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CONTRIBUTION OF AGROFORESTRY SYSTEM IN MAINTAINING CARBON STOCKS AND REDUCING EMISSION RATE AT JANGKOK WATERSHED, LOMBOK ISLAND

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ABSTRACT

Agroforestry systems under rules of community-based forest management support local livelihoods in the Jangkok watershed, Lombok Island. One of the conditions from the forest authoritiesfor allowing agroforestry system is that it should maintain forest conditions. Since 1995 the Jangkok watershed has undergone rapid land use change, especially in the forest area. These changes led to a reduction of carbon stocks and thus to emission of CO_2. This research aimed to: (1) Measure the carbon stocks in several land use system within the Jangkok watershed, (2) Assess the contribution of agroforestry systems in maintaining carbon stocks and reducing emissions. The assesment was performed based on the RaCSA (Rapid Carbon Stock Appraisal) method using three phases: (1) Classify land use change applying TM5 Landsat Satellite images for the period 1995-2009, (2) Measure carbon stock in the main land uses identified, (3) Quantify the contribution of agroforestry practices. Results showed that (1) The total amount of carbon stock at Jangkok watershed (19,088 ha) was 3.69 Mt (193 $Mgha^{-1}$); about 23% of this stock found in the agroforestry systems (32% of the area),(2) Gross CO_2 emission from the Jangkok watershed was 8.41 Mg ha^{-1} yr^{-1}, but due to the net gain in agroforestry of 2.55 $Mgha^{-1}$ yr^{-1} the net emission became 5.86 $Mgha^{-1}$ yr^{-1}

Keywords: agroforestry, carbon stocks, carbon emission rate

INTRODUCTION

The Jangkok watershed on Lombok Island has been experiencing rapid change and associated conflicts, resulting from two prominent factors: (1) Jangkok watershedis densely populated and close to Mataram city, with land conversion to dwellings, peri-urban farming, and infrastructure development; (2) 60% of Jangkok watershed is classified as forest area (19.088 ha) with high biodiversity and providing water to 3 regencies (Tjakrawarsa *et al.,* 2008).Interpretation of satellite (Landsat) images for the 2000 – 2006 period showed that the closed natural forest on the slopes of the Rinjani volcano, Lombok Island, lost 3.2 % every year (Tjakrawarsa *et al*., 2008). Such decrease is due to the way local and national policies on forest management are implemented in the local context, with a lack of enforcement capacity.

Deforestration and forest degradation leads to a decrease of land-based carbon stock, and thus to carbon emission (Hairiah *et al*., 2006; Mutuo *et al*., 2005; Silver *et al*., 2004; van Noordwijk *et al*., 2002; Woomer *et al*., 2000;). Countering this trend and establishing tree-based farming systems (agroforestry) can lead to carbon sequestration in the long term (Van Noordwijk *et al*., 2008; Wang *et al.,* 2010).

Carbon stocks vary according to land use, and are related to tree density and its diversity , soil type and management of land and landscape (Hairiah et al., 2008; Woodbury *et al.,* 2006), therefore carbon stocks can be used as an indicator of forest quality. In general, the carbon stock (five pools: trees, understory vegetation, litter, roots and C_{org} in top 30 cm) in tropical ranges from 350 – 500 $Mgha^{-1}$ (Mutuo *et al*., 2005). Conversion of natural forest into

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agroforestry system may reduce carbon stocks to around 260 $Mgha^{-1}$, and carbon stock will drop seriously until 38% or 133 $Mgha^{-1}$ when forest lands are converted into cassava land (Hairiah *et al*., 2002).

Carbon stock change resulting from land use changeis primarily related to the tree density and the loss of large-diameter trees, due to forest fire or harvest (Hairiah *et al*., 2011; Markum, 2000), while the loss of soil carbon stock is relatively smaller and slower. In reverse, enhancement of tree density in open lands will increase carbon sequestration (Corbera *et al.,* 2010). The ratio between total emission and sequestration due to the land use change per unit time determines net emission rate in a certain area (emission factor) (Cabezas *et al*., 2008; Elverfeldt, 2010, Glenda,2008).

Since 1995, about 50% of Sesaot protected forest areas have been managed by local farmerss under agroforestry system in accordance with community-based forest management rules, aimed at increasing local income along side environmental conservation (Khususiyah *et al*., 2010). Agroforestry systemsare here dominated by Multi-Purpose Tree Systems (MPTs) that can stock 44 $Mgha^{-1}$ averaged over a period of 10-40 years; this is 44 % lower than the carbon stock in secondary forest, measured to be 114 $Mgha^{-1}$ (Rahayu, 2010). However, estimation of carbon emission rate at the Jangkok watershedas a whole still requiresfurther analysis.

The objective of this research was to evaluate the role of agroforestry systems as land use in reducing the net carbon emission rate from the Jangkok watershed area.

MATERIALS AND METHODS

The research was conducted at the Jangkok watershed, Lombok Island from 2010-2011. The research took place in the forest area of Sesaot with geographical position of 116°20'-116°31'E and 8°43' - 8°49'S, covering 3 villages in Sesaot, Ranget and Buwun Sejati. Estimation of carbon stock and emission rate was carried out based on the RaCSA (*Rapid Carbon Stock Appraisal*) method (Hairiah *et al*., 2011; Chave *et al.,* 2005) which included three phases: (1) estimating land use change areas by analyzing TM5 Landsat Satellite images of 1995, 2000, 2006 and 2009; (2) measuring carbon stock in relevant land use types; (3) calculating emission rates and sequestration by combining data of land use change and time-averaged carbon stock.

Estimation of Land Use Change

TM5 Landsat Satellite images of path row 116/66 date of 26th May 1995, 2nd July 2000, 13th May 2000 and 24th March 2009 were subjected to supervised classification by grouping training areas based on the similarity of spectral values and by visual checks on the image to obtain 8 categories of land cover/land use: (1) natural forest, (2) secondary forestwhich includes some agroforestry systems, (3) pine plantation forest, (4) shrub which includes other agroforestry systems, (5) crop, (6) open land, (7) dwelling and (8) water body.Estimation of coverage area and agroforestry class based on tree density was determined by ground check, plot level measurement and through focus group discussion inviting fiveteen local farmers.

Based on analysis results through Landsat image, agroforestry (as part of the secondary forest) was further divided into two classes: dense and medium tree density. It is categorized as dense when ground truthing indicated on average 144 trees ofdiameter (DBH) > 30 cm and 844 trees of DBHranging from 5 to 30 cm , respectively; for the medium class 42 trees and 742 trees were found for the two diameter categories.

Carbon Stock Measurement

The measurement of carbon stock was initially conducted at Jangkok watershed on 20 plots representing some land uses: natural forest (5 plots), mahogany forest (2 plots), candlenut (Aleurites) forest (3 plots), candlenut dominated agro-forestry (2 plots), fruit-dominated agro-forestry (2 plots), coffee and cacao -dominated agro-forestry (2 plots), shrub (2 plots) and crops (2 plots). The measurement of carbon stock involved fivemain components:biomassof tree and understorey , necromass and soil surface litter, and soil organic matter (FAO, 2004; Hairiah *et al*., 2011), while root biomass was estimated using default shoot:root ratios of 4:1. Extrapolation of carbon stock from plot to watershed level was conducted by calculating the typical of C stock (*time-averaged C stock*).

Carbon Sequestration Calculation

Estimation of net emission rate referred to the land use change and time-averaged C stock data for every land use which had been measured in advance.

Analysis on contribution of carbon stock of agroforestry system to carbon stock was calculated by comparing the amount of carbon in agroforestry system with carbon stock throughout the watershed as follow:

$$KC(agrf)=\frac{C(agrf)}{C(DAS)}\times 100\%$$

Where:

KC(agrf) = Contribution of agroforestry C stock
C(agrf) = C stock in agroforestry
C(DAS) = C stock throughout watershed

Analysis on the contribution of agro-forestry in reducing the emission rate was calculated by comparing the difference of CO_2 emission factor value which is assumed without agroforestry sequestration, with the following total of CO_2 emission factor value:

$$KE\ (agrf)=\frac{FE(1)-FE(2)}{FE(1)}\times 100\%$$

Where:

FE(1) = CO_2 emission factor value which is assumed no net sequestration or emission of agroforestry once the time-averaged C stock is used
FE(2) = CO_2 emission factor value (total)

RESULTS AND DISCUSSION

Land Use Change

The land use change in Jangkok watershed over 14 years (1995 – 2009), reduced natural forestby 22% of its area (8087 ha), linked to an increase of secondary forest area (Figure 1). The rate of natural forest loss reached around 125 ha yr^{-1}. On the other hand, shrub, settlement and crop area went up by 25%, 28% and 35%, respectively.

The areas for crop planting had been fluctuating due to the shift from rice fields to dwelling areas. Meanwhile, the area of open landincreased by 60% before 2000, especially due to logging in the mahoganys. However, by 2005, vegetation had come back to these areas.

Agroforestry Areas at Jangkok Watershed

In 2009, the area of agroforestry at Jangkok watershed comprised 32% of total area (19088 ha), where around 20% of the total areaat Jangkok watershed was in the dense class of agroforestry. About 61% of the area was inside the watershed area, while the rest was outside of the watershed area. Meanwhile, the dense class comprised 12% of the toal area,with 19% inside and 81% outside of the forest area. Dense agroforestry inside the forest area kept increasing, while the medium class kept increasing outside the forest area (Figure 2).

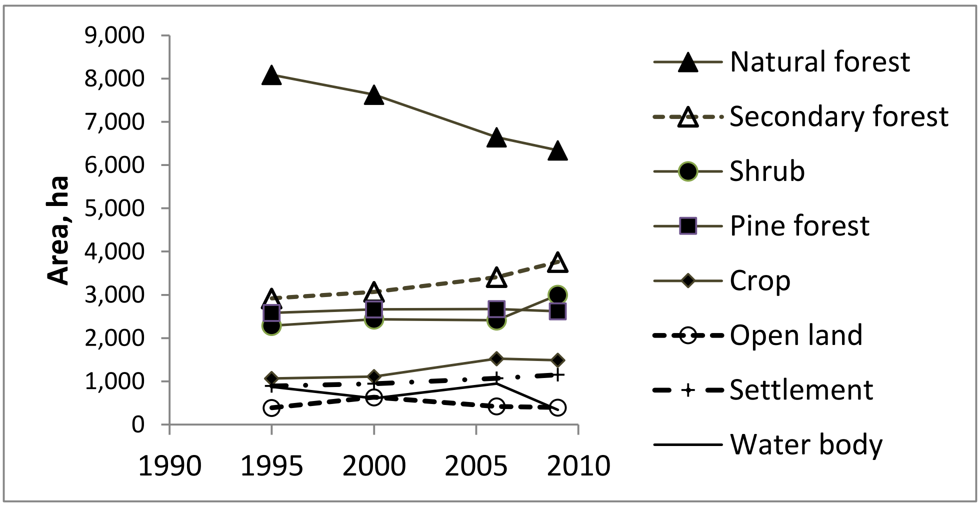


Figure 1. Land use change areas at Jangkok watershed

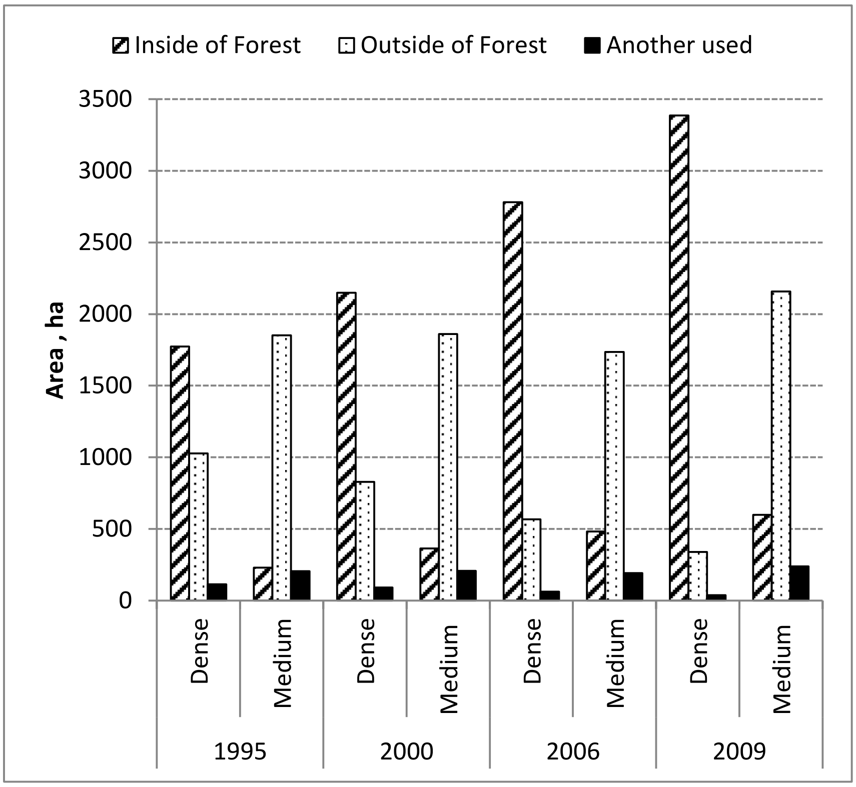


Figure 2. Class of agroforestry based oninterpretation of 5-TM Landsat Satellite

Estimation of Carbon Stock

In interpreting the TM5 Landsat images for Jangkok watershed a number of land use classes had to be combined as no spectral distinction was feasible. Adjustments were needed to match available data on time-averaged carbon stock from previous research (Table 3).

The implication of the decrease of natural forest area within 14 years contributed a direct impact to the degradation of carbon stock at Jangkok watershed. In 1995, it was recorded that the total of carbon stock at Jangkok watershed reached 4.05 Mton, subsequently decrease to 3.94 Mton, 3.67 and 3.65 in 2000, 2005 and 2009, respectively. The overall loss of carbon stock was 28 576 $Mgyr^{-1}$ within 14 years.

Natural forest, despite its decreasing area stillhad the largest carbon stock compared to the other land uses, while carbon stock in the secondary forest remains increasing. Consequently, Jangkok watershed had decreased in carbon stock by as much as 400 Mg within 14 years (Figure 3).

Table 3. Classification of land use and time- averaged carbon stock

No	Land cover class	Forming components	Time-averaged of C Stock, Mgha^{-1}	Source
1	Natural forest (dense forest cover)	Natural forest, mahogany forest, disturbed natural forest	361	Primary data
2	Secondary forest (dense vegetation cover)	Secondary forest: candlenut forest,	178	Primary data
3	Shrub (medium vegetation cover)	Shrub: banana-dominant agroforestry and highly dense vegetation, logged-over forest	68	Primary data
4	Pine forest	Pinedominant upland forest	144	Hairiah *et al*., 2010
5	Crop	Paddyfield, generally sesbania trees, banana, and various types of fruit treesare planted along the dike	64	
6	Open land	Degradedland, barren land, rocky land	20	Palm *et al*. 1999

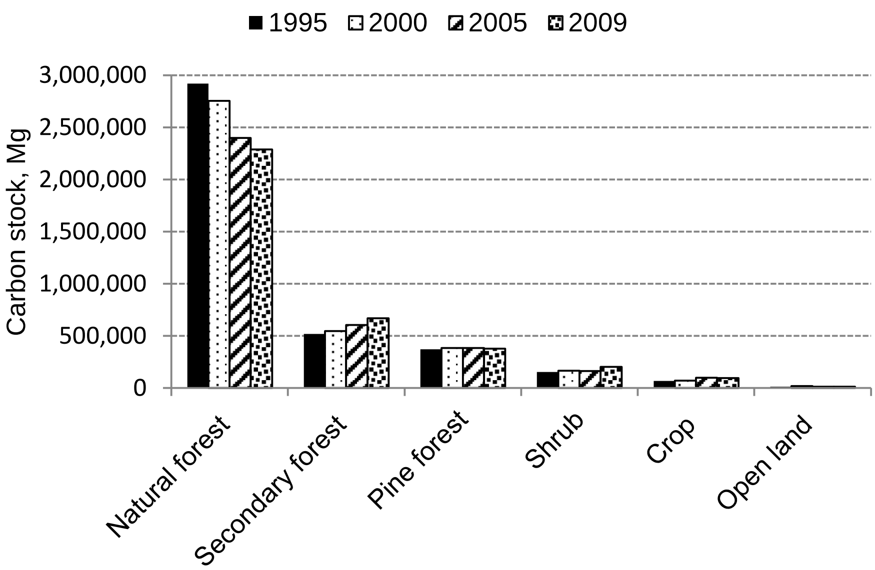


Figure 3. Carbon stock of various type land use systems in Jangkok watershed

Change of Carbon Stock at Jangkok Watershed

The loss of carbon stock from 1995 to 2000 and 2000 to 2005 as a resultof degradation of natural forest into secondary forest and the existence of open land (deforestration). In 2006-2009, however, the loss of carbon stock in secondary forest camefrom either shrub cover or open land was recovered due to the implementation of Agroforestry initiated in 1995. The distribution of carbon stock at Jangkok watershed is presented in Figure 4.

Table 4. Time-averaged carbon stock and carbon stock change from 1995-2009 in Jangkok watershed

No	Land cover	Time-averaged C-stock, Mgha^{-1}	Difference in C total, Mg			
			1995-2000	2000-2005	2006-2009	1995-2009
1	Natural forest	361	-165,702	-356,166	-109,326	-631,195
2	Pine forest	144	11,952	576	-7,057	5,471
3	Secondary forest/dense agroforestry	178	27,540	60,411	62,588	150,539
4	Shrub/medium agroforestry	68	9,849	-1,544	39,707	48,012
5	Crop	64	2,904	26,320	-2,352	26,872
6	Open land	30	7,320	-6,312	-778	230
	Total		-106,137	-276,715	-17,218	-400,071

Remarks: (-) means reduction of C-stock

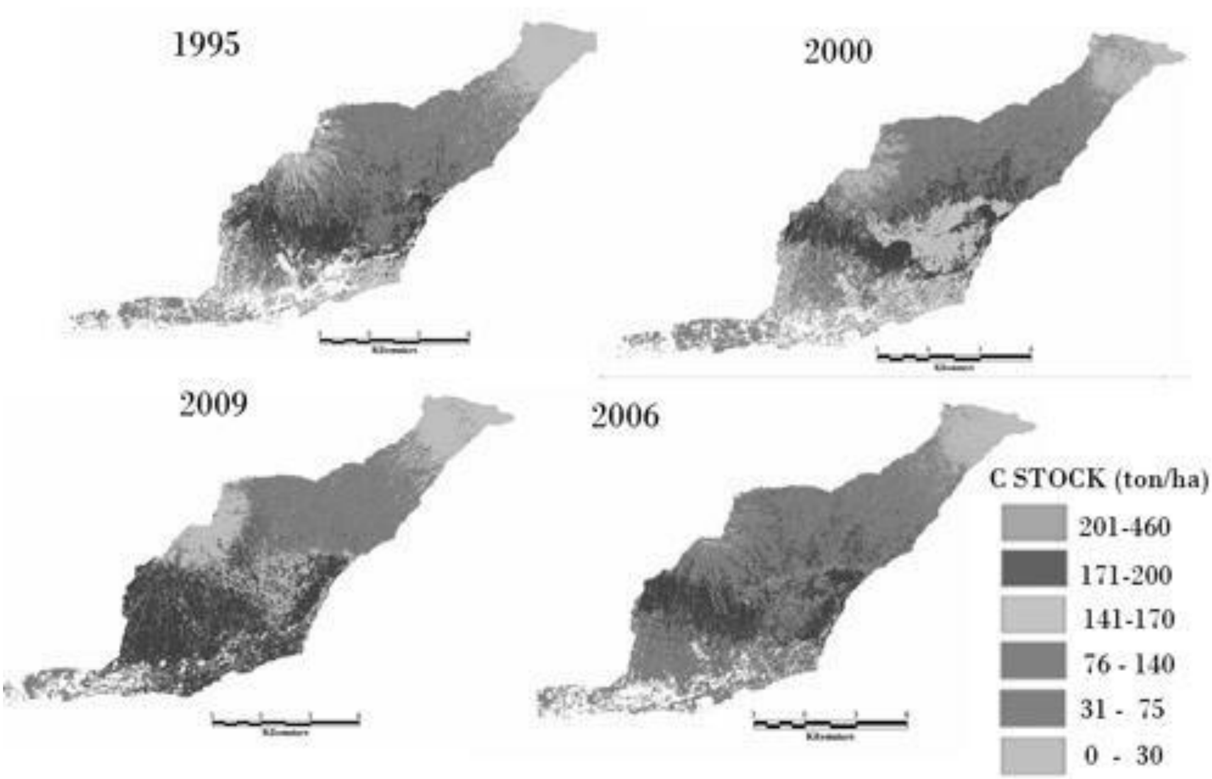


Figure 4. Land use and carbon stock changes at Jangkok watershed based on TM5 Landsat

Carbon Contribution from Agroforestry System

Agroforestry practice through community-based forest scheme (PHBM) was officially initiated in 1995 in Sesaot forest area. However, beyond its scheme, such a practice was carried out in 1980 when a buffer zone for protected forest areas was established. In this research, areas identified as secondary forest and shrub areas have obviously been managed by implementing agroforestry system which combined forest plants and MPTs. Secondary forests representing agroforestry system with complex multistrata character was categorized in dense class, and shrub representing simple Agroforestry system was categorized in medium class. Based on the categorization and results of FGD, it was estimated that 90 %of secondary forest and shrub were agroforestry system, and 10% were for another used (based onTM5 Landsat Image, 2011).

Referring to the average values of carbon stock in complex Agroforestry (177.7 $Mgha^{-1}$) and simple Agro-forestry (67.8 $Mgha^{-1}$) (Table 3), it was concluded that agroforestry secured a carbon stock at Jangkok watershed of as much as 0.639, 0.680 , 0.745 and 0.848 Gg in 1995, 2000, 2006 and 2009, respectively. The amount of Agro-forestry carbon tended to go up and contributed around 16% in 1995 and 23% in 2009 (Figure 5).

Emission Rate and Carbon Sequestration

Emission rate and sequestration repre-sented the increase or decrease of CO_2 either released or absorbed by plants due to the land use change. The land use change at Jangkok watershed occurred dynamically where land use change had influence on one another. For instance, areas of agroforestry land covers increased in size due to the decrease of natural forest and result of agroforestry practiced in open land areas. Based on the results of analysis on land use change and data of time-averaged carbon stock (Table 4), were used to calculate of emission values and sequestration from 1995-2009 (Figure 6).

Figure 6 indicates that total emission of carbon was greater than the sequestration values, where it could be concluded that within 14 years, Jangkok watershed had been emitting carbon on average of 1.6 $Mgha^{-1}yr^{-1}$, or as much as the emission of CO_2 (5.6 $Mgha^{-1}yr^{-1}$). However, the emission rate of carbon had tended to decrease since 2006, and this situation was affected by agroforestry practice (Table 7). The emission values at Jangkok watershed could be considered relatively higher than those of other research in Tahura R Suryo (1.98 $Mgha^{-1}yr^{-1}$) and in Kalikonto watershed (3.76 $Mgha^{-1}yr^{-1}$) (Hairiah *et al*., 2010; Kurniawan *et al*., 2008).

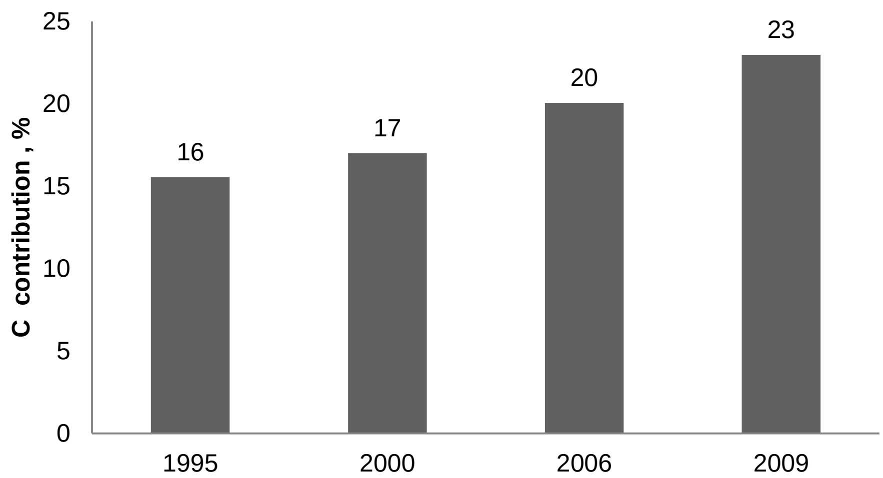
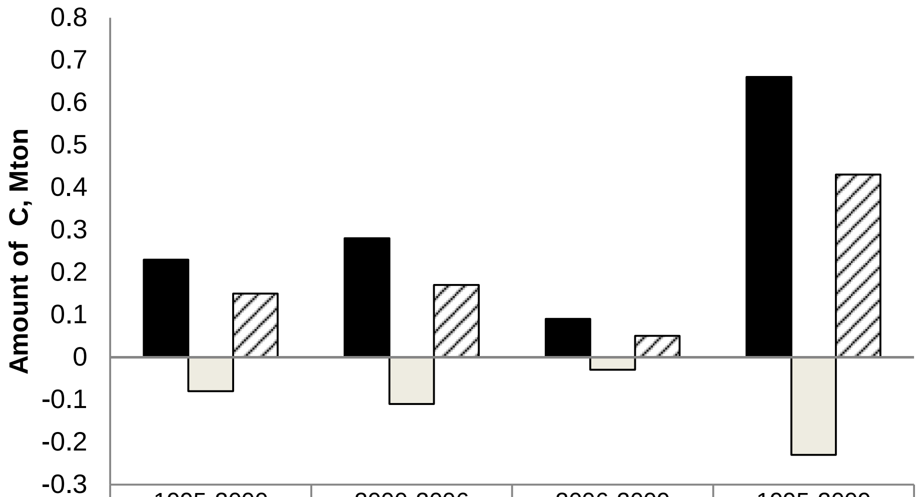


Figure 5. Percentage of contribution C from agroforestry to landscape level carbon stock



	1995-2000	2000-2006	2006-2009	1995-2009
■ Total emission	0.23	0.28	0.09	0.66
□ Sequestration	-0.08	-0.11	-0.03	-0.23
▨ Net emission	0.15	0.17	0.05	0.43

Figure 6. Total emission, sequestration and net emission due to the shift of land covers

Table 7. Emission and sequestration with influenced and withinfluenced by agroforestry

No	Category	Time Interval							
		1995-2000		2000-2006		2006-2009		1995-2009	
		-AF	**+AF**	**-AF**	**+AF**	**-AF**	**+AF**	**-AF**	**+AF**
1	Total emission (Mton C)	0.23	0.23	0.28	0.28	0.09	0.09	0.66	0.66
2	Total sequestration (Mton C)	-0.08	-0.02	-0.11	-0.01	-0.03	0.00	-0.23	-0.05
3	Emission net (Mton C)	0.15	0.21	0.17	0.27	0.05	0.09	0.43	0.61
4	Emission level (Mg C ha^{-1})	7.70	11.3	8.91	14.2	2.75	4.45	22.4	32.1
5	C emission factor ($Mgha^{-1}yr^{-1}$)	1.54	2.25	1.48	2.37	0.92	1.48	1.60	2.29
6	CO_2emission factor ($Mgha^{-1}yr^{-1}$)	**5.64**	**8.26**	**5.44**	**8.69**	**3.36**	**5.44**	**5.86**	**8.41**

Remarks: +AF **:** influenced by agroforestry**,** -AF**:** not influenced by agroforestry

Agroforestry Contribution in Reducing Emission Rate

Based on the previous calculation, it was obtained that average CO_2 emission rate throughout Jangkok watershed was 5.6 $Mgha^{-1}yr^{-1}$. Another analysis was carried out to estimateagroforestry contribution in reducing emission rate at Jangkok watershed by eliminating the influence of sequestration values from agroforestry land cover followed. The analysis results were presented in Table 7.

Agroforestry has played a very important role in reducing net emission rates of CO_2, which reached around 2.55 $Mgha^{-1}yr^{-1}$ (30%) on average. Agroforestry system has succeeded in transforming the lands with medium tree density into denser land covers. However, there is still emission released in the practice of agroforestry with smaller values of emission than those of sequestration (Figure 7).

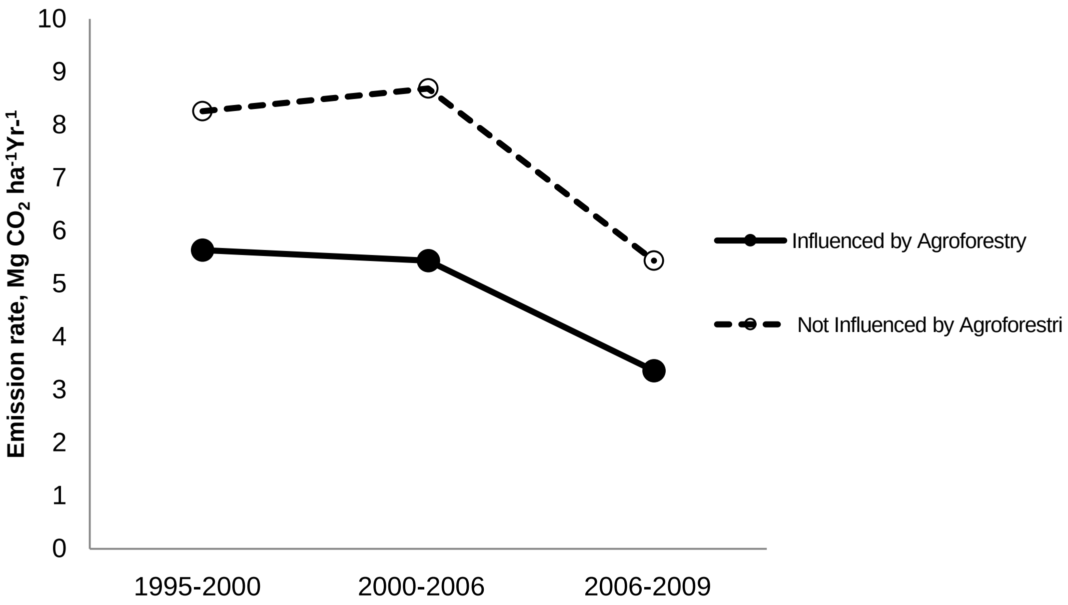


Figure 7. Comparison in emission rate where there was influenced and not influenced by Agroforestry

CONCLUSIONS

Agroforestry system contributed a significant carbon stock (16% - 23%), and also played a role (32-38%) in reducing net emission rates. These results lead to some concluding points: (1) Total carbon stock at Jangkok watershed was as much as 3.65 Mton in 2009, and the agroforestry system contributed 0.85 Mton (23%) of carbon stock; (2) Land use changehad put the carbon emission factor at 1.6Mg $ha^{-1}yr^{-1}$or CO_2 emission rate at 5.86 $Mgha^{-1}yr^{-1}$; (3) Agroforestry with no sequestration had put CO_2 emission rate at Jangkok watershed at the total of 8.41 $Mgha^{-1}yr^{-1}$, while this agroforestry practice managed to reduce the emission rate of CO_2 to become 5.86 $Mgha^{-1}yr^{-1}$.

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