 0.8523 \quad (3)$$

Where; D = Diameter at breast height (cm), H = Height of tree (m), W_S = Stem biomass (kg), W_B = Branch biomass (kg), W_L = Leaf biomass (kg). Root biomass was calculated by using root equations (Viriyabuncha, Rattanaproncharoen, & Tiyanon, 2003).

$$W_R = 0.0054\, D^2\, H^{0.9894};\ R^2 = 0.9890 \quad (4)$$

Where; W_R = Root biomass (Kg), D = Diameter at breast height (cm), H = Height of tree (m)

To estimate the soil organic carbon (SOC), soil samples were collected up to the depth of 0-0.15, 0.15-0.3, 0.3- 0.5, 0.5-0.6, 0.6-0.9 and 0.9-1.0 m, at five random locations in each 50 m x 50 m plot. Soil samples were then air-dried and crushed to pass through a sieve of 2 mm mesh. Roots, other plants and debris were also removed. The content of SOC was estimated by organic matter measurement using the Walkley and Black method (Walkley & Black, 1934), and bulk density of the soil was determined using undisturbed soil samples. The aboveground carbon stock per given area ($tCha^{-1}$) and all the biomass contents of all plants were determined. The aboveground and root biomass were then multiplied by 0.47 (IPCC, 2006) to indicate the quantity of carbon stock ($tCha^{-1}$).

2.4 Carbon dioxide sequestered

The absorption rate of carbon dioxide can be calculated from carbon stock in biomass multiplied by weight of molecule of carbon. Carbon dioxide (CO_2) composes of one molecule of Carbon and 2 molecules of Oxygen. The atomic weights of Carbon and Oxygen are 12.00 and 15.99, respectively. The weight of CO_2 is 43.99. The ratio of CO_2 to C is 43.99/12.00=3.67. Therefore, to determine the weight of carbon dioxide sequestered in the carbon stock is to multiply the weight of carbon by 3.67 (McPherson, 1998). The equation to calculate CO_2 sequestration is as below:

$$\text{Carbon dioxide sequestered} = Cs \times C \quad (5)$$

Where; Cs = carbon stock (t/ha^{-1}); C= the atomic weight of carbon

2.5 Carbon sequestration rate

The carbon sequestration rate (Mandal *et al.,* 2016) in teak plantation shall be evaluated between the different age stages and other parts of teak along with litter production and carbon stock in soil. The age stages used for evaluating the sequestration rate are 21, 22, 24, 25, 26, 28, 30, 31, 33, 34, 35 and 36 years. This study uses the following equation to determine the sequestration rate.

$$CSr = \left[\frac{S}{T} \right] \quad (6)$$

Where; CSr = Carbon sequestration rate (tC/ha^{-1}/year), S = Carbon sequestration (tC/ha^{-1}), T = age of tree (year)

2.6 Evaluation of carbon stock in different parts of teak plantation

Evaluation of carbon stocks in different parts of teak and in soil by using the adjusted equations of carbon stock in plants (Vashum & Jayakumar, 2012), litters and trees (Zheng *et al.,* 2008) are as follows:

$$CS_t = \sum_{i=1}^{n} CS + \sum_{i=1}^{n} CB + \sum_{i=1}^{n} CL + \sum_{i=1}^{n} CG + \sum_{i=1}^{n} CLI + \sum_{i=1}^{n} SOC \quad (7)$$

Where, CSt = carbon stock in plantation teak (t/ha),

$\sum_{i=1}^{n} CS$ = Stem carbon stock of plantation teak,

$\sum_{i=1}^{n} CB$ = Branch carbon stock of plantation teak,

$\sum_{i=1}^{n} CL$ = Leaf carbon stock of plantation teak,

$\sum_{i=1}^{n} CG$ = Ground plant carbon stock of plantation teak,

$\sum_{i=1}^{n} CLI$ = Litter carbon stock on ground of plantation teak,

$\sum_{i=1}^{n} SOC$ = Soil organic carbon

2.7 The estimated carbon offset

The evaluation of carbon offset or assessment of carbon offset (Chiarawipa *et al.*, 2012) in different age stages of teak for a period of 5 years was conducted to estimate the annual value and total income in US dollar. The equations were adjusted to evaluate the income from the carbon offsets in the sampled teak plantations by using the method for Voluntary Market in Chicago Climate Exchange (CCX) (Current *et al.*, 2010; Ignosh *et al.*, 2009). The case study for this research consisted the steady carbon stock quantity in each and every year for a period of 5 years beginning with teak of 21, 22, 21 24, 25, 26, 28, 35 and 36 years old to estimate the annual value and total income in US dollar for a whole period of 5 years. The adjusted equations are as follows:

$$Tc = Nc + Rc \quad (8)$$

Where; Tc is the total income from all carbon offsets for the whole contract period (USD), Nc is the income from carbon offset contract (USD).

$$Nc = (Ia)-(Fi) \quad (9)$$

$$Ia = (Ct) \times (CCX) \quad (10)$$

Where; Ia is the revenue from carbon offset trade (USD per year), Ct is the traded carbon offset quantity (80% of Cs) (Ton), Cs is the quantity of carbon stock in teak plantation (Ton), CCX is the mean trading price for carbon offsets in market CCX (4 USD/ton carbon), and Fi is the contract fees (USD).

$$Fi = (Fi, a + Fi, v + Fi, c) \quad (11)$$

Where; Fi, a is the contract fees with aggregator (10% of Ia value) (USD), Fi, v is the project verification fees (0.15 USD/ton of Ct) (USD), Fi, c = Market CCX trading fees (0.2 USD/ton of Ct) (USD)

$$Rc = (Ir) - (Fj) \quad (12)$$

Where, Rc = Income from carbon offsets of carbon offset quantity as a reserve pool after the end of contract (USD), Ir = Revenue from carbon offsets of carbon offset quantity as a reserve pool (USD)

$$Ir = (Cr) \times (CCX) \quad (13)$$

Where, Cr = Quantity as a reserve pool (20% of Cs) (ton), CCX = Mean trading price for carbon offsets in market CCX (4 USD/(ton) carbon)

$$Fj = (Fj, a + Fj, v + Fj, c) \quad (14)$$

Where, Fj = Project verification fees (USD), Fj,a = Contract fees with aggregator (10% of I_r value) (USD), Fj, v = Project verification fees (0.15 USD/ton of Cr value) (USD), Fj, c = Market CCX trading fees (0.2 USD/ton of Cr) (USD)

2.8 The revenue from carbon offsets in teak plantation

The evaluation of income from carbon offsets in teak plantation by all contract value in voluntary market by using the contract method of Chicago Climate Exchange (CCX) (Current *et al.*, 2010; Ignosh *et al.*, 2009) was a case study for this research. The carbon quantity was steady for each and every year following the rate of carbon stock at the age of 21, 22, 24, 25, 26, 28, 30, 31, 33, 34, 35 and 36 years. The annual value and total income (USD) were then to be estimated for the whole life span of teak plantation by using the adjusted equations.

3. Results and Discussion

3.1 Carbon stock in teak plantation associated with plantation age

Carbon stock in teak plantation tended to increase according to age with statistically significant correlation between the mean DBH and teak age (R^2=0.672; $P<0.05$). Plantation teak trees in subtropical region of the lower northern Thailand can store aboveground and underground carbon at the highest total amount of 45.62 $tCha^{-1}$ when the plants reached 36 years old. This amount was higher than that of 10-year-old teak (Derwisch, Schwendenmann, Olschewski, & Hölscher, 2009). The carbon contents in stems and branches were 26.28 $tCha^{-1}$ and 6.58 $tCha^{-1}$, respectively. The carbon stock in leaves was the highest at 2.03$tCha^{-1}$ for the plantation aged 22. The highest total carbon stock of under growth at 2.52$tCha^{-1}$ was found at the age of 30. This was comparable to the undergrowth of 20-year-old teak (Kraenzal, Castillo, Moore, & Potvin, 2003). Carbon stock in litters at the age of 25 was highest at 3.44 $tCha^{-1}$ which is similar to the litter of teak plantation of 20 years old (Kraenzal *et al.*, 2003) and teak root carbon stock was the highest at 7.60 $tCha^{-1}$ for teak aged 36 (Boonyanuphap & Kongmeesup, 2016).

The content of soil organic carbon in teak plantation tended to decrease with depth of ground. The percentages of soil organic carbon were between 0.5 and 2.4 at the depth of 1-15 cm whilst they were between 0.5 and 1.5 for 90-100 cm. Teak plantation at the age of 36 had the highest soil organic carbon at 175.89 $tCha^{-1}$. The proportions of carbon stock in different age stages of teak plantations are shown in Table 1. This study found that age of teak correlates with and has influence over the total carbon stocks as seen here that the lowest total carbon stock of 140 $tCha^{-1}$ was evidently present in teak aged 21 to 22 and the highest of 220 $tCha^{-1}$ in aged 35 to 36.

3.2 Carbon offsets and carbon revenue

This evaluation draws upon incomes from contracts made in the voluntary market in accordance with the Chicago Climate Exchange (CCX) (Current *et al.*, 2010; Ignosh *et al.*,

Table 1. Aboveground and belowground carbon stock in teak plantation (tCha^{-1}).

Age	C_S	C_B	C_L	C_R	TTC	UG_C	L_C	FFC	ABGC	TFFC	SOC	TC
21	13.79	3.26	1.09	3.96	22.1	1	4.38	5.38	23.52	27.48	53.86	81.34
22	18.12	5.8	2.03	5	30.95	2.32	2.11	4.43	30.38	35.38	169.64	205.02
24	20.52	4.86	1.6	5.9	32.88	1.37	3.29	4.66	31.64	37.54	90.48	128.02
25	20.81	4.93	1.62	5.99	33.35	1.39	3.44	4.83	32.19	38.18	161.15	199.33
26	12.36	2.98	0.92	3.56	19.82	1.06	1.64	2.7	18.96	22.52	174.04	196.56
28	13.78	3.2	1.24	3.77	21.99	1.09	4.37	5.46	23.68	27.45	65.81	93.26
30	18.04	4.32	1.44	5.19	28.99	2.52	1.64	4.16	27.96	33.15	140.98	174.13
31	17.64	4.34	1.21	5.09	28.28	2.24	2.3	4.54	27.73	32.82	125.43	158.25
33	19.74	5.04	1.21	5.72	31.71	1.46	1.72	3.18	29.17	34.89	175.18	210.07
34	11.96	3.01	0.76	3.46	19.19	1.52	1.95	3.47	19.2	22.66	175.18	197.84
35	19.94	6.28	2.1	5.74	34.06	1.54	1.88	3.42	31.74	37.48	132.91	170.39
36	26.28	6.58	1.72	7.6	42.18	1.8	1.64	3.44	38.02	45.62	175.89	221.51
Mean	17.74	4.55	1.41	5.08	28.79	1.6	2.53	4.13	27.84	32.93	183.29	177.67

Remarks: C_S: teak stem carbon; C_B: teak branch carbon; C_L: teak leaf carbon; C_R: teak root carbon; TTC: total tree organic carbon ($C_S + C_B + C_L + C_R$); UG_C: total carbon stock of under growth, seedling, and sampling Under growth carbon ; L_C: carbon in litter ; FFC: forest floor carbon ($UG_C + L_C$); ABGC: aboveground carbon ($C_S + C_B + C_L$+ FFC); TFFC: Total carbon stock of aboveground SOC: Soil Organic Carbon: TC: total carbon stock. (Boonyanuphap & Kongmeesup, 2016)

2009) which was used as a case study. Despite the fact that this market has been discontinued, its high standard of calculation method can still be implemented. Carbon is steadily evaluated for estimated annual value and total revenue (USD) according to the ratio of carbon sequestration in teak aged 21, 22, 24, 25, 26, 28, 30, 31, 33, 34, 35 and 36 years.

In this study, to portray a clear purpose of the case study, the researcher specifically set a fixed volume of carbon in a 5-year period (year 2014 - 2019) to be used in revenue estimation for the first 5 years. Trading and assessment of carbon depend on buyers and sellers who may wish to continue trading after the period ends and carbon stock is to be verified every few years, more or less as agreed upon. The contract should be fair and based on academic principles, for example, if the verification is done every 5 years and the contract is made for the period of 25 years, thus the verification should be conducted altogether 4 times throughout the period. This may result in revenue that are subject to change based on the carbon stock calculated (Ignosh *et al.*, 2009). In this study the revenue calculated from the trading of carbon offsets is as shown in Table 2.

Total carbon stocks slightly correlated with age of teak plantation (r=0.521; p=0.08), whereas CO_2 adsorption capacity was not significantly correlated with plantation age (r=0.462; p=0.13) (Figure 2). Teak plantations with the ages between 21 to 24 years old had the lowest total carbon stock of 140 tCha^{1}. The highest total carbon stock of 220 tCha^{-1} was found in teak plantation with the ages between 35 and 36 years old. The sequestration rate of carbon for each age stage of teak is as shown in Table 2 whereas the evaluation can be determined to combine the carbon stock for all 12 age stages, equivalent to 357.45 tCha^{-1} for a 5-year period, and to estimate the total revenue of carbon offsets to be 1,429.80 USD ha^{-1}. In summary, the annual revenue that teak growers were to receive in a 5-year contract would be equivalent to 875.75 USD ha^{1} whereas the revenue from reserve carbon credit would be 20% after the end of contract period (20% reimbursement from carbon reserve) in par with 285.96 tCha^{-1}. Various fees consist of aggregator fee, verification fee and

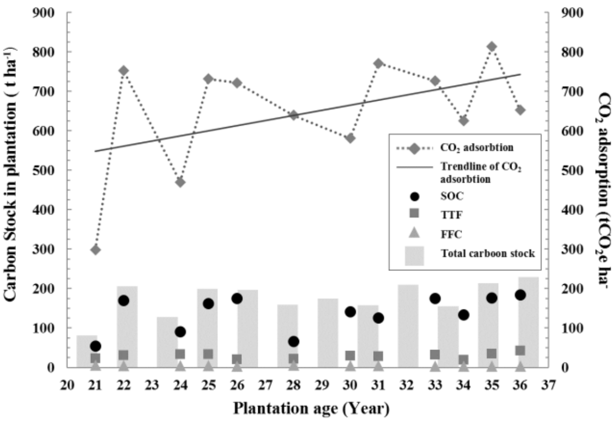

Figure 2. The proportion of carbon stock and CO_2 adsorption in teak plantation. SOC: soil organic carbon, TTF: total carbon stock of aboveground, FFC: forest floor carbon.

market exchange CCX fee totaled at 125.1 USD ha^{-1}. The net revenue after carbon offsets following all deductions for the whole period of a 5-year contract equals to 1,161.71 USDha^{-1} (232.342 USD ha^{-1} per year). Carbon credit contracts for areas with forestation may vary in the aspects of minimum time periods, methods to calculate the fees, duties and revenue. All of which can draw a variation of results following a different verification fee or fee exemption on the 20% reserved carbon stock (Farlee & Stelzer, 2008) whilst some organizations may apply a higher compensation for the same (Current et al., 2010), including the market's different referential pricing or at lower than 4 USD per tonnage and so forth. The carbon credit's total revenue can consequently be varied. From the study for other tree species such as rubber, it was estimated that the average income in comparison with land occupancy for rubber plantations in Thailand was about 1.6 ha per household (Somboonsook *et al.*, 2002) whereas the majority of farmers would fetch the total amount of 917.42 USD per household for the whole lifespan of rubber tree (25 years). In the reference study by Chiarawipa *et al.*, it showed that the

Table 2. Estimated annual value of carbon stock and carbon sequestration rate.

Contract (year)	Sequestration rate[1] (t Cha^{-1} yr^{-1})	Annual Tonnages (t Cha^{-1})	Estimate annual value[2] (USD ha^{-1})
21	3.87	3.87	19.35
22	9.32	9.32	46.60
24	5.33	5.33	26.65
25	7.97	7.97	39.85
26	7.56	7.56	37.80
28	3.33	3.33	16.65
30	5.80	5.80	29.00
31	5.10	5.10	25.50
33	6.37	6.37	31.85
34	5.82	5.82	29.10
35	4.87	4.87	24.35
36	6.15	6.15	30.75
		71.49	1,429.80
contact period (5 year)		357.45	1,429.80
Fees and deduction			
20% carbon reserve pool			285.96
10% aggregator fee			142.98
Project verification fee (0.15 USD/ton)[3]			53.61
CCX exchange fee (0.20 USD /ton)			71.49
Payment at end of contact period (5 year)			875.75
20% reimbursement from carbon reserve			285.96
Net income (calculation based on a contract period of 5 years)			1,161.71
** 1 t C = 4 USD			

Remarks:
1.Sequestration rates are determined by direct field measurement.
2. Estimated annual value will vary with fluctuating market prices over time; rate used for comparison purposes only. Teak aged 21, 22, 24, 25, 26, 28, 30, 31, 33, 34, 35 and 36.
3.Project verification cost varies among different aggregators, as does the timing and form in which these fees are assessed.
4.Payment schedule varies among aggregators and projects; some companies pay semiannually while others pay annually.
5. For comparison, this value assumes one consecutive five-year forestry contract.

carbon offset in rubber plantation equaled 705.71 USD / ha and the net income from carbon offset after all relevant deductions for the contract period of 25 years was 573.39 USD / ha whereas the evaluation for carbon credits in the 160 ha eucalyptus plantation (2 m x 2 m) would draw a profit of approximately 74.66 USD / $tCha^{-1}$. (Pumjamnong, 2004). This research study however shall apply all 3 fees on both portions of the revenue and will be able to evaluate the net income. The result in this study indicates that teak plantations can be developed and promoted to be in the project of voluntary carbon credit in the same way as other forestry sectors from being a great source of carbon stock in both aboveground and underground. With a good management to reduce the carbon emission for the whole life span of teak, teak plantations will adequately be prolonged to procure a carbon credit contract in accordance with the regulations of Chicago Climate Exchange. Carbon credit contracts however should be carefully reviewed to determine the real value in order to seek the most efficient way in carbon credit trading for a teak plantation.

4. Conclusions

The evaluation of income from carbon offsets in teak plantation by all contract value in voluntary market of Chicago Climate Exchange (CCX) and the total carbon stocks highly correlate with age of teak. Total carbon stock of teak aged between 21-24 years had the lowest total carbon stock of 140 $tCha^{-1}$. The highest total carbon stock of 220 $tCha^{-1}$ was found in teak plantation aged between 35 and 36 years. Carbon can be stored at the highest amount of 45.62 $tCha^{-1}$ when the plants were 36 year sold. The net income from buyer equals to 1,161.71 USD/ ha^{-1} (232.342 USD ha^{1} per year) for the whole period of 5 years. In addition, this study can be used as a guide to calculate carbon sequestration and revenue for other projects such as $Redd^{+}$, Voluntary Carbon Credit and CDM forestry sector. This could be an attractive incentive for teak growers not to cut their teak prematurely and to prolong the cutting period as they realize that income from carbon offsets can then be generated instead. As a matter of fact, this practice in a long run will tremendously boost carbon sequestration and eventually improve the quality of wood.

Acknowledgements

The researcher would like to express sincere thanks to the officers and workers of the Forest Industry Organization in Ladyao, Maepoen, Nakorn Sawan province, for data and information accounted for and used in this study.

References

Al-Kaisi, M. M., Yin, X. H., & Licht, M. A. (2005). Soil carbon and nitrogen changes as influenced by tillage and cropping systems in some Iowa soils. *Agriculture, Ecosystems and Environment, 105*(4), 635-647.

Amuntakul, W. (2010). *Teak plantation* (in Thai). Bangkok, Thailand: Conservation Forest Management and Development Research Group. Department of National Parks, Wildlife and Plant Conservation. Retrieved from http://www.dnp.go.th/development/teak.htm

Boonyanuphap, J., & Kongmeesup, I. (2016). Carbon stock of teak plantation in subtropical region of lower northern Thailand. *Naresuan University Journal: Science and Technology, 24*(1), 64-71.

Chiarawipa, R., Petchkaew, S., Kaewduang, M., & Prommani, W. (2012). Assessment of carbon stock and the potentail income of the carbon offset in rubber plantation. *Burapha Science Jourmal*, *17*(2), 91-102.

Current, D., Scheer, K., Harting, J., Zamora, D., & Ulland, L. (2010). *A Landowner's guide to carbon sequestration credits: In association with the Common wealth Project*. Minnesota, MN: Regional Sustainable Development Partnership.

Derwisch, S., Schwendenmann, L., Olschewski, R., & Hölscher, D. (2009). Estimation and economic evaluation of aboveground carbon storage of *Tectona grandis* plantations in Western Panama. *New Forests*, *37*, 227-240.

Ignosh, J., Stephenson, K., Yancey, M., Whittle, B., Alley, M., & Wysor, W. G. (2009). *Virginia landowner's guide to the carbon market*. Virginia, VA: College of Agriculture and Life Sciences, Virginia Polytechnic Institute and State University, Publication no. 442-138.

Intergovernmental Panel on Climate Change. (2007). Climate change 2007: Synthesis report. In Pachauri R. K., & Reisinger A. (Eds.). *Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change* (pp 104). Geneva, Switzerland: Author.

Kraenzal, M., Castillo, A., Moore, T., & Potvin, C. (2003). Carbon storage of harvest-age teak plantations in Panama. *Forest Ecology and Management, 173*, 213-225.

McHale, M. R., McPherson, E. G., & Burke, I. C. (2007). The potential of urban tree plantings to be cost effective in carbon credit markets. *Urban Forestry and Urban Greening, 6*(1), 49-60.

Mandal, R. A., Jha, P. K., Dutta, I. C., Thapa, U., & Karma charya, S. B. (2016). Carbon sequestration in tropical and subtropical plant species in collaborative and community forests of Nepal. Retrieved from https://www.omicsonline.org/methods-to-estimate-above-ground-biomass-and-carbon-stock-in-natural-forests-a-review-2157-7625.1000116.php?aid=8804

Petmark, P., & Sahunalu, P. (1980). *Primary production of various age plantations II. Net primary production of various age plantations of teak at Ngao, Lampang*. Bangkok, Thailand: Academic Press.

Pumjamnong, N. (2007). Storage source of greenhouse gas in forestry sector and activities to change of land usage under the Kyoto protocol. *Proceeding of the Climate Change in Forestry Sector: Forestry and Climate Change* (16 pages), 16-17 August 2007, Bangkok, Thailand.

Redondo-Brenes, A., & Montagnini, F. (2006). Growth, productivity, aboveground biomass, and carbon sequestration of pure and mixed native tree plantations in the Caribbean lowlands of Costa Rica. Forest *Ecology and Management, 232*(1-3), 168-178. doi:10.1016/j.foreco.2006.05.067

Royal Forest Department. (2002). Plantation data. Bangkok, Thailand: Author.

Soil Survey Staff. (2014). *Key to soil taxonomy* (12^{th} ed.). Washington, DC: Natural Resources Conservation Service, Department of Agriculture.

Solberg, B. (1997). Forest biomass as carbon sink-economic value and forest management/policy implications. *Critical Reviews in Environmental Science and Technology, 27*, 323-333.

Stephenson, K., Bosch, D., & Groover, G. (2004). Carbon credit potential from intensive rotational grazing under carbon credit certification protocols. *American Agricultural Economics Association Annual Meeting*. (18 pp.). Retrieved from http://ageconsearch.umn.edu/bitstream/20225/1/sp04st02.pdf

Vashum, K. T., & Jayakumar, S. (2012). Methods to estimate above-ground biomass and carbon stock in natural forests. *Ecosystem and Ecography Journal,* Retrieved from https://www.omicsonline.org/methods-to-estimate-above-ground-biomass-and-carbon-stock-in-natural-forests-a-review-2157-7625.1000116.p hp?aid=8804

Viriyabuncha, C., Rattanaproncharoen,V., & Tiyanon, S. (2003). Thai teak knowledge. Retrieved from http://forprod.forest.go.th/forprod/Flipbook/OK%20Thai%20Teak/files/page/233.swf

Walkley, A., & Black, I. A. (1934). An examination of Degtjareff method for determining soil organic matter, and proposed modification of the chromic acid tritation method. *Soil Science, 37*, 29-38.

Watkins, K. B., Hignight, J. A., & Anders, M. M. (2009). Assessing the impacts of soil carbon credits and risk on no-till rice profitability. *Southern Agricultural Economics Association Annual Meeting*. (25 pp.). January 31-February 3, 2009, Atlanta, Georgia.

Zhang, H., & Zhang, G. L. (2003). Microbial biomass carbon and total organic carbon of soil a affected by rubble cultivation. *Pedosphere*, 13(4), 353-357.